PLANNING COMMISSION
REGULAR MEETING AGENDA

CALL TO ORDER & ROLL CALL 7:30 PM

APPEARANCES
This is the time set aside for members of the public to speak to the Commission about issues of concern. If you wish to speak, please consider the following points:
- Speak audibly into the podium microphone
- State your name and address for the record
- Limit your comments to three minutes
(Note: The Commission may limit the number of speakers and modify the time allotted. Total time for appearances: 15 minutes)

APPROVAL OF MINUTES Minutes from May 5, 2010

REGULAR BUSINESS 7:45 PM
Agenda Item #1
Shoreline Master Program update – Post Open Record Hearing discussion, and review of shoreline language in MICC 19.07, Shoreline Master Program Cumulative Impacts Analysis, and Restoration Plan.

OTHER BUSINESS Council Liaison Report
- Staff Comments
- Planned Absences for Future Meetings
- Announcements & Communications
- Next Regular Meeting: June 2, 2010

ADJOURN

AGENDA TIMES ARE APPROXIMATE
CALL TO ORDER:
Chair Adam Cooper called the meeting to order at 7:32 PM in the Council Chambers, at 9611 SE 36th Street, Mercer Island, Washington.

ROLL CALL:
Chair Adam Cooper, Vice-Chair Eric Laschever, Commissioners Bryan Cairns, Jon Friedman, Steve Marshall, Craig Olson and Kristen White were present. Council Liaison El Jahncke was present. City staff was represented by Katie Knight, City Attorney; Manny Ocampo, Interim Development Services Group Director; George Steirer, Principal Planner; and Travis Saunders, Planner.

APPEARANCES:
None

MINUTES:
Commissioner Laschever motioned to approve the minutes from April 21, 2010. Commissioner Olson seconded the motion. The Commission unanimously approved the minutes as written.

REGULAR BUSINESS:
Agenda Item #1: Open Record Hearing for a Zoning Text Amendment (file# ZTR10-001) for a proposed amendment to existing regulations related to the City of Mercer Island Shoreline Master Program.

Travis Saunders, Planner, provided a staff presentation.

Chair Cooper opened the public comment segment of the hearing.

Arye Gittelman of 4877 Forest Avenue SE provided testimony.

George Smith of 6820 96th Avenue SE provided testimony.

Emmett Maloof of 4835 Forest Avenue SE provided testimony.

Tim Trohimovich, Futurewise, 814 Second Avenue, Suite 500, Seattle, WA 98104 provided testimony.

Sue Stewart, Citizens to Preserve Upper Luther Burbank Park and Friends of Luther Burbank Park, 3205 84th Avenue SE provided testimony.

Michael Post of 3848 East Mercer Way provided testimony.
Monica Robbins of 3817 West Mercer Way provided testimony.

Mark Robbins of 3817 West Mercer Way provided testimony.

Steve Bryan of 2426 70th Avenue SE provided testimony.


Dr. Gill Pauley of 244 West Lake Sammamish Parkway SE, Bellevue, WA 98008 provided testimony.

Dave Douglas, Integrity Shoreline Permitting, 818 Mill Avenue, Snohomish, WA 98290 provided testimony.

Bob Kessler of 4438 Ferncroft Road provided testimony.

Robert Thorpe AICP, R.W. Thorpe and Associates, Inc., 705 2nd Avenue, Suite 710, Seattle, WA 98104 provided testimony.

Kirk Lakey, Washington State Department of Fish and Wildlife, 800 Capital Way, Olympia WA 98501 provided testimony.

Anita Neil, Washington Sensible Shorelines Association, 9302 SE Shoreland Drive, Bellevue, WA 98004 provided testimony.

Lisa Tall of 6308 SE 22nd Street provided testimony.

John Radovich of 5425 West Mercer Way provided testimony.

John Hall of 4006 East Mercer Way provided testimony.

The Commission requested Robert Thorpe to provide suggested changes to the draft Shoreline Master Program.

The Commission asked question of staff regarding public comments, project timing, scientific information, and preparation of Hearing summary documents.

The Commission discussed scientific information, asking questions of Dr. Gill Pauley; Barbara Nightingale, Department of Ecology; and Kirk Lakey, Washington State Department of Fish and Wildlife. Dr. Pauley stated he would provide additional scientific studies to the Commission.

Chair Cooper called a recess at 10:16 PM.

The Commission reconvened at 10:24 PM.

COUNCIL LIAISON REPORT:
The Council adopted the 2009 Construction Codes and reviewed the Pedestrian and Bicycles
Facility Plan at its May 3, 2010 meeting.

**STAFF COMMENTS:**
The Shoreline Master Program update will come before the Commission on May 19, 2010. Code Text Amendments to MICC Chapter 19, Unified Land Code will come before the Commission on June 2, 2010.

**PLANNED ABSENCES FOR FUTURE MEETINGS:**
Commissioner Cairns will be absent on May 19, 2010 and June 2, 2010. Commissioners Marshall and White will be absent on June 2, 2010.

**ANNOUNCEMENTS AND COMMUNICATIONS:**
None

**NEXT REGULAR MEETING:**
The next Planning Commission meeting is scheduled for May 19, 2010.

**ADJOURNMENT:**
The Planning Commission meeting was adjourned at 10:32 PM.

Respectfully submitted by Travis Saunders, Planner
To: City of Mercer Island Planning Commission and Deputy Mayor Jahncke
From: Travis Saunders, Planner
Re: May 19, 2010 Shoreline Master Program (SMP) Update Meeting
Date: May 13, 2010

On May 19, 2010, the Commission will review public testimony presented at the May 5, 2010 Open Record Hearing, along with comments received by the Department of Ecology (DOE) and Dave Douglas, Integrity Shoreline Permitting. A copy of the Draft Shoreline Master Program, Draft Cumulative Impacts Analysis, and Draft Restoration Plan are also included in the meeting packet for discussion after review of public testimony and comment letters. Staff has included additional items requested by the Commission, shown below in the exhibit list.

NEXT STEPS:
Following review and discussion, staff requests direction from the Commission on any revisions to the documents, and any additional information needed.

At the May 5, 2010 hearing, the Commission requested Dr. Gill Pauley to provide scientific papers to supplement the science already presented to the Commission. Staff followed up with Dr. Pauley post-hearing to obtain the requested documents. They are included in the packet for the Commission’s review.

At the May 5, 2010 hearing, the Commission also requested specific text edits/comments from Robert Thorpe, AICP. Staff followed up with Mr. Thorpe post-hearing to obtain the requested edits/comments. Mr. Thorpe informed staff that he would not have edits/comments prepared in time for the May 19, 2010 meeting. Staff proposes review of Mr. Thorpe’s comments on June 16, 2010, or as they become available.

EXHIBITS:
The enclosed Shoreline Master Program update packet contains the following Exhibits:

Exhibit 1 is a copy of the Draft Shoreline Master Program, including Exhibit A – Proposed Shoreline Environment Designations Map and Exhibit B – Comprehensive Plan Shoreline Element Goals and Policies. The draft contains edits requested by the Commission over the course of the past year. (Black text represents existing code. Red text is language approved or deleted by the Commission.)

Exhibit 2 is the Draft Cumulative Impacts Analysis, which is required by WAC 173-26-201(3)(d)(iii) as demonstration that the City’s regulation of development will achieve no net loss of ecological functions.

Exhibit 3 is the Draft Restoration Plan, which is required by WAC 173-26-201(2)(f) in order to identify existing and ongoing projects and programs that are designed to contribute to local shoreline restoration goals.
Exhibit 4 is a summary of the public testimony presented at the May 5, 2010 hearing. Comments are categorized into areas of concern, with a staff response to each comment.

Exhibit 5 in the packet is a letter from the Department of Ecology that expresses concern regarding some of the language in the City’s proposed draft of the Shoreline Master Program. This letter is carried over from the April 21, 2010 meeting, at which, the Commission requested to review the letter along with testimony presented at the hearing.

Exhibit 6 is an email from the Department of Ecology that states a departure from the Army Corps of Engineers RGP-3 standards would need to be addressed via incentives or mitigation to avoid a net loss of ecological functions.

Exhibit 7 contains staff comments to Mr. Dave Douglas’ April 21, 2010 letter to the Commission, per the Commission’s request at the May 5, 2010 hearing. Many of the issues raised in the letter were brought up by Mr. Douglas at the March 17, 2010 meeting, to which the Commission made edits based on discussion at that time. Comments are provided for the Commission’s consideration.

Exhibit 8 is a copy of the Washington Department of Fish and Wildlife (WDFW) White Paper on overwater structures, as requested by the Commission at the May 5, 2010 hearing.

Exhibit 9 is the report that is likely the product resulting from the “salmon watch” discussed at the May 5, 2010 hearing – Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems of the Lake Washington Basin. This report was originally provided to the Commission on August 5, 2009.

Exhibit 10 is a copy of Resolution 1347 Ratifying the WRIA Chinook Salmon Conservation Plan, as requested by the Commission at the May 5, 2010 hearing.

Exhibit 11 is a schedule/timeline for completion of the SMP by the Commission, per the Commission’s request at the May 5, 2010 hearing.

Exhibit 12 contains science papers recommended by Dr. Gill Pauley.

QUESTIONS:
Should you have questions regarding the materials or the update process, feel free to contact me at (206) 275-7717 or travis.saunders@mercergov.org.
CITY OF MERCER ISLAND
ORDINANCE NO. 10C-XX

AN ORDINANCE OF THE CITY OF MERCER ISLAND, WASHINGTON
ADOPTING THE MERCER ISLAND SHORELINE MASTER PROGRAM
UPDATE; AMENDING THE SHORELINE ELEMENT IN THE MERCER
ISLAND COMPREHENSIVE PLAN; AMENDING THE SHORELINE
DESIGNATION MAP; ADOPTING AND AMENDING SHORELINE
DEFINITIONS IN CHAPTER 19.16 OF THE MERCER ISLAND UNIFIED
LAND DEVELOPMENT CODE; AMENDING DEVELOPMENT
REGULATIONS RELATING TO SHORELINES IN TITLES 19.07.100
AND 19.07.110 OF THE MERCER ISLAND UNIFIED LAND
DEVELOPMENT CODE; PROVIDING FOR SEVERABILITY AND
ESTABLISHING AN EFFECTIVE DATE.

WHEREAS, the Washington Shoreline Management Act (RCW 90.58, referred to herein as
“SMA”) recognizes that shorelines are among the most valuable and fragile resources of the
state, and that the state and local government must establish a coordinated planning program to
address the types and effects of development occurring along shorelines of state-wide
significance; and

WHEREAS, the City of Mercer Island (“City”) is required to update its Shoreline Master
Program (“SMP”) pursuant to the SMA and WAC 173-26; and

WHEREAS, on July 20, 2009, the City submitted a Final Shoreline Analysis Report to the
Washington State Department of Ecology (“DOE”), which is an inventory and characterization
of the City’s shorelines to assess ecological functions and ecosystem-wide processes operating
within the City’s shoreline jurisdictions and to serve as a baseline from which future
development actions in the shoreline jurisdiction will be measured; and

WHEREAS, there has been extensive public participation opportunities with respect to the SMP
update, including but not limited to a public open house, and public meetings.

WHEREAS, on March 8, 2010, the City’s Responsible Official reviewed the proposed
amendments to Chapters 19.07.100, 19.07.110, and 19.16 and the Shoreline Element of the
Comprehensive Plan, and under the provisions of the State Environmental Policy Act (SEPA),
issued a Determination of Non-Significance; and

WHEREAS, the Mercer Island Planning Commission, after numerous meetings and a public
hearing, recommended approval of the SMP update at its April 7, 2010 meeting; and

WHEREAS, the Mercer Island City Council considered the SMP at its Regular Meeting of
________ _____, 2010, and Regular Meeting of ________ _____, 2010; and
WHEREAS, the Mercer Island City Council did conclude that the SMP will result in “no net loss” in shoreline ecological function relative to the baseline due to implementation and will ultimately produce a net improvement in shoreline ecological function; and

WHEREAS, on “MONTH DAY YEAR”, the Mercer Island City Council concludes that the SMP is consistent with and meets the guidelines established under WAC Chapter 173.26; and

WHEREAS, the Mercer Island City Council concludes that the SMP is consistent with and implements Shoreline Management Act (RCW 90.58 and the Growth Management Act (RCW 36.70; and

WHEREAS, the Washington State Department of Ecology is authorized under the SMA to approve, deny or propose modifications to the City’s SMP; and

WHEREAS, after considering all public testimony and written comments, the City Council adopts the following Ordinance.

NOW, THEREFORE, THE CITY COUNCIL OF THE CITY OF MERCER ISLAND, WASHINGTON DOES HEREBY ORDAIN AS FOLLOWS:

Section 1: Amendments to 19.07.100 MICC, Shoreline Areas. MICC 19.07.100

“Shoreline Areas” is hereby amended as follows:

Shorelands directly impact water quality as surface and subsurface waters are filtered back into the lake. Additionally, shorelines are a valuable fish habitat area characterized by lake bottom conditions, erosion tendencies, and the proximity to watercourse outfalls. These may combine to provide a suitable environment for spawning fish.

A. Critical Areas Delineations.
   1. A survey to determine the line of ordinary high water (OHW) shall be current to within one year of the application for single lots, short subdivisions, long subdivisions, or lot line revisions.
   2. The survey may be included in the site construction plan (see MICC 19.07.060, Reports and Surveys) or waived by city staff if the OHW has been delineated by an existing bulkhead.
   3. Mark the shoreline setback on the site prior to the preconstruction meeting.

B. Site Development.
   1. A 25-foot setback from OHW is required.
   2. If a wetland is adjacent to the shoreline, measure the shoreline setback from the wetland’s boundary.
   3. 25% of the 20 feet closest to the OHW shall contain vegetation coverage. The five feet nearest the OHW shall contain at least 25% native coverage. A shoreline vegetation plan shall be submitted to the City for approval. A variety of ground cover, shrubs, and trees that provides lake shading is encouraged.
C. Site Coverage. The amount of impervious surfaces which will be permitted is as follows:

<table>
<thead>
<tr>
<th>Distance from OHW</th>
<th>Impervious Surface Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 25 feet</td>
<td>10% – No building(s) allowed</td>
</tr>
<tr>
<td>26 – 50 feet</td>
<td>30% – Structure(s) allowed</td>
</tr>
</tbody>
</table>

D. Storm Water and Erosion Control. Erosion control devices shall be installed along the boundaries of the shoreland setback following the preconstruction meeting and prior to clearing or grading.

E. Alteration. Any alteration in this area requires either: (1) a shoreline exemption or (2) a substantial development permit, a building/grading permit, and storm water permit. Some development or alteration may also require a conditional use permit. (Ord. 08C-01 § 3; Ord. 05C-12 § 6; Ord. 02C-09 § 6; Ord. 99C-13 § 1. Formerly 19.07.050).

Section 2: **Amendments to 19.07.110 MICC, Shoreline Management Master Program.**
MICC 19.07.110 “Shoreline Management Master Program” is hereby amended as follows:

A. General Information.

1. Introduction and Purpose. The Washington State Legislature enacted the Shoreline Management Act (SMA) of 1971 (Chapter 90.58 RCW) to provide a uniform set of rules governing the development and management of shoreline areas. As a basis for the policies of the

<table>
<thead>
<tr>
<th>Required Landscaping</th>
<th>Coverage</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>0’ – 5’ From Ordinary High Water Mark</td>
<td>25% Native vegetation</td>
<td>A variety of ground cover, shrubs, and trees that provides lake shading is encouraged.</td>
</tr>
<tr>
<td>0’ – 20’ From Ordinary High Water Mark</td>
<td>25% Vegetation coverage of the total area</td>
<td>A variety of ground cover, shrubs, and trees that provides lake shading is encouraged.</td>
</tr>
</tbody>
</table>
SMA, the Legislature incorporated findings that “the shorelines are among the most valuable and fragile” of the state’s resources, that they are under “ever increasing pressure of additional uses” and that “unrestricted construction on the privately or publicly owned shorelines of the state is not in the best public interest.” The Legislature further finds that “coordinated planning is necessary in order to protect the public interest associated with the shorelines of the state, while, at the same time, recognizing and protecting private property rights consistent with the public interest.”

The SMA sets up a process for managing development of the state’s shorelines through state-monitored, locally administered permitting program. Local governments are required to prepare shoreline master programs to manage shoreline development within their jurisdiction. The SMA specifies that each local shoreline master program includes goals and policies that take into account the specific local conditions influencing the shoreline jurisdiction.

The purpose of the shoreline master program is to implement the Shoreline Management Act of 1971 and to establish regulations for development based on the local shoreline goals and policies.

a. The shoreline master program specifies boundaries of a shoreline jurisdiction and shoreline designated environments;

b. The shoreline master program establishes regulations for development within the shoreline jurisdiction;

c. The shoreline master program specifies requirements for public participation in decisions about shoreline development.

2. Shoreline Jurisdiction. The shoreline jurisdiction is geographically defined as:

a. All lands extending landward 200 feet in all directions as measured on a horizontal plane from the ordinary high water mark and all associated shorelands (RCW 90.58.030).

b. All lands under Lake Washington extending waterward to the line of navigability/inner harbor line as established in 1984 by the Board of natural Resources No. 461, middle of Lake Washington, pursuant to RCW 35.21.160.

The following illustration shows the applicability of the shoreline master program jurisdiction:
3. Applicability. The regulations and procedures of the shoreline master program apply to all development within the shoreline jurisdiction of the city including the waters and
underlying land of Lake Washington and to the shoreline uses established within the shoreline designated environments.

4. Adoption Authority. The regulations contained in MICC 19.07.080 within the Shoreline Master Program are hereby adopted as the shoreline master program for the City of Mercer Island. These regulations are adopted under the authority of the Chapter 90.58 RCW and Chapter 173-1626 WAC.

5. Relationship to Land Use Code and Other Ordinances.
   a. The shoreline master program regulations are supplemental to the city of Mercer Island comprehensive plan, the Mercer Island development code and various other provisions of city, state and federal laws. Applicants must comply with all applicable laws prior to commencing any use, activity, or development.
   b. The shoreline jurisdiction and the shoreline designated environments are superimposed upon the existing zoning classifications. The zoning regulations specified in the development code and this section are intended to operate together to produce coherent and thorough regulations. All uses, activities and developments must comply with both the Mercer Island development code and shoreline master program. If there is a conflict between the two, the more restrictive regulation applies.

6. Shoreline Master Program Goals and Policies. In 1974 the city of Mercer Island adopted shoreline goals and policies. These goals and policies are consistent with the city’s comprehensive plan adopted in 1993. The goals and policies contained within the City’s Comprehensive Plan Shoreline Chapter shall constitute Mercer Island’s Shoreline Master Program goals and policies.

7. Shoreline Master Program Regulations. The following regulations shall constitute the City of Mercer Island shoreline development regulations:
   a. MICC 19.07.100, Shoreline Areas
   b. MICC 19.07.110, Shoreline Master Program
   c. MICC 19.07, Critical Areas (Ord. No. 05C-12)
   d. MICC 15.09, Storm Water Management Program
   e. Definitions – Those specific to shorelines shall have the meaning ascribed to them below. Terms not defined in this section shall be defined as set forth in MICC 19.16

Boat Lift: A structure or device used to raise a watercraft above the waterline for secure moorage purposes.
Boat Ramp: An inclined structure upon which a watercraft is raised or pulled onto land or a dock.
Breakwater: A protective structure usually built offshore for the purpose of protecting the shoreline or harbor areas from wave action.
Bulkhead: A solid or open pile of rock, concrete, steel, timber or other materials erected parallel to, and normally erected at, the ordinary high water line for the purpose of protecting adjacent property from waves or currents.
Covered Moorage: A pier, dock, boatlift, series of piles, or other structure intended for moorage over which a roof or canopy is erected.
Ecological functions or shoreline functions: means the work performed or role played by the physical, chemical, and biological processes that contribute to the maintenance of the aquatic and terrestrial environments that constitute the shoreline’s natural ecosystem.
Ecosystem-wide processes: means the suite of naturally occurring physical and geologic processes of erosion, transport, and deposition; and specific chemical processes that shape landforms within a specific shoreline ecosystem and determine both the types of habitat and the associated ecological functions.

Feasible: means an action, such as a development project, mitigation, or preservation requirement, meets all of the following conditions: (a) The action can be accomplished with technologies and methods that have been used in the past in similar circumstances, or studies or tests have demonstrated in similar circumstances that such approaches are currently available and likely to achieve the intended results; (b) The action provides a reasonable likelihood of achieving its intended purpose; and (c) The action does not physically preclude achieving the project's primary intended legal use. In cases where these guidelines require certain actions unless they are infeasible, the burden of proving infeasibility is on the applicant. In determining an action's infeasibility, the reviewing agency may weigh the action's relative public costs and public benefits, considered in the short- and long-term time frames.

Fill: means the addition of soil, sand, rock, gravel, sediment, earth retaining structure, or other material to an area waterward of the OHWM, in wetlands, or on shorelands in a manner that raises the elevation or creates dry land.

Finger Pier: An extension from a dock used to create moorage slips.

Floating Platform: A flat structure or device moored or anchored, not permanently secured by piles, which floats upon the water.

Geotechnical report or geotechnical analysis: means a scientific study or evaluation conducted by a qualified expert that includes a description of the ground and surface hydrology and geology, the affected land form and its susceptibility to mass wasting, erosion, and other geologic hazards or processes, conclusions and recommendations regarding the effect of the proposed development on geologic conditions, the adequacy of the site to be developed, the Washington State Shoreline Master Program Guidelines, Chapter 173-26 WAC 96 of 100 Washington State Shoreline Master Program Guidelines, Chapter 173-26 WAC 97 of 100 impacts of the proposed development, alternative approaches to the proposed development, and measures to mitigate potential site-specific and cumulative geological and hydrological impacts of the proposed development, including the potential adverse impacts to adjacent and downcurrent properties. Geotechnical reports shall conform to accepted technical standards and must be prepared by qualified professional engineers or geologists who have professional expertise about the regional and local shoreline geology and processes.

Groin: A structure used to interrupt sediment movement along the shore.

Jetty: A barrier used to protect areas from accumulations of excess sediment.

Landward: Any point located inland from the ordinary high water mark.

Lateral Line: The extension waterward of a property line into Lake Washington beyond the ordinary high water mark. How property lines extend waterward from the ordinary high water mark is an area of misconception. If the title does not clearly state the location of the property lines waterward from the ordinary high water mark, waterfront owners are not allowed to unilaterally project the upland boundaries out into the shorelands (waterward). There are no statutes defining the direction of the lateral lines waterward from the ordinary high water mark. The Supreme Court has the final word to decide location of lateral line on case-by-case basis.

Light Rail Transit Facilities: A public rail transit line, including all ancillary facilities such as transit power substations, that operates at grade level, above grade level, on a bridge or in a tunnel and that provides high capacity, regional transit service owned or operated by a regional
transit authority authorized under Chapter 81.112 RCW. A regional light rail transit system will be designed to cross I-90 right-of-way.

Marina: A commercial basin providing rental or sale of docks, watercraft, moorage, and/or supplies. Casual single-family renting of moorage is excluded from this definition.

May: means the action is acceptable, provided it conforms to the provisions of this chapter.

Mean Low Water: The level of Lake Washington during the fall and winter when the water level is lowered to minimize winter storm damage to lakeside properties. Mean low water is one and one-half feet lower than ordinary high water.

Moorage Facility: Any device or structure used to secure a boat or a vessel, including piers, docks, piles, lift stations or buoys.

Must: means a mandate; the action is required.

Nonwater-oriented uses: means those uses that are not water-dependent, water-related, or water-enjoyment.

Normal maintenance or repair of existing structures or developments, including damage by accident, fire or elements. "Normal maintenance" includes those usual acts to prevent a decline, lapse, or cessation from a lawfully established condition. "Normal repair" means to restore a development to a state comparable to its original condition, including but not limited to its size, shape, configuration, location and external appearance, within a reasonable period after decay or partial destruction, except where repair causes substantial adverse effects to shoreline resource or environment. Replacement of a structure or development may be authorized as repair where such replacement is the common method of repair for the type of structure or development and the replacement structure or development is comparable to the original structure or development including but not limited to its size, shape, configuration, location and external appearance and the replacement does not cause substantial adverse effects to shoreline resources or environment.

Ordinary High Water (OHW): The point on the shore that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual, and so long continued in all ordinary years, as to mark upon the soil a character distinct from that of the abutting upland, in respect to vegetation as that condition exists on June 1, 1971, as it may naturally change thereafter in accordance with permits issued by a local government or the department.

Personal Watercraft (PWC) Lift: A structure or device used to raise a personal watercraft such as a jet-ski or wave runner above the water line for secure moorage purposes.

Public Access: A means of physical approach to and along the shoreline, or other area, available to the general public. Public access may also include visual approach.

Restoration or ecological restoration: means the reestablishment or upgrading of impaired ecological shoreline processes or functions. This may be accomplished through measures including but not limited to re-vegetation, removal of intrusive shoreline structures and removal or treatment of toxic materials. Restoration does not imply a requirement for returning the shoreline area to aboriginal or pre-European settlement conditions.

Shall: means a mandate; the action must be done.

Shoreline areas and shoreline jurisdiction: means all shorelines of the state and shorelands as defined in RCW 90.58.030.

Shoreline master program or master program: means the comprehensive use plan for a described area, and the use regulations together with maps, diagrams, charts, or other descriptive material and text, a statement of desired goals, and standards developed in accordance with the policies enunciated in RCW 90.58.020. As provided in RCW 36.70A.480, the goals and policies
of a shoreline master program for a county or city approved under chapter 90.58 RCW shall be considered an element of the county or city's comprehensive plan. All other portions of the shoreline master program for a county or city adopted under chapter 90.58 RCW, including use regulations, shall be considered a part of the county or city's development regulations.

Shoreline modifications: means those actions that modify the physical configuration or qualities of the shoreline area, usually through the construction of a physical element such as a dike, breakwater, pier, weir, dredged basin, fill, bulkhead, or other shoreline structure. They can include other actions, such as clearing, grading, or application of chemicals.

Should: means that the particular action is required unless there is a demonstrated, compelling reason, based on policy of the Shoreline Management Act and this chapter, against taking the action.

Water-Dependent: A use or a portion of a use which cannot exist in any other location and is dependent on the water by reason of the intrinsic nature of its operations. Examples of water-dependent uses may include ship cargo terminal loading areas, ferry and passenger terminals, the I-90 bridges, barge loading facilities, ship building and dry docking, marinas, aquaculture, float plane facilities and sewer outfalls.

Water-enjoyment use: means a recreational use or other use that facilitates public access to the shoreline as a primary characteristic of the use; or a use that provides for recreational use or aesthetic enjoyment of the shoreline for a substantial number of people as a general characteristic of the use and which through location, design, and operation ensures the public's ability to enjoy the physical and aesthetic qualities of the shoreline. In order to qualify as a water-enjoyment use, the use must be open to the general public and the shoreline-oriented space within the project must be devoted to the specific aspects of the use that fosters shoreline enjoyment.

Water-oriented use: means a use that is water-dependent, water-related, or water-enjoyment, or a combination of such uses.

Water-related use: means a use or portion of a use which is not intrinsically dependent on a waterfront location but whose economic viability is dependent upon a waterfront location because: (a) The use has a functional requirement for a waterfront location such as the arrival or shipment of materials by water or the need for large quantities of water; or (b) The use provides a necessary service supportive of the water-dependent uses and the proximity of the use to its customers makes its services less expensive and/or more convenient. Washington State Shoreline Master Program Guidelines, Chapter 173-26 WAC 100 of 100.

Waterfront Structure: Docks, piers, wharves, floats, mooring piles, anchor buoys, bulkheads, bridges, submerged or overhead wires, pipes, cables, and any other object passing beneath, through or over the water beyond the line of ordinary high water.

Waterward: Any point located in Lake Washington, lakeward from the ordinary high water mark.

B. Shoreline Designated Environments.

1. Designated Environments. Different areas of the city’s shoreline have different natural characteristics and development patterns. As a result, three-two shoreline designated environments are established to regulate developments and uses consistent with the specific conditions of the designated environments and to protect resources of the Mercer Island shoreline jurisdiction. They are:

a. Conservancy Environment. This environment constitutes large undeveloped areas with some natural constraints such as wetland conditions, containing a variety of flora and fauna. The
The purpose of this environment is to protect and manage the existing natural resources in order to achieve sustained resource utilization and provide recreational opportunities.

ba. Urban Park. This environment consists of shoreline areas designated for public access and active and passive public recreation. It includes, but is not limited to, street ends, public utilities and other publicly owned rights-of-way. The uses located in this environment should be water-dependent and designed to maintain the natural character of the shorelines.

eb. Urban Residential. The purpose of this environment is to provide for residential and recreational utilization of the shorelines, compatible with the existing residential character in terms of bulk, scale and type of development.

2. Shoreline Environment Map. The map in Appendix F of this development code is the official map of the city designating the various shoreline environments and the shoreline jurisdiction within the city.

3. Permit Requirements for Shoreline Uses and Development within the Designated Environments. All proposed development within the shoreline jurisdiction shall be consistent with the regulations of this Shoreline Master Program, the Shoreline Management Act of 1971 and the Mercer Island development code. In addition all development shall conform to permit requirements of all other agencies having jurisdiction within the designated environments.

The following table specifies the shoreline uses and developments which may take place or be conducted within the designated environments. It also specifies the type of shoreline permit required and further states the necessary reviews under the State Environmental Policy Act (SEPA). The uses and developments listed in the matrix are allowed only if they are not in conflict with more restrictive regulations of the Mercer Island development code and are in compliance with the regulations specified in subsection D of this section.

<table>
<thead>
<tr>
<th>Key:</th>
<th>CE: Categorically Exempt</th>
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<tbody>
<tr>
<td>SEP:</td>
<td>Shoreline Exemption Permit</td>
</tr>
<tr>
<td>SDP:</td>
<td>Substantial Development Permit</td>
</tr>
<tr>
<td>SEPA:</td>
<td>Required Review under the State Environmental Policy Act</td>
</tr>
<tr>
<td>NP:</td>
<td>Not Permitted Use</td>
</tr>
</tbody>
</table>

The regulations of the shoreline master program apply to all shoreline uses and development, whether or not that development is exempt from the permit requirements (CE, SEP, or SDP).

<table>
<thead>
<tr>
<th>Designed Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoreline Use</td>
</tr>
<tr>
<td>Conservancy Environment</td>
</tr>
<tr>
<td>Urban Park Environment</td>
</tr>
<tr>
<td>Urban Residential Environment</td>
</tr>
<tr>
<td>Single-family residential and associated appurtenances</td>
</tr>
<tr>
<td>Use</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Multifamily residential</td>
</tr>
<tr>
<td>Public and private recreational facilities and parks</td>
</tr>
<tr>
<td>Moorage facilities (including piers, docks, piles, lift stations, or</td>
</tr>
<tr>
<td>buoys)</td>
</tr>
<tr>
<td>Commercial marinas, moorage and storage of commercial boats and ships</td>
</tr>
<tr>
<td>Bulkheads and shoreline protective structures</td>
</tr>
<tr>
<td>Breakwaters and jetties</td>
</tr>
<tr>
<td>Utilities</td>
</tr>
<tr>
<td>Dredging</td>
</tr>
<tr>
<td>Alterations over 250 cubic yards – outside the building footprint</td>
</tr>
<tr>
<td>Boating Facilities</td>
</tr>
<tr>
<td>Transportation and Parking Facilities</td>
</tr>
<tr>
<td>Light Rail Transit Facilities</td>
</tr>
</tbody>
</table>

If a use is not listed in this matrix, it shall be considered as a conditional use, pursuant to WAC 173-26-160.

C. Administration and Procedures.
   1. Administrative Responsibility. Except as otherwise stated in this section, the code official is responsible for:
      a. Administering the shoreline master program.
      b. Approving, approving with conditions or denying shoreline exemption permit, substantial development permits, variances and permit revisions in accordance with the provisions of this shoreline master program.
      c. Determining compliance with Chapter 43.21C RCW, State Environmental Policy Act.
2. Permits and Decisions. No development shall be undertaken within the shoreline jurisdiction without first obtaining a permit in accordance with the procedures established in the shoreline master program. In addition such permit shall be in compliance with permit requirements of all other agencies having jurisdiction within the shoreline designated environment.

a. Shoreline Exemption Permit. A shoreline exemption permit (SEP) may be granted to the following development as long as such development is in compliance with all applicable requirements of this shoreline master program, the city of Mercer Island development code and WAC 173-27-040:

i. Any development of which the total cost or fair market value, whichever is higher, does not exceed $5,718 or as periodically revised by the Washington State Office of Financial Management, if such development does not materially interfere with the normal public use of the water or shorelines of the state;

ii. Normal maintenance or repair of existing structures or developments, including damage by accident, fire or elements. “Normal maintenance” includes those usual acts established to prevent a decline, lapse, or cessation from a lawfully established condition. “Normal repair” means to restore a development to a state comparable to its original condition within a reasonable period after decay or partial destruction except where repair involves total replacement which is not common practice or causes substantial adverse effects to the shoreline resource or environment. Normal maintenance of single-family dwellings is categorically exempt as stated above;

iii. Construction of the normal protective bulkhead common to single-family dwellings. A "normal protective" bulkhead is constructed at or near the ordinary high water mark to protect a single-family dwelling and is for protecting land from erosion, not for the purpose of creating land. Where an existing bulkhead is being replaced, it shall be constructed no further waterward of the existing bulkhead than is necessary for construction of new footings;

iv. Emergency construction necessary to protect property from damage by the elements. An “emergency” is an unanticipated and imminent threat to public health, safety, or the environment which requires immediate action within a time too short to allow full compliance with this section;

v. Construction or modification of navigational aids such as channel markers and anchor buoys;

vi. Construction of a dock, designed for pleasure craft only, for the private noncommercial use of the owners, lessee, or contract purchaser of a single-family dwelling, for which the cost or fair market value, whichever is higher, does not exceed $10,000;

vii. Any project with a certification from the governor pursuant to Chapter 80.50 RCW.

If a development is exempt from the requirements of the substantial development permit, but a deviation or variance from the provisions of the shoreline master program is required, the applicant must request said deviation or variance through the procedures established in this section.

b. Substantial Development Permit. A substantial development permit (SDP) is required for any development within a shoreline jurisdiction not covered under a categorical exemption or shoreline exemption permit. Requirements and procedures for securing a substantial development permit are established below. Compliance with all applicable federal and state regulations is also required.
c. Deviations and Deviation Criteria. The city planning commission shall have the authority to
grant deviations from the regulations specified in Table B in subsection D of this section;
provided, the proposed deviation:
   i. Will not constitute a hazard to the public health, welfare, and safety, or be injurious to
affected shoreline properties in the vicinity;
   ii. Will not compromise a reasonable interest of the adjacent property owners;
   iii. Is necessary to the reasonable enjoyment of property rights of the applicant; and
   iv. Is not in conflict with the general intent and purpose of the SMA, the shoreline master
program and the development code.

d. Variances and Variance Criteria. Variances to the shoreline master program requirements
are only granted in circumstances where denial of the permit would result in a thwarting of the
policy enumerated in RCW 90.58.020. In addition, in all instances the applicant for a variance
shall demonstrate strict compliance with all variance criteria set out in MICC 19.15.020(G)(4)
and the following additional criteria:
   i. In the granting of all variance permits, consideration shall be given to the cumulative impact
of additional request for like actions in the area. For example if variances were granted to other
developments in the area where similar circumstances exist the total of the variances shall also
remain consistent with the policies of RCW 90.58.020 and shall not produce substantial adverse
effects to the shoreline environment.
   ii. Variance permits for development that will be located landward of the ordinary high water
mark may be authorized; provided, the applicant can demonstrate all of the following:
      (a) That the strict application of the bulk, dimensional or performance standards set forth in
the applicable master program precludes or significantly interferes with reasonable use of the
property not otherwise prohibited by the master program;
      (b) That the hardship in subsection (C)(2)(d)(ii)(a) of this section is specifically related to the
property, and is the result of unique conditions such as irregular lot shape, size, or natural
features and the application of the master program, and not, for example, from deed restrictions
or the applicant’s own actions;
      (c) That the design of the project is compatible with other permitted activities in the area and
will not cause adverse effects to adjacent properties or the shoreline environment;
      (d) That the requested variance does not constitute a grant of special privilege not enjoyed by
the other properties in the area, and is the minimum necessary to afford relief; and
      (e) That the public interest will suffer no substantial detrimental effect.
   iii. Variance permits for development that will be located waterward of the ordinary high
water mark may be authorized; provided, the applicant can demonstrate all of the following:
      (a) That the strict application of the bulk, dimensional or performance standards set forth in
the applicable master program precludes reasonable use of the property not otherwise prohibited
by the master program;
      (b) That the proposal is consistent with the criteria established under subsections
(C)(2)(d)(ii)(b) through (e) of this section; and
      (c) That the public rights of navigation and use of the shorelines will not be adversely affected.


   Step 1. Application.

   The applicant shall arrange a preapplication meeting for all substantial development permits,
deviations and variances. Upon completion of the preapplication meeting, a complete application
including the required processing fees shall be filed with the city on approved forms to ensure
compliance with development codes and standards. A complete application for the shoreline exemption permit (SEP), substantial development permit (SDP), or variance and SEPA checklist, if applicable, shall be filed with the city on required forms.

SEP Review Process: The city shall issue or deny the SEP within 10 calendar days of receiving the request, or after SEPA review. The city shall then send the SEP to the applicant and the Department of Ecology, pursuant to WAC 173-27-130, and to all other applicable local, state, or federal agencies.

Step 2. Public Notice.
Public notice of an application for a substantial development permit shall be made in accordance with the procedures set forth in MICC 19.15.020; provided, such notice shall be given at least 30 days before the date of final local action.

If an application is not exempt from SEPA and no prior SEPA notice has been given, the city shall publish the SEPA determination and a notice that comments on the SEPA documents may be made during the review of the SDP, deviation and variance application.

Within 30 days of the final publication, posting or mailing of the notice, whichever comes last, any interested person may submit written comments on the proposed application. The city will not make a decision on the permit until after the end of the comment period.

Step 3. Review.
The Shoreline Management Act does not require that public hearing be held on SDP and/or variance application. The technical review of SDP and/or variance must ensure that the proposal complies with the criteria of the shoreline master program, Shoreline Management Act policies and all requirements of the city of Mercer Island development code.

An open record hearing before the planning commission, as set out in MICC 19.15.020(F), shall be conducted on all deviation applications and may be conducted on the SDP or variance application when the following factors exist:
(a) The proposed development has broad public significance; or
(b) Within the 30-day comment period, 10 or more interested citizens file a written request for a public hearing; or
(c) The cost of the proposed development, exclusive of land, will exceed $100,000.

Step 4. Decision.
After the 30-day comment period has ended, the city shall decide whether to approve or deny any SDP, deviation and/or variance application, unless the applicant and any adverse parties agree in writing to an extension of time with a certain date.

The city’s action in approving, approving with conditions, or denying SDP, deviation and/or variance shall be given in writing in the form required by WAC 173-27-120 (or its successor) and mailed to the applicant, all persons who submitted written comments, the Department of Ecology, the Washington State Attorney General, and all other applicable local, state, or federal agencies.

The city’s action in approving, approving with conditions, or denying any SDP and/or deviation is final unless an appeal is filed in accordance with applicable law.

The final decision in approving, approving with conditions, or denying variance is rendered by the Department of Ecology in accordance with WAC 173-27-200, and to all other applicable local, state, or federal agencies.

Step 5. Filing.
The city’s final action in approving, approving with conditions, or denying SDP, deviation and/or variance shall be filed with the Department of Ecology and Washington State Attorney General.


If the SDP and/or variance is approved, the applicant shall not begin construction until after the 21-day review period by the Department of Ecology is over and/or any appeals concluded. The applicant shall also comply with all applicable federal, state and city standards for construction.

4. Time Limits of Permits. The following time limits shall apply to all shoreline exemption, substantial development, deviation and variance permits:
   a. Construction or substantial progress toward construction of a development for which a permit has been granted must be undertaken within two years of the effective date of a shoreline permit. The effective date of a shoreline permit shall be the date of the last action required on the shoreline permit and all other government permits and approvals that authorize the development to proceed, including all administrative and legal actions on any such permit or approval.
   b. A single extension before the end of the time limit, with prior notice to parties of record, for up to one year, based on reasonable factors may be granted.

5. Suspension of Permits. The city may suspend any shoreline exemption, substantial development, deviation and variance permit when the permittee has not complied with the conditions of the permit. Such noncompliance may be considered a public nuisance. The enforcement shall be in conformance with the procedures set forth in MICC 19.15.030, Enforcement.

6. Revisions. When an applicant seeks to revise a SDP, deviation and/or variance permit the requirement of WAC 173-27-100, as amended, shall be met.

D. Use Regulations. All development within the shoreline jurisdiction shall be in compliance with all development requirements specified in this section.

1. Table A. Requirements for Development Located Landward from the OHWM

<table>
<thead>
<tr>
<th>Setbacks for All Structures (Including Fences over 48 Inches High) and Parking</th>
<th>A*</th>
<th>25 feet from the OHWM and all required setbacks of the development code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height Limits for All Structures</td>
<td>B</td>
<td>Shall be the same as height limits specified in the development code but shall not exceed a height of 35 feet above average grade level (WAC 173-27-040); provided that the trackway, overhead wires, support poles, and similar features necessary to operate light rail transit facilities on the I-90 bridges are exempt from these height limits</td>
</tr>
<tr>
<td>Maximum Impervious Surface Coverage</td>
<td>C</td>
<td>10%: between 0 – 25 feet from OHWM</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>30%: between 25 – 50 feet from OHWM</td>
</tr>
<tr>
<td>Minimum Land Area Requirements</td>
<td>E</td>
<td>All semi-private, commercial and noncommercial recreational tracts and areas shall have minimum land area: 200 square feet per family, but not less than 600 square feet, exclusive of driveways or parking areas. Screening of the boundaries with abutting properties and a planning commission approval of a site plan is required</td>
</tr>
</tbody>
</table>

*The letters in this column refer to the Plan View(A) and Section(A) diagrams.
1. Table B. Requirements for Moorage Facilities and Development Located Waterward from the OHWM

| Setbacks for All Moorage Facilities, Covered Moorage, Lift Stations, Boatlifts and Floating Platforms | A* | 10 feet from the lateral line  
| Setbacks for adjoining moorage structures (except where moorage facility is built pursuant to the agreement between adjoining owners as shown in Figure B below)  
| 50 feet or 50% of the water frontage of the property, whichever is less, from the common boundary of the subject property urban park or conservation environment | B | 35 feet from adjoining moorage structures  |
| C |  |

| Setbacks for Boat Ramps and Other Facilities for Launching Boats by Auto or Hand, Including Parking and Maneuvering Space | D | 25 feet from any adjacent private property line |

| Length or Maximum Distance Waterward from the OHWM for Moorage Facilities, Covered Moorage, Lift Stations, Boatlifts and Floating Platforms | E | Maximum 100 feet, but in cases where water depth is less than 10 feet from the mean low water, length may extend up to 150 feet or to the point where water depth is 10 feet at mean low water, whichever is less |

| Width | F | Maximum 8 feet; does not apply to boat ramps, lift stations, or floating platforms |

| Square Footage of Piers/Docks |  
| Single ** Waterfront Owner- Maximum 1,000 square feet, including floats  
| 2 **Waterfront Owners- Maximum 1,150 square feet including floats.  
| 3 or more **Waterfront Owners- Maximum 1,300 square feet including floats  
| ** -Must meet minimum water frontage standards | |

| Decking requirements for New Piers/Docks | For the construction of new piers/docks, decking shall be constructed of material that provides a minimum of 40% open space. |

| Height Limits for Piers and Docks | G | 1.5 feet minimum and 5 feet maximum above the elevation of the OHWM |

| Height Limits for Walls, Handrails and Storage Containers Located on Piers | H | 3-3.5 feet above the decking surface of the moorage facility dock or pier.  
| 4 feet above the surface of a dock or pier for ramps and gangways designed to clear span within the 30 feet of the nearshore area. |

| Height Limits for Mooring Piles, Diving Boards and Diving Platforms | I | 10 feet above the elevation of the OHWM |
| Height Limits for Light Rail Transit Facilities within the Existing I-90 Corridor | The trackway and overhead wires, support poles, and similar features necessary to operate light rail transit facilities may be erected upon and exceed the height of the existing I-90 bridges |

*The letters in this column refer to the Plan View(B) and Section(B) diagrams.*
Table B (continued) Requirements for Moorage Facilities and Development Located Waterward from the OHWM

<table>
<thead>
<tr>
<th>Minimum Water Frontage for Moorage Facility</th>
<th>J*</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-family lots: 40 feet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared – two adjoining lots: 40 feet combined</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Semi-private recreational tracts:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 families: 40 feet</td>
<td></td>
<td></td>
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<tr>
<td>3 – 5 families: 40 feet plus 10 feet for each family more than 2</td>
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<tr>
<td>6 – 10 families: 70 feet plus 5 feet for each family more than 5</td>
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<tr>
<td>11 – 100 families: 95 feet plus 2 feet for each family more than 10</td>
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<tr>
<td>101+ families: 275 feet plus 1 foot for each family more than 100</td>
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</tbody>
</table>

Covered Moorage

Permitted on single-family residential lots subject to the following:
(a) Maximum height above the OHWM: 20 feet; 20 to 25 feet subject to deviation process (MICC 19.07.080(C)(2)(d) – MICC 19.07.110(C)(2)(c))
(b) Location/area requirements: See Figure A for single-family lots and Figure B for shared moorage.
   Outside the triangle subject to deviation process (MICC 19.07.080(C)(2)(d) – MICC 19.07.110(C)(2)(c)).
(c) Building area: 600 square feet.
   Building areas larger than 600 square feet are subject to conditional use permit within the triangle, or variance outside the triangle
(d) Covered moorage shall have open sides.
   Prohibited in semi-private recreational tracts, commercial and noncommercial recreational areas.
(e) Translucent canopies are required.

Boatlifts

Permitted subject to the following:
(a) Minimum distance waterward from the OHWM: 30 feet. This does not apply to personal watercraft lifts.

*The letters in this column refer to the Plan View(C).
Table 1: Figure A: Area of Permitted Covered Moorage, Individual Lots
The covered portion of a moorage shall be restricted to the area lying within a triangle. The base of the triangle shall be a line drawn between the points of intersection of the property sidelines with the ordinary high water mark. The location of the covered moorage shall not extend more than 100 feet from the center of the base line of such triangle. In cases where water depth is less than 10 feet from the mean low water, the location of the covered moorage may extend up to 150 from the center of the base line or to the point where water depth is 10 feet at mean low water, whichever is less. The required 10 foot setbacks from the side property lines shall be deducted from the triangle area.
Table 2: Figure B: Area of Permitted Covered Moorage and Moorage Facilities, Two Adjoining Single-family Lots

Where a covered moorage or moorage facility is built pursuant to the agreement of adjoining owners of single-family lots, the covered moorage area shall be deemed to include, subject to limitations of such joint agreement, all of the combined areas lying within the triangles extended upon each adjoining property and the inverted triangle situated between the aforesaid triangles.

   a. Moorage facilities may be developed and used as an accessory to dwellings on shoreline lots with water frontage meeting or exceeding the minimum lot width requirements specified in Table A.
   b. Piles, floats or other structures in direct contact with water shall not be treated or coated with toxic substances harmful to the aquatic environment. Chemical treatment of structures shall comply with all applicable state and federal regulations.

   a. An existing shoreline stabilization structure may be replaced with a similar structure if there is a demonstrated need to protect principal uses or structures from erosion caused by currents or waves. The following conditions apply:
      i. The replacement structure should be designed, located, sized, and constructed to assure no net loss of ecological functions.
      ii. Replacement walls or bulkheads shall not encroach waterward of the ordinary high water mark or existing structure unless the primary structure was occupied prior to January 1, 1992 and there are overriding safety or environmental concerns. In such cases, the replacement structure shall abut the existing shoreline stabilization structure.
      iii. Soft shoreline stabilization measures that provide restoration of shoreline ecological functions may be permitted waterward of the ordinary high-water mark.
   [additional conditions...]

   aiv. Construction and maintenance of normal protective bulkhead common to single-family dwellings requires only a shoreline exemption permit, unless a report is required by the code official to ensure compliance with the above conditions; however, if the construction of the
bulkhead is undertaken wholly or in part on lands covered by water, such construction shall comply with the SEPA Rules, Chapter 197-11 WAC.

b.- New Structures for Existing Primary Structures: New or enlarged structural shoreline stabilization measures for an existing primary structure, including residences, should not be allowed unless there is conclusive evidence, documented by a geotechnical analysis, that the structure is in danger from shoreline erosion caused by currents, or waves. Normal sloughing, erosion of steep bluffs, or shoreline erosion itself, without a scientific or geotechnical analysis, is not demonstration of need. The geotechnical analysis should evaluate on-site drainage issues and address drainage problems away from the shoreline edge before considering structural shoreline stabilization. New or enlarged erosion control structure shall not result in a net loss of shoreline ecological functions.

c.- New development should be located and designed to avoid the need for future shoreline stabilization to the extent feasible. Future shoreline stabilization does not apply to stabilization that occurs pursuant to subsection (a) of this section. New structural stabilization measures in support of new nonwater-dependent development, including single-family residences, shall only be allowed when all of the conditions below apply:
   i. The erosion is not being caused by upland conditions, such as the loss of vegetation and drainage.
   ii. Nonstructural measures, such as placing the development further from the shoreline, planting vegetation, or installing on-site drainage improvements, are not feasible or not sufficient.
   iii. The need to protect primary structures from damage due to erosion is demonstrated through a geotechnical report, in compliance with MICC 19.07.110(D)(4)(k). The damage must be caused by natural processes, such as currents, and waves.
   iv. The erosion control structure will not result in a net loss of shoreline ecological functions.

d.- New development on steep slopes or bluffs shall be set back sufficiently to ensure that shoreline stabilization is unlikely to be necessary during the life of the structure, as demonstrated by a geotechnical analysis, in compliance with MICC 19.07.110(D)(4)(g). New development that would require shoreline stabilization which causes significant impacts to adjacent or down-current properties and shoreline areas should not be allowed.

e.- New structural stabilization measures in support of water-dependent development shall only be allowed when all of the conditions below apply:
   i. The erosion is not being caused by upland conditions, such as the loss of vegetation and drainage.
   ii. Nonstructural measures, planting vegetation, or installing on-site drainage improvements, are not feasible or not sufficient.
   iii. The need to protect primary structures from damage due to erosion is demonstrated through a geotechnical report, in compliance with MICC 19.07.110(D)(4)(k).
   iv. The erosion control structure will not result in a net loss of shoreline ecological functions.

f.- New structural stabilization measures to protect projects for the restoration of ecological functions or hazardous substance remediation projects pursuant to RCW 70.105D shall only be allowed when all of the conditions below apply:
   i. Nonstructural measures, planting vegetation, or installing on-site drainage improvements, are not feasible or not sufficient.
ii. The erosion control structure will not result in a net loss of shoreline ecological functions.

b. Bulkheads shall be located generally parallel to the natural shoreline. No filling may be allowed waterward of the ordinary high water mark, unless there has been severe and unusual erosion within one year immediately preceding the application for the bulkhead. In this event the city may allow the placement of the bulkhead to recover the dry land area lost by erosion.

c. Replacement bulkheads may be located immediately in front of and abutting an existing bulkhead, but no filling shall be allowed waterward of the ordinary high water mark.

d. Geotechnical reports pursuant to this section that address the need to prevent potential damage to a primary structure shall address the necessity for shoreline stabilization by estimating time frames and rates of erosion and report on the urgency associated with the specific situation. As a general matter, hard armoring solutions should not be authorized except when a report confirms that there is a significant possibility that such a structure will be damaged within three years as a result of shoreline erosion in the absence of such hard armoring measures, or where waiting until the need is that immediate, would foreclose the opportunity to use measures that avoid impacts on ecological functions. Thus, where the geotechnical report confirms a need to prevent potential damage to a primary structure, but the need is not as immediate as the three years, that report may still be used to justify more immediate authorization to protect against erosion using soft measures.

i. When any structural shoreline stabilization measures are demonstrated to be necessary, pursuant to above provisions, the following shall apply:

i. Limit the size of stabilization measures to the minimum necessary. Use measures designed to assure no net loss of shoreline ecological functions. Soft approaches shall be used unless demonstrated not to be sufficient to protect primary structures, dwellings, and businesses.

ii. Ensure that publicly financed or subsidized shoreline erosion control measures do not permanently restrict appropriate public access to the shoreline except where such access is determined to be infeasible because of incompatible uses, safety, security, or harm to ecological functions. See public access provisions; WAC 173-26-221(4). Where feasible, incorporate ecological restoration and public access improvements into the project.

iii. Mitigate new erosion control measures, including replacement structures, on feeder bluffs or other actions that affect beach sediment-producing areas to avoid and, if that is not possible, to minimize adverse impacts to sediment conveyance systems. Where sediment conveyance systems cross jurisdictional boundaries, local governments should coordinate shoreline management efforts. If beach erosion is threatening existing development, local governments should adopt master program provisions for a beach management district or other institutional mechanism to provide comprehensive mitigation for the adverse impacts of erosion control measures.

j. Breakwaters, jetties, groins, and weirs. Breakwaters, jetties, groins, and weirs located waterward of the ordinary high-water mark shall be allowed only where necessary to support water-dependent uses, public access, shoreline stabilization, or other specific public purpose. Breakwaters, jetties, groins, weirs, and similar structures should require a conditional use permit, except for those structures installed to protect or restore ecological functions, such as woody debris installed in streams. Breakwaters, jetties, groins, and weirs shall be designed to protect critical areas and shall provide for mitigation according to the sequence defined in WAC 173-26-201 (2)(e).

5. Utilities.
a. Utilities shall be placed underground and in common rights-of-way wherever economically and technically practical.
b. Shoreline public access shall be encouraged on publicly owned utility rights-of-way, when such access will not unduly interfere with utility operations or endanger public health and safety. Utility easements on private property will not be used for public access, unless otherwise provided for in such easement.
c. Restoration of the site is required upon completion of utility installation.
d. Construction of utility buildings and structures require a conditional use permit.

6. Dredging.
a. Dredging waterward or landward of the ordinary high water mark shall be permitted only if navigational access has been unduly restricted or other extraordinary conditions in conjunction with water-dependent use; provided, that the use meets all state and federal regulations.
b. Dredging shall be the minimum necessary to accommodate the proposed use.
c. Dredging shall utilize techniques that cause the least possible environmental and aesthetic impact.
d. Dredging is prohibited in the following locations:
   i. Fish spawning areas.
   ii. In unique environments such as lake logging of the underwater forest.
e. Disposal of dredged material shall comply with Ecology Water Quality Certification process and U.S. Army Corps of Engineers permit requirements. The location and manner of the disposal shall be approved by the city.

7. Transportation and Parking
a. Shoreline circulation system planning shall include safe, reasonable, and adequate systems for pedestrian, bicycle, and public transportation where appropriate. Circulation planning and projects should support existing and proposed shoreline uses that are consistent with the master program.
b. Transportation and parking facilities shall be planned, located, and designed where routes will have the least possible adverse effect on unique or fragile shoreline features, and will not result in a net loss of shoreline ecological functions or adversely impact existing or planned water-dependent uses.
c. Where other options are available and feasible, new roads or road expansions should not be built within shoreline jurisdiction.
d. Parking facilities in shorelines shall be allowed only as necessary to support an authorized use.
e. Parking facilities in shorelines shall minimize the environmental and visual impacts.

E. General Provisions
1. Archaeological and Historic Resources
a. If archaeological resources are uncovered during excavation, the developer and property owner shall immediately stop work and notify the City, the Office of Archaeology and Historic Preservation, and affected Indian tribes.
b. In areas documented to contain archaeological resources by the Office of Archaeology and Historic Preservation, a site inspection or evaluation is required by a professional archaeologist in coordination with affected Indian tribes.

2. Public Access
Section 3: Amendments to 19.16 MICC, Definitions. MICC 19.16 “Definitions” is hereby amended as follows:

Words used in the singular include the plural and the plural the singular. For definitions that are specific to the Shoreline, see 19.07.110(A)(7)(e).

B

... Boat Ramp: An inclined structure upon which a watercraft is raised or pulled onto land or a dock.

Breakwater: a protective structure usually built offshore for the purpose of protecting the shoreline or harbor areas from wave action.

... Bulkhead: A solid or open pile of rock, concrete, steel, timber or other materials erected parallel to, and normally erected at, the ordinary high water line for the purpose of protecting adjacent property from waves or currents.

C

... Covered Moorage: A pier, dock, boatlift, series of piles, or other structure intended for moorage over which a roof or canopy is erected.

... Finger Pier: An extension from a dock used to create moorage slips.

... Floating Platform: A flat structure or device moored or anchored, not permanently secured by piles, which floats upon the water.
G

Groin: A structure used to interrupt sediment movement along the shore.

J

Jetty: A barrier used to protect areas from accumulations of excess sediment.

L

Lateral Line: The extension waterward of a property line into Lake Washington beyond the ordinary high water mark. How property lines extend waterward from the ordinary high water mark is an area of misconception. If the title does not clearly state the location of the property lines waterward from the ordinary high water mark, waterfront owners are not allowed to unilaterally project the upland boundaries out into the shorelands (waterward). There are no statutes defining the direction of the lateral lines waterward from the ordinary high water mark. The Supreme Court has the final word to decide location of lateral line on case-by-case basis.

Lift Station (Boat Hoist): A structure or device normally attached to a dock or pier used to raise a watercraft above the waterline for secure moorage purposes.

M

Marina: A commercial basin providing rental or sale of docks, watercraft, moorage, and/or supplies. Casual single-family renting of moorage is excluded from this definition.

Mean Low Water: The level of Lake Washington during the fall and winter when the water level is lowered to minimize winter storm damage to lakeside properties. Mean low water is one and one-half feet lower than ordinary high water.

Moorage Facility: Any device or structure used to secure a boat or a vessel, including piers, docks, piles, lift stations or buoys.

W

Water-Dependent: A use or a portion of a use which cannot exist in any other location and is dependent on the water by reason of the intrinsic nature of its operations. Examples of water-dependent uses may include ship cargo terminal loading areas, ferry and passenger terminals, barge loading facilities, ship building and dry docking, marinas, aquaculture, float plane facilities and sewer outfalls.

Waterfront Structure: Docks, piers, wharves, floats, mooring piles, anchor buoys, bulkheads, submerged or overhead wires, pipes, cables, and any other object passing beneath, through or over the water beyond the line of ordinary high water.

Waterward: Any point located in Lake Washington, lakeward from the ordinary high water mark.
Section 4: **Repeal and Replace Appendix F to Title 19 MICC.** Appendix F to MICC Title 19 is hereby repealed and replaced with the attached EXHIBIT A.

Section 5: **Amendments to the Shoreline Element of the Comprehensive Plan.** The City of Mercer Island Comprehensive Plan, Shoreline Element is hereby amended as set forth in the attached EXHIBIT B.

Section 6: **Severability/Validity.** The provisions of this ordinance are declared separate and severable. If any section, paragraph, subsection, clause or phrase of this ordinance is for any reason held to be unconstitutional or invalid, such decision shall not affect the validity of the remaining portions of this ordinance. The City Council hereby declares that they would have passed this ordinance and each section, paragraph, subsection, clause or phrase thereof irrespective of the fact that any one or more sections, paragraphs, clauses or phrases may subsequently be found by a competent authority to be unconstitutional or invalid.

Section 7: **Ratification.** Any act consistent with the authority and prior to the effective date of this ordinance is hereby ratified and affirmed.

Section 8: **Effective Date.** This Ordinance shall take effect and be in force 30 days after its passage and publication.

PASSED by the City Council of the City of Mercer Island, Washington at its regular meeting on the _________ day of ________ 2010 and signed in authentication of its passage.

CITY OF MERCER ISLAND

________________________________
Jim Pearman, Mayor

ATTEST:

______________________________
Allison Spietz, City Clerk

Approved as to Form:

______________________________
Katie Knight, City Attorney

Date of Publication: ________________
Appendix F - Proposed Shoreline Environment Designations
Shoreline Master Program - City of Mercer Island

All areas within shoreline jurisdiction that are not mapped and/or designated are automatically assigned the "Urban Residential" designation until the shoreline can be redesignated through a master program amendment. In the event of a mapping error, the City of Mercer Island shall rely upon common boundary descriptions and the criteria contained in RCW 90.58.030(2) and Chapter 173-22 WAC pertaining to determinations of shorelands, as amended, rather than the incorrect or outdated map.

Landward extent of Shoreline Management Area is measured 200 ft landward of the Ordinary High Water Mark.

Waterward extent of Shoreline Management Area is measured from the Ordinary High Watermark to the middle of Lake Washington.

Waterward extent of City jurisdiction is measured to the middle of Lake Washington, pursuant to RCW 35.21.150.

Watercourse
Urban Park Environment
Urban Residential Environment
Major Roads
Minor Roads

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Further information at www.mercerisland.gov/shoreplan
EXHIBIT B to Ordinance No. 10C-XX

INTRODUCTION

The purpose of this document is four-fold:

1. To fulfill the requirements of the Shoreline Management Act (SMA) of 1971, Chapter 286, Laws of 1971, Chapter 90.58. RCW and Chapter 173-46 26 WAC by developing a Master Program to guide the future use and development of Mercer Island’s shoreline.

2. To recognize the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan.

3. To recognize the Regional Lake Washington Master Program as a basis for Mercer Island’s Master Program.

4. To provide guidelines and recommendations for revising local ordinances and zoning codes and for updating the comprehensive plan.

5. To provide a basis for evaluating applications for shoreline permits on Mercer Island.

The State of Washington Shoreline Management Act of 1971 recognizes that the shorelines of the state are among our most valuable and fragile natural resources and directs all local governments to develop a Master Program for the management of these shorelines. The Law specifies that all lakes over 1,000 acres in surface area are Shorelines of Statewide Significance. Lake Washington is such a shoreline and in our planning we must, as the Shoreline Management Act specifies, provide for uses in the following order of preference: those which

1. Recognize and protect the state-wide interest over local interest;
2. Preserve the natural character of the shoreline;
3. Result in long term over short term benefit;
4. Protect the resources and ecology of the shoreline;
5. Increase public access to publicly owned areas of the shoreline;
6. Increase recreational opportunities for the public in the shoreline;
7. Provide for any other element deemed appropriate or necessary.

PROLOGUE

To the early developers who built metropolitan Seattle, Lake Washington was perceived as a utilitarian resource. During the past hundred years the Lake has been utilized for transportation, agricultural and domestic water supplies, waste disposal, and numerous types of commercial and industrial enterprises. Many of these activities had adverse impacts on the Lake, and the discharge of sewage eventually led to serious problems with respect to water quality. In response to the rapidly declining quality of Lake Washington, the public voted to create the Municipality of Metropolitan Seattle (METRO) for the purpose of treating sanitary sewage and diverting its discharge from the Lake to Puget Sound. Today the lake is once again suitable for swimming and other recreational activities.

Many of the functions previously related to the lake are now met by other means. The region’s water supply is from rivers, one of which feeds into Lake Washington. Sanitary sewers have
been diverted and measures are being taken to minimize further pollutants from entering the Lake. Water-borne transportation has been largely replaced by an extensive road network around and across the Lake. Also, commercial and industrial uses of the Lake have declined in recent years. In contrast, the use of Lake Washington for leisure activities has increased. The vast majority of the Lake is presently used for residential or recreational purposes. Thus, the future of Lake Washington may be quite different from the expectations of its early developers.

Mercer Island was originally utilized as a source of timber, and although proposed as a “regional park” in its entirety at one time, it became a recreational and, later, a prime residential area. Until 1940, boat and ferry travel was the primary means of reaching the Island from Seattle. In 1940 the Lake Washington floating bridge was completed. At this time the population of the Island and, subsequently, the complexion of development changed rapidly. Developers took advantage of the relatively easy access and relatively close proximity to Seattle’s employment centers, and land quickly changed from forest to subdivision.

Planning during this time and up until the early 1960’s was done-conducted by King County. Since accepting the County zoning upon incorporation of the City in 1960, few changes affecting the shoreline uses have occurred, with single-family residential and recreation constituting the primary shoreline uses.

The City developed its first Shoreline Master Program in 1974. Key considerations within this plan included conservation, public access to the shoreline, residential development, and the guidance for recreational uses along the Mercer Island shoreline. These initial policy objectives are reflected in today’s protection of the City’s shoreline, which includes approximately 6,000 lineal feet of publicly owned shoreline, developed as waterfront recreation areas. Included in these publicly owned lands are nineteen street ends; Groveland Beach Park; Clarke Beach Park; and Luther Burbank Park, which was transferred in 2003 from King County to the City of Mercer Island via an Intergovernmental Land Transfer Agreement.

During the 35 years since the City adopted its first SMP, the Mercer Island has matured to the point where it is largely developed with the priority uses planned for in the first SMP. For example, an inventory of the shoreline prepared as part of this SMP update identified only 30 shoreline properties that are currently undeveloped.

Since 1990, when the state enacted the Growth Management Act, state policy has promoted greater density in urban areas, such as the City of Mercer Island and the other cities that surround Lake Washington. In addition, the increased land values on the Island have created pressures for more intense use of lands during redevelopment.

The City’s and region’s development during this time has impacted the shoreline. Docks and bulkheads, impervious surfaces in shoreline area and in adjacent areas have impacted the shoreline environment, including salmonid habitat. In 1999, Chinook salmon and bull trout were listed as “Threatened” under the Federal Endangered Species Act. New scientific data and
research has improved our understanding of shoreline ecological functions and their value in terms of fish and wildlife, water quality, and human health. Scientific information, however, remains incomplete and sometimes inconsistent in some areas important to Mercer Island’s development pattern.

INTENT
To address changes in the shoreline environment, comply with the mandates of the Shoreline Management Act, and enable the City to plan for emerging issues, the City has initiated an extensive update of its Shoreline Master Program. The new program is intended to respond to current conditions and the community’s vision for the future.

The largely built out character of the shoreline, as well as the increasing protections under state and federal law for shoreline habitat are two factors that have strongly influenced the Update’s direction. In updating the program, the City’s primary objectives are to:

- Enable current and future generations to enjoy an attractive, healthy and safe waterfront.
- Protect the quality of water and shoreline natural resources to preserve fish and wildlife and their habitats.
- Protect the City’s investments, as well as those of property owners along and near the shoreline.
- Produce an updated Shoreline Master Program (SMP) that is supported by Mercer Island’s elected and appointed officials, citizens, property owners, the State of Washington, and other key groups with an interest in the shoreline.
- Fairly allocate the responsibilities for increased shoreline protection among new development and redevelopment.

The City of Mercer Island, through adoption of the Shoreline Master Program, intends to implement the Washington State Shoreline Management Act (RCW 90.58) and its policies, including protecting the State’s shorelines and their associated natural resources, planning for and fostering all reasonable and appropriate uses, and providing opportunities for the general public to have access to and enjoy shorelines.

The City of Mercer Island’s Shoreline Master Program represents the City’s participation in a coordinated planning effort to protect the public interest associated with the shorelines of the State while, at the same time, recognizing and protecting private property rights consistent with the public interest. The Program preserves the public’s opportunity to enjoy the physical and aesthetic qualities of shorelines of the State and protects the functions of shorelines so that, at a
minimum, the City achieves a ‘no net loss’ of ecological functions, as evaluated under the Final Shoreline Analysis Report issued in July 2009. The Program also promotes restoration of ecological functions where such functions are found to have been impaired, enabling functions to improve over time.

The goals and policies of the SMA constitute one of the goals for growth management as set forth in RCW 36.70A.020 and, as a result, the goals and policies of this SMP serve as an element of Mercer Island’s Comprehensive Plan and should be consistent with other elements of the Comprehensive Plan. In addition, other portions of the SMP adopted under chapter 90.58 RCW, including use regulations, are considered a part of the city's development regulations.

Most of the shoreline of Mercer Island had been platted previous to incorporation. Some of these areas are zoned R-8.4 which is a higher density than the R-15 which Mercer Island preferred to impose on the unplatted land it had the opportunity to regulate. Changes in zoning to a lower density along the shoreline have been virtually impossible to achieve. However, the City has developed several ordinances such as those relating to waterfront structures, community waterfront tracts, tree clearing, preserving of watercourses and others that directly or indirectly preserve and enhance shoreline areas.

INTENT

The Lake Washington Regional Citizens and Technical Committees have recognized that the shoreline of Lake Washington is a valuable and fragile natural resource and that there is a great concern throughout the region relating to its utilization, protection, restoration, and preservation. They further recognized that unrestricted construction on the shoreline of Lake Washington is not in the best public interest, while at the same time recognizing and protecting private property rights consistent with the public interest. In addition, they recognized that the shoreline of Lake Washington is located within a major urbanized area and is subjected to ever increasing pressures of additional uses necessitating increased coordination in the management and development of said shoreline. They stated that there is a clear and urgent demand for a planned, rational and concerted effort to insure coordinated and optimum utilization of the shoreline of Lake Washington.

Although the Regional Program provides a basis for the Mercer Island Master Program, historically, shoreline development and, more recently, the nature of our land use ordinances, zoning codes and comprehensive plan, have established a fairly set land use pattern. Community attitudes have strongly emphasized the desire to retain the residential/recreational uses of the shoreline. Therefore, there appears to be a need to slightly modify the tone of the Regional Program to fit Mercer Island.

The Mercer Island Citizen Advisory Committee has indicated that the order of preference for shoreline development should be evaluated according to the following considerations:

1. Low-density single-family residences should continue to be the primary land use of the shoreline of Mercer Island.

2. Conservation of marshes, spawning grounds and other unique or fragile areas is of primary
3. Importance of the public having ample access to the shoreline.

4. Water-oriented recreation is deemed to be appropriate and desirable.

Planning and usage of the Mercer Island shoreline should reflect these priorities.

This document should be read in its entirety and be considered as a whole. These goals and policies were developed with the above priorities in mind and should be applied accordingly. The goals and policies within the following Elements: Shoreline Uses and Activities, Conservation, Public Access, and Components are intended by the Committees to be applicable in all cases.

LAKE WASHINGTON REGIONAL GOALS

The Regional Goals have provided a basis for the Goals and Policies developed for Mercer Island. The Regional Goals are, therefore, summarized below to provide a reference to the Goals and Policies formulated by the Mercer Island Citizens Committee.

PRIMARY GOAL
The natural amenities and resources of Lake Washington are to be conserved in a predominately recreational/residential environment with adequate access available to the public.

The regional goals established by the Regional Committees are listed below in order of preference:

— The shoreline of Lake Washington is to be planned and coordinated to afford optimal use of the limited water resource.

— The shoreline of Lake Washington is to provide natural amenities within an urban environment.

— The resources and amenities of Lake Washington are to be protected and preserved for use and enjoyment by present and future generations.

— Increase public access to and along the shoreline areas, provided public safety, private property rights, and unique or fragile areas are not adversely affected.

— Water-dependent recreational activities available to the public are to be encouraged and increased on the shoreline of Lake Washington where appropriate and consistent with public interest.

— Existing residential uses are to be recognized and new residential construction will be subject to certain limitations, if applicable.
-- Existing economic uses and activities on the shoreline of Lake Washington are to be recognized, while economic uses of activities that are not dependent on a Lake Washington location are to be discouraged.

-- A balanced transportation system for moving people and goods is to be encouraged within existing corridors.

**DESIGNATED ENVIRONMENTS**

The Final Guidelines – Shoreline Management Act of 1971 requires that as a part of the Master Program the City is required to do the following:

1. Designated type of environments the Mercer Island shorelines represent.

2. The environmental designations be consistent with the information in the Shoreline Inventory.

3. The designation must be consistent with the provisions of the Guidelines and Mercer Island’s Goals and Policies.

More generally the Guidelines state that:

“In order to plan and effectively manage shoreline resources, a system of categorizing shoreline areas is required for use by local governments in the preparation of the master programs. The system is designated to provide a uniform basis for applying policies and use regulations within distinctively different shoreline areas. To accomplish this, the environmental designation to be given any specific area is to be based on the existing development pattern, the biophysical capabilities and limitations of the shoreline being considered for development and the goals and aspirations of local citizenry.

WAC 173-26-211 states, “Master programs shall contain a system to classify shoreline areas into specific environment designations. This classification system shall be based on the existing use pattern, the biological and physical character of the shoreline, and the goals and aspirations of the community as expressed through comprehensive plans as well as the criteria in this section. Each master program’s classification system shall be consistent with that described in WAC 173-26-211 (4) and (5) unless the alternative proposed provides equal or better implementation of the act.”

The recommended system classifies shorelines into four distinct environments (natural, conservancy, rural and urban) which provide the framework for implementing shoreline policies and regulatory measures.

WAC 173-26-211(4)(c) allows for local governments to establish a designation system, provided it is consistent with the purposes and policies of WAC 173-26-211 and WAC 173-26-211(5).

Mercer Island contains two distinct shoreline designations, pursuant to WAC 173-26-
211(4)(c): urban residential, and urban park.

This system is designed to encourage uses in each environment which enhance the character of that environment. The basic intent of this system is to utilize performance standards which regulate use activities in accordance with goals and objectives defined locally rather than to exclude any use from any one environment. Thus, the particular uses or type of developments placed in each environment should be designed and located so that there are no effects detrimental to achieving the objectives of the environment designations and local development criteria. This approach provides an ‘umbrella’ environment class over local planning and zoning on the shorelines. Since every area is endowed with different resources, has different intensity of development and attaches different social values to these physical and economic characteristics, the enforcement designations should not be regarded as a substitute for local planning and land-use regulations.”

Although none of the four categories precisely fit Mercer Island, the most appropriate environment designation is that of Urban as designated in WAC 173-16040(4)(b)(iv).

The objective of the urban environment is to ensure optimum utilization of shorelines within urbanized areas by providing for intensive public use and by managing development so that it enhances and maintains shorelines for a multiplicity of urban uses. Because shorelines suitable for urban uses are a limited resource, emphasis should be given to development within already developed areas. In the master program, priority is also to be given to planning for public visual and physical access to water in the urban environment. Identifying needs and planning for the acquisition of urban land for permanent public access points to the shoreline should be linked to non-motorized transportation routes, such as bicycle and hiking trails.

In some instances, the Conservancy Environment designation may apply. Designation of these areas should be undertaken at the time unique and fragile areas are further inventoried and mapped.

Urban Residential

The purpose of the urban residential environment is to accommodate residential development and appurtenant structures that are consistent with this chapter. An additional purpose is to provide appropriate public access and recreational uses.

Designation Criteria. Areas that are predominantly single-family or multifamily residential development or are planned and platted for residential development.

Management Policies.

1. Standards for density or minimum frontage width, setbacks, lot coverage limitations, buffers, shoreline stabilization, vegetation conservation, critical area protection, and water quality shall be set to assure no net loss of shoreline ecological functions, taking into account the environmental limitations and sensitivity of the shoreline area, the level of infrastructure and services available, and other comprehensive planning considerations.
2. Development of multifamily-recreational and residential subdivisions of five or more lots should provide public access and joint use for community recreational facilities.

3. Access, utilities, and public services should be available and adequate to serve existing needs and/or planned future development.

4. Commercial development should be limited to water-oriented uses.

Urban Park Environment
The purpose of the urban park environment is to protect and restore ecological functions in urban and developed settings, while allowing public access and a variety of park and recreation uses.

Designation Criteria. An urban park environment designation will be assigned to publicly owned shorelands, including all parks, street ends and public access points.

Management policies

1. Uses that preserve the natural character of the area or promote preservation of open space, or sensitive lands either directly or over the long term should be the primary allowed uses. Uses that result in restoration of ecological functions should be allowed if the use is otherwise compatible with the purpose of the environment and the setting.

2. Standards should be established for shoreline stabilization measures, vegetation conservation, water quality, and shoreline modifications within the urban park designation. These standards shall ensure that new development does not result in a net loss of shoreline ecological functions or further degrade other shoreline values.

3. Public access and public recreation objectives should be implemented whenever feasible and significant ecological impacts can be mitigated.

4. Water-oriented uses should be given priority over nonwater-oriented uses. For shoreline areas adjacent to commercially navigable waters, water-dependent uses should be given highest priority.

SHORELINE USES AND ACTIVITIES

The Mercer Island Shoreline Inventory indicates that present usage of the shoreline is primarily residential/recreational in character. As the population of both the Island and the region grows, demands for all forms of shoreline use and activities on Lake Washington are expected to increase. At some future time this demand is likely to exceed the existing supply of the Lake’s shoreline. Several studies related to appropriate uses of the shoreline, particularly those of a residential or recreational nature, have been undertaken on Mercer Island to determine the best...
Most of these studies and plans have only indirectly addressed the question of proliferation of shoreline development on Lake Washington. To date a water use management plan has also been indirectly considered. This document is intended to complement existing studies and to provide criteria to assist in determining the optimal mix of shoreline uses.

The following goals and policies address the general distribution, location, and extent of all uses within shoreline jurisdiction.

**GOALS**

1. Ensure that the land use patterns within shoreline areas are compatible with shoreline environment designations and will be sensitive to and not degrade habitat, ecological systems, and other shoreline resources. The Shoreline of Mercer Island is to be planned and coordinated to afford optimal use of the limited resource.

2. The shoreline of Mercer Island is to provide natural amenities within an urban environment.

**POLICIES**

1. Plans should be made for reasonable and appropriate shoreline uses and activities.
   
   a. Short-term economic gain or convenience in development should be evaluated in relationship to potential long-term effects on the shoreline.
   
   b. Preference should be given to those uses or activities which enhance the natural amenities of the Lake and which depend on a shoreline location or provide public access to the shoreline.
   
   c. Planning, zoning, capital improvements and other policy and regulatory standards should not increase the density or intensity of shoreline uses or activities.
   
   d. Shorelines particularly suited for a specific appropriate water-dependent use or activity should be planned for and designated.
   
   e. Multiple-use of shorelines should be planned where location and integration of compatible uses or activities are feasible.
   
   f. Aesthetic values must be considered when evaluating new development, redevelopment of existing facilities or for general enhancement of shoreline areas.
   
   g. Shoreline uses and activities should be discouraged if they are objectionable due to noise or odor or if they create offensive or unsafe conditions in relating to reasonable and appropriate uses and activities.
1. All activities, development and redevelopment within the City’s shoreline jurisdiction should be designed to ensure no net loss of shoreline ecological functions.

2. Existing shoreline use or activities identified as being inappropriate should be encouraged to relocate away from the shoreline.

3. Uses and activities in unique or fragile shoreline areas should be discouraged unless measures can be satisfactorily undertaken to mitigate all related adverse impacts.

4. Sufficient amounts of open space should be distributed along the shoreline to provide nearby recreational opportunities for the general public.

5. Shoreline uses or activities not specified in this document should be consistent with the intent of the goals and policies stated herein.

RECOMMENDATIONS:

1. Mercer Island should formulate programs for the relocation of inappropriate uses and activities. The use of public funds, trading of other public lands where feasible, or other incentives should be considered when necessary to accomplish this objective.

2. Unique and fragile shoreline areas should be defined and inventoried on Mercer Island by appropriate City staff members and Boards and Commissions as soon as possible.

CONSERVATION ELEMENT

The following goal and policies address the protection of the resources of the shoreline. According to the Shoreline Management Act, three of the highest priorities for Shorelines of Statewide Significance are to a) preserve the natural character of the shorelines; b) result in long term over short term benefit; and c) protect the resources and ecology of the shoreline. Although some natural resources are non-renewable in character, Lake Washington is a unique biological, economic and recreational resource which can be managed in a way to allow its assets to be continually available to the region and the state.

Human activities have either directly or indirectly influenced the Lake’s entire shoreline. Some areas (stream outlets, marshes, embayments, wooded areas and others) have remained in a somewhat natural condition. As the population of the Island increases, the pressures to develop these natural condition. But the costs involved in preparing some of these sites for development may be high due to soil or hydrologic conditions. There may be greater long term value in preserving these areas for purposes of open space within an urbanizing region. Often these areas are also important habitats for fish and wildlife. Preservation of these remaining areas, during the subdivision or development process, could be accomplished through the use of the open space option of the Subdivision Ordinance.

Conservation efforts are not directed solely toward undeveloped areas. Activities on the shoreline or within the drainage basin may adversely affect water quality, aquatic life or other
resources of the Lake. Normal single-family residential activities within the shoreline appear to have minimal negative effects on the resources of the Lake. Long Range planning should seek to minimize such adverse impacts.

The concept of conservation should also apply to structures or areas worth preserving for their historical, cultural, educational or scientific value. The use of some areas, either on a temporary basis for special events or festivals, or permanently for facilities reflecting our past or enhancing our future, are considered as reasonable and appropriate.

**GOAL**

*The resources and amenities of Lake Washington are to be protected and preserved for use and enjoyment by present and future generations.*

**POLICIES:**

1. Existing natural resources should be conserved, consistent with private property rights.
   a. Aquatic habitats, particularly spawning grounds, should be protected, improved and, if feasible, increased.
   b. Wildlife habitats should be protected, improved and, if feasible, increased.
   c. Unique and fragile areas should be so designated and have been mapped. Access and use should be restricted if necessary for the conservation of these areas. The type and degree of development to be allowed should be based upon such factors as: slope, soils, vegetation, geology and hydrology.
   d. Water quality should be maintained at a level to permit recreational use (specifically swimming), provide a suitable habitat for desirable forms of aquatic life and satisfy other required human needs.

2. Existing and future activities on Lake Washington and its shoreline should be designed to minimize adverse effects on the natural systems.

3. Uses or activities within all drainage basins related to Lake Washington should be considered as an integral part of shoreline planning.
   a. Developers should be required to bear the cost of providing safeguards to prevent storm drainage damage resulting from their development.
   b. Excessive soil erosion and sedimentation and other polluting elements should be prevented from entering and adversely affecting the Lake and its constituent watercourses.
   c. Restoration of natural systems adversely affected by sedimentation and pollution should
The destruction of watercourses feeding into Lake Washington should be discouraged.

e. The planning and control of surface drainage water from Mercer Island into Lake Washington should be based on such factors as the quality and quantity of water, rate of flow and containment, etc. The latest applicable data should be used in the implementation of a storm drainage system.

4. Shoreline areas having historical, cultural, educational or scientific value should be protected and restored.
   a. Public and private cooperation should be encouraged in site preservation and protection.
   b. Suspected or newly discovered sites should be kept free from intrusion until their value is determined.
   c. Festivals and temporary uses involving public interest and not substantially or permanently impairing water quality or unique and fragile areas should be permitted.

RECOMMENDATIONS

1. Since the shorelines are valuable and fragile resources, Mercer Island should designate use regulations to minimize man-made intrusions on the shoreline. Conservancy environments should be designated and mapped where the natural conditions so indicate.

2. Unique and fragile areas on the Island’s shoreline should be further defined, inventories and mapped by August, 1974.

3. Discharge of sewage (sewage is defined as treated or untreated wastes which do not meet Federal, State, or local standards for discharge in Lake Washington), waste, rubbish and litter from boats on Lake Washington should not be permitted. Pumping and tank facilities for the discharge of sewage, waste, rubbish and litter from boats equipped with marine toilets and/or galleys, should be provided in all new marinas or public moorages.

4. Comment should be solicited from Metro concerning proposed activities affecting water quality in Lake Washington or its tributaries.

5. Mercer Island should consider designating sites of historic value such as the passenger boat and ferry landings and areas of early settlement such as the Proctor, Calkins and Olds homesites.

6. Where appropriate, natural watercourses should be retained.

7. A watercourse ordinance to preserve the systems of natural drainage on the Island should be passed.
8. Information concerning the use of the State Open Space Taxation legislation of 1970, 1971 and 1973 should be made available to encourage preservation of unique and fragile areas.

9. The open-space option of Mercer Island’s Ordinance 59, the Subdivision Ordinance, should be utilized for preserving unique and fragile areas.

PUBLIC ACCESS ELEMENT

The waters of Lake Washington are in the public domain and should be readily accessible to the public. As the population around Lake Washington grows, there will be an increasing need for public access to the shoreline. The Shoreline Management Act and the Final Guidelines make repeated reference to the issue of public access to the shoreline. In accordance with the Act, a Public Access Element has been included in this study. However, this situation is not unique to Lake Washington, and other planning efforts have addressed this challenge in a variety of ways.

The intent of the Shoreline Management Act and these goals and policies is not to reduce unlawfully the rights attached to private property to condone trespass, but rather to recognize and protect private property rights consistent with the public interest. The public access requirements of this section are not applicable to single family residences. The following goal and policies address the ability of the public to reach, touch, view, and travel on Lake Washington and to view the water and the shoreline from public places.

**GOAL**

*Increase and enhance public access to and along the Mercer Island Shoreline where appropriate and consistent with public interest, provided public safety, private property rights, and unique or fragile areas are not adversely affected.*

**POLICIES:**

1. Public access to and along the water’s edge should be consistent with the public safety, private property rights, and conservation of unique or fragile areas.

2. Public access to and along the water’s edge should be available in publicly owned shoreline areas.

3. In new substantial shoreline development, developers should be encouraged to provide public access to and along the water’s edge provided that no private property shall be taken involuntarily for public purposes without due compensation.

4. When substantial modifications or additions are proposed to substantial developments, the developer should be encouraged to provide for public access to and along the water’s edge if physically feasible provided that no private property be taken involuntarily without due compensation.

5. In new developments on the shoreline, the water’s edge should be kept free of buildings.
6. Where publicly owned shoreline areas are available for public pedestrian and bicycle pathways, these should be developed as close to the water’s edge as reasonable.

7. Views of the shoreline and water from shoreline and upland areas should be preserved and enhanced. Enhancement of views shall not be construed to mean excessive removal of vegetation.

8. Rights-of-way on the shoreline should be made available for public access where appropriate.

9. Access onto shoreline public street ends should be enhanced.

**RECOMMENDATION**

10. Consideration should be given to provisions for the handicapped, disabled, and elderly when developing public access to shoreline areas.

**RECREATION ELEMENT**

Mercer Island has approximately 15 miles of shoreline most of which is devoted to low density single family residences. It could be said that almost 100% of the developed shoreline of Mercer Island is devoted to water-dependent recreation, assuming that the waterfront residents find both active and passive enjoyment from their shoreline location. The remainder of the shoreline is set aside for public or semi-public water-related recreation except for a fraction which is utilized for bridge crossings and utilities. The latter, in some cases, is also available for public access to the water.

The City presently owns 2,600–approximately 6,000 feet of shoreline which is developed as waterfront parks with facilities for swimming, fishing and car-top boat launching. Beaches at Luther Burbank Park and Groveland Beach Park are staffed with lifeguards during the summer season. Unguarded designated swimming areas also exist at Calkins Landing and Clarke Beach Park. Dock facilities that serve fishing and other activities are located at Luther Burbank Park and Proctor Landing, and seasonally at Clarke and Groveland Beaches. The City manages several summer camps for youth and adult with instruction on sailing and kayaking based at Luther Burbank Park.

Nineteen street ends of widths varying from 30’ to 75’ add an additional 938 600 lineal feet of shoreline to the public domain and provide the potential for considerable access to the water’s edge in all segments of the Island. Development of six–some street ends has been undertaken as a cooperative effort between the city and the adjacent neighborhoods. Some provide swimming access, others offer car-top launching access, others provide minimal access solely for passive enjoyment because of the limitation of size or topography, and lack of neighborhood interest and availability of funds. Three street ends were re-developed in 2003, which included eliminating bulkheads and enhancing near shore habitat.
There are two private waterfront clubs owning a combined 1,840 feet of frontage. They provide swimming, moorage, and boat launching facilities to a significant portion of the Island’s families.

Shorewood Apartments, Covenant Shores, a continuing care retirement community, owns approximately 650 feet of shoreline which serves as open space, swimming, picnicking, and moorage for its 690 residential units. Numerous private neighborhood waterfront “parks,” with shared access for neighboring residences, offering access to up, and residents exist along the shoreline.

Regarding waterfront recreation, The City of Mercer Island Parks and Recreation Plan, adopted in 2007, calls for Capital improvements at 2 waterfront facilities to enhance recreation opportunities. Shoreline restoration, swim beach enhancements and dock area improvements are anticipated at Luther Burbank Park, and improved boat launching and retrieval is anticipated with planned improvements at the Mercer Island Boat Launch. Future development of Luther Burbank Park is also subject to the Luther Burbank Master Plan.

The Mercer Island Park and Open Space Plan, adopted by the City in 1966, was specific in expressing the desire to acquire and develop waterfront parks and public access to the water’s edge. As of 1973 several of the plans have been implemented. Yet to be accomplished, is the goal to acquire a waterfront park in the East Seattle area, further utilize the street ends and provide public trailer boat launching facilities.

**GOAL**

*Water-dependent recreational activities available to the public are to be encouraged and increased on the shoreline of Mercer Island where appropriate and consistent with the public interest.*

**POLICIES**

1. Provide additional public water-oriented recreation opportunities.

2. Locate public recreational uses in shoreline areas that can support those uses without risks to human health, safety, and/or security, while minimizing effects on shoreline functions, private property rights, and/or neighboring uses.

1. Water-dependent recreational activities should be increased and given priority.

   a. Public shoreline parks should be increased in size and number.
e. Additional swimming areas should be developed on the shoreline.

e. Recreational fishing should be maintained or increased.

d. Recreational boating activities should be encouraged as long as they are compatible with other uses. Day moorage should be a permitted use in recreational areas where feasible except in unique and fragile areas.

e. Accommodations should be made for launching small water craft at public shoreline parks and street ends where feasible.

2. Open space and opportunity for passive forms of recreation should be encouraged and increased.

3. Retention of some public shoreline in a nearly natural state is desirable.

4. Based on the Mercer Island Comprehensive Plan, the appropriate governmental agency should avail itself of the earliest opportunity to acquire shoreline when available. See Recommendations.

5. Mercer Island and other appropriate governmental agencies should join in a cooperative effort to expand recreational opportunities through programs of acquisition, development, and maintenance of waterfront areas.

6. Semi-public water-dependent recreational facilities (e.g., private beach clubs, yacht clubs, etc.) should be permitted and recognized as providing access to the water for a segment of the population of Mercer Island and should be recognized as providing a vital part of the island’s recreational facilities.

7. Every opportunity should be taken to acquire private recreational facilities if they are likely to be developed for other than recreational purposes.

8. Recreational shoreline activities adjacent to residential uses are not to constitute a public nuisance.

RECOMMENDATIONS:

1. The Mercer Island Park and Open Space Plan should be coordinated with appropriate, adopted regional plans.

2. Early efforts should be made to suitably develop presently held public shoreline for water-dependent public recreational uses and open space.

3. Cooperation between the City of Mercer Island and neighborhoods should be continued in the
planning and development of small neighborhood parks and street ends.

4. Mercer Island should cooperate with other governmental agencies to undertake studies to determine the optimum level of boating activity on Lake Washington.

5. Rental or provision of small, non-motorized water craft and water-related recreational equipment should be made available at several waterfront parks when feasible.

6. Small non-motorized water craft are nondestructive to the shoreline environment and such boating activity should be shown preference by policies governing waterfront recreation facilities.

7. The designation of underwater areas for skin or scuba diving should be considered.

8. Interest in fishing for bass, perch, crappie, and other under-utilized species should be stimulated through community education.

9. Procedures should be developed for real estate agencies to notify public agencies when waterfront property is available for purchase.

RESIDENTIAL ELEMENT

Residential development presently accounts for over 85% of Mercer Island’s wetland area. Single-family dwellings comprise the majority of this use with Shorewood Apartments being the only multi-family use. The Shoreline Management Act specifically excludes individual homes in the permit process, but the Act does not exclude other types of residential development, such as multi-family structures or residential subdivisions. Inasmuch as the Act encourages the inclusion of elements deemed sufficiently important or necessary, although not specifically named therein, the Residential Element is included herein.

Present residential zoning on Mercer Island’s shoreline is for single family dwellings, residential uses, and conditional uses that are complementary to the single family environment, such as public parks, private recreational areas, retirement homes located on properties used primarily for a place of worship, and noncommercial recreational areas. It should be noted that some of the shoreline is not yet developed as intensely as it could be under existing zoning. Several large shoreline properties now used by one family could be subdivided to allow from one to three additional residences.

GOAL

Existing residential uses are to be recognized, and new residential construction will be subject to certain limitations where applicable.

POLICIES
1. Existing single-family residential uses will be protected. New construction or modifications shall be allowed within the framework of the policies in this document and City Ordinance.

2. New residential uses over water will not be permitted.

3. In single-family development developments within the shoreline, the water’s edge should be kept free of buildings other than components required for boat and equipment storage. Such components should be screened by appropriate landscaping. Single-family uses may include fences or other means to minimize trespassing and provide protection.

4. Public access to and along the water’s edge should be encouraged in the design of multi-family structures, subdivisions of five or more lots, and planned unit developments occurring on the shoreline, provided that no private property shall be taken involuntarily without due compensation.

5. Public access does not include the right to enter upon single-family residential property without the permission of the owner.

RECOMMENDATIONS

1. The Mercer Island Planning Department should have information available for shoreline homeowners regarding the enhancement of fish and wildlife habitats, especially at the water’s edge.

2. Consideration should be given to revising the Mercer Island Zoning Code regarding back yard structures to reflect the intent of Policy No. 2. Boat houses on the water’s edge should be considered as an alternative to, not in addition to, a boat moorage.

3. The Planning Commission should consider actions to clarify the City Zoning Code to provide for a minimum twenty-five (25) foot setback from the water’s edge for all primary residential structures and appropriate accessory structures.

ECONOMIC DEVELOPMENT ELEMENT

Economic development of the shorelines of Mercer Island is essentially non-existent. Such shorelines and associated wetlands, being zoned single-family and multi-family residential, preclude economic development other than that associated with recreation. Thus, zoning and the Comprehensive Plan do not allow for economic development on the shoreline of Mercer Island.

GOAL

Existing economic uses and activities on the shorelines of Mercer Island are to be recognized. Economic uses or activities that are not dependent upon a Mercer Island Shoreline location are to be discouraged.
POLICIES

1. Shoreline economic uses and activities on Lake Washington should locate where commercial or industrial areas exist.

2. Economic uses and activities which do not depend on a Mercer Island shoreline location shall not be permitted.

3. Drilling for oil or gas and deep or surface mining for minerals is prohibited in the shoreline areas of Mercer Island.

CIRCULATION ELEMENT

Lake Washington is a 22,139 acre body of water located in the midst of an urban area. An extensive network of transportation routes exists around and across the Lake. Although transportation facilities were developed in response to projected demands, these facilities have in turn helped generate additional transportation needs. For example, construction of the Lake Washington bridges has permitted the eastern portion of the region to change from a low density, summer home area to a higher density, suburban/commercial area. This increase in activity has resulted in suggestions for third and fourth bridges crossing the Lake. Lake Washington itself is a navigable body of water and is connected to Puget Sound by a system of canals and locks. Although some commercial navigation does occur, most of the boating activities in Lake Washington are recreational in nature. Seaplane activity is also present on the Lake, and three airfields are located on the shoreline. The automobile, however, is the predominant means of transportation to, from, around and across the lake. Our heavy reliance on the automobile has contributed to problems in air quality, fuel supply and traffic congestion. In the long term, urban areas should look toward providing alternatives to the automobile as the primary means of transportation.

Principal transportation routes on Mercer Island include Inter-State 90, a highway that crosses Lake Washington via Mercer Island and two connecting bridges, and a series of arterial roads that follow the shoreline around the Island a short distance inland. Thus, shoreline-related roads form an important element of principal transportation routes on the Island. In addition, numerous lateral roads connect the shoreline following arterials with properties along the water’s edge, and frequently provide public access to the lake through developed and undeveloped street ends as well as visual access to the lake.

A rudimentary system of pedestrian and bicycle ways has gradually developed along portions of the shoreline following arterials; more definitive development of such ways is planned via the City’s Pedestrian and Bicycle Facility Plan. Metro buses provide important modes of on-Island transportation as well as access to neighboring municipalities and employment centers. Other forms of transportation are non-existent, except for privately owned boats and a few seaplanes along the shore.
GOAL

A balanced transportation system for moving people and goods is to be encouraged within existing corridors.

POLICIES

1. Develop efficient circulation systems in a manner that assures the safe movement of people and goods while minimizing adverse effects on shoreline use, developments and shoreline ecological functions.
2. Provide and/or enhance physical and visual public access to shorelines along public roads in accordance with the public access goals.
3. Encourage shoreline circulation systems that provide alternative routes and modes of travel.
4. Roadways serving shoreline areas should be developed principally as scenic avenues rather than major arterials.
5. Public transportation should be provided to facilitate access to recreation areas on the shoreline.
6. Pedestrian and bicycle pathways, including provisions for maintenance, operation and security, should be developed around and across the Lake, consistent with private property rights.

Access points to and along the shoreline should be linked by pedestrian and bicycle pathways developed as close to the water’s edge as reasonable.

Pedestrian and bicycle pathways should be included in new or expanded bridges.

Pedestrian and bicycle pathways should be included in publicly-financed transportation systems or rights-of-way, consistent with public interest and safety.

4. Provisions for METRO Public Transit should be implemented in transportation facilities crossing Mercer Island.

5. No new regional vehicular traffic corridors should be opened across Mercer Island’s shoreline.

   a. The width of the I-90 corridor shall be limited to that approved by the City of Mercer Island as stated in Mercer Island Resolution 595 adopted September 24, 1973.

   b. Future regional requirements for moving people through Mercer Island’s shorelines shall be limited to public mass transit systems constructed within the approved I-90 corridor.

6. Commercial aircraft facilities on the shoreline should not be permitted.
7. Moorage, storage, servicing and operation facilities for ocean-going or commercial ships and barges should not be permitted on the shoreline.

8. Proposals for additional transportation across Lake Washington should consider alternative modes above, on, or below the surface of the Lake.

9. Cross lake transportation facilities must be designed to minimize the increase in noise, air or water pollution above existing levels and, in addition, must reduce to the maximum extent, similar impacts from existing facilities via upgrading and improvement.

RECOMMENDATIONS

1. Mercer Island should cooperate with Metro to coordinate public transportation routes with public access points along the shoreline.

2. Mercer Island should coordinate with King County and neighboring communities in the implementation of its Trails Plan when feasible.

3. The connection of upland trails on the Island to the shoreline activity nodes and pedestrian and bicycle pathways, along the Mercer Ways, should be encouraged and developed.

4. To assist in developing pedestrian and bicycle pathways, easements along rights-of-way should be obtained and incentives should be offered to property owners for utilizing setback areas.

5. Mercer Island and other governmental agencies should consider using waterborne modes of transporting commuters and sightseers in a manner compatible with environmental quality and recreational activity. Such considerations should include terminals and connections.

COMPONENTS

Lake Washington’s shoreline has been recognized as a “valuable and fragile resource” by the Shoreline Management Act of 1971. The extent and the desirability of man-made modifications to these shorelines has not yet been determined. Although several studies relative to this issue have been made, are being conducted, and are envisioned, it is unlikely that any conclusive evidence will be available in the near future.

In instances where the literal interpretation of the policies in the Components Element create a demonstrated hardship, unique to an individual property, relief may be sought through the variance process as delineated in the Variance and Conditional Uses Section, pages 38 and 39.

POLICIES

Activities, Conservation, Public Access, NOTE: The policies set forth within the following Elements: Shoreline Uses and Components, are to apply to all uses and activities contained within this document. The policies under this heading are to apply to all components.
1. Components in or near the water should not be constructed from materials which have significant adverse physical or chemical effects on water quality, vegetation, fish and/or wildlife.

2. Components should be discouraged in unique or fragile areas, unless it can be shown that measures can be taken to adequately mitigate all related adverse impacts.

3. Components should be designed to permit normal circulation of water, sediments, fish and other aquatic life in and along the shoreline area.

4. High rise structures should be prohibited on the shoreline.

5. Shoreline low-rise development should provide substantial grade level views of the water from public shoreline roads running generally parallel to the water’s edge.

6. Enclosed overwater structures should not be allowed except when overriding considerations of the public interest are served. This would not preclude the use of covered, unenclosed moorage’s.

7. Substantial repairs or alterations to nonconforming structures should be in conformance with the policies contained herein.

8. Non-conforming shoreline structures which receive little use and/or are in a general state of disrepair should be abated within a reasonable period of time.

RECOMMENDATIONS:

1. The Component Section of this document should be reviewed and modified as necessary at the completion of the research program being undertaken by the cooperative Fishery Unit at the University of Washington, and any other relevant studies.

2. Site planning should include setbacks from the shoreline. Landscaping should also be considered as a method of retaining a sense of nature in developed shoreline areas. Retention of trees and other natural vegetation should be encouraged where possible, particularly in those areas in or adjacent to marshes, wetlands, or other areas of ecological and environmental significance. (Note: all site planning, landscaping, and development for non-single family uses is subject to review by the Design Commission under Ordinance No. 297 and the Design Commission Guidelines.)

LANDFILL AND DREDGING

Landfill is usually contemplated in locations where the water is shallow and where rooted vegetation often occurs. In their natural condition these same areas provide suitable habitat for
fish and wildlife feeding, breeding and shelter. Biologically the shallow vegetation areas tend to be highly productive portions of the Lake. For these reasons governmental agencies and scientific experts have generally taken a stand against landfill.

In most cases when dredging is done it also occurs in shallow areas and may disturb the environment in the following ways: 1) temporary reduction of water clarity from suspended sediments, 2) losses in aquatic plants and animals by direct removal or from the sedimentation of suspended materials, 3) alteration in the nutrient and oxygen levels of the water column, and 4) suspension of toxic materials from the sediments into the water column.

Mercer Island has some uneven shorelines due to the historically varying degrees of control over filling and bulkheading beyond the ordinary high water line. In some instances, it may be appropriate to bulkhead and do minor landfill. These instances may include, but not be limited to, provision of protection of slide prone areas where necessary and to add to or repair failing bulkheads. These and other unusual situations in which the literal interpretation of the Shorelines Master Program, Guidelines or Mercer Island Goals and Policies creates a demonstrated hardship can be addressed through variance procedures. (Note: See Variance and Conditional Uses Section)

POLICIES

1. Fills shall be located, designed, and constructed to protect shoreline ecological functions and ecosystem-wide processes, including channel migration.

2. Fills waterward of the ordinary high-water mark shall be allowed only when necessary to support: water-dependent use, public access, cleanup and disposal of contaminated sediments as part of an interagency environmental clean-up plan, disposal of dredged material considered suitable under, and conducted in accordance with the Dredged Material Management Program of the Department of Natural Resources, expansion or alteration of transportation facilities of statewide significance currently located on the shoreline and then only upon a demonstration that alternatives to fill are not feasible, mitigation action, environmental restoration, beach nourishment or enhancement project. Fills waterward of the ordinary high-water mark for any use except ecological restoration should require a conditional use permit.

3. Dredging and dredge material disposal shall be done in a manner which avoids or minimizes significant ecological impacts and impacts which cannot be avoided should be mitigated in a manner that assures no net loss of shoreline ecological functions.

4. New development should be sited and designed to avoid or, if that is not possible, to minimize the need for new and maintenance dredging. Dredging for the purpose of establishing, expanding, or relocating or reconfiguring navigation channels and basins should be allowed where necessary for assuring safe and efficient accommodation of existing navigational uses and then only when significant ecological impacts are minimized and when mitigation is provided. Maintenance dredging of established navigation channels and basins should be restricted to maintaining previously dredged and/or existing authorized location, depth, and width.

5. Dredging waterward of the ordinary high-water mark for the primary purpose of obtaining fill material shall not be allowed, except when the material is necessary for the
restoration of ecological functions. When allowed, the site where the fill is to be placed must be located waterward of the ordinary high-water mark. The project must be either associated with a MTCA or CERCLA habitat restoration project or, if approved through a shoreline conditional use permit, any other significant habitat enhancement project.

Landfill and dredging should be prohibited in unique or fragile areas.

2. Landfill or dredging should not be permitted except in the following cases, and even then should generally be discouraged.

   a. Landfill or dredging may be permitted where necessary for the development and maintenance of public shoreline parks.

   b. Landfill or dredging may be permitted where necessary to improve water quality where no other possible alternatives are available.

   c. Replenishing sand on public and private community beaches should be allowed.

   d. Landfill or dredging may be permitted where additional public access is provided, and/or where there is anticipated to be a significant improvement to fish or wildlife habitat; provided there is no major reduction upon the surface waters of the Lake.

3. Dredging spoils should be deposited on approved dumping sites. Dumping sites should not be allowed in the Lake or in unique or fragile areas.

4. Dredging should be permitted to maintain water flow, navigability, and water depth in cases of water course siltation.

5. Dredging for the purpose of obtaining fill or construction material should be prohibited.

RECOMMENDATIONS

1. When reviewing applications for landfill intended to improve water quality, Mercer Island Planning Department should consult with appropriate governmental agencies to determine the necessity and proper location for such fill.

2. Appropriate governmental agencies and local jurisdictions should approve funding and/or personnel to undertake a short term study on the biological impacts of dredging and landfills and to devise suitable criteria or guidelines for such activities.

SHORELINE PROTECTIVE STRUCTURES STABILIZATION

Shoreline protective structures are used to diminish the destructive forces of waves and currents.
on beaches, to protect anchorages, to encourage the deposition of littoral materials or, in some cases, for purposes of convenience of appearance. Although these structures protect the backshore, they may also encourage scouring or erosion on adjacent shoreline or submerged land.

On Mercer Island individual situations and related problems may dictate that the repair of bulkheads or placing of new ones in order to control slides may occur very near to, rather than precisely at, the ordinary high water line. Such minor deviations should remain within the province of the City Planning Department discretion. However, in any other instances where significant changes occur to the water side of the ordinary high water line, these can be addressed through variance procedures.

**BULKHEADS**

The purpose of a bulkhead is to stabilize land at the water’s edge to prevent erosion. When structures reflect rather than absorb wave energy, the destructive forces are largely redirected. In some cases, bulkheads transmit wave energy downward, thereby eroding the beach at the base of the structure. Sloping, permeable structures, on the other hand, absorb wave energy, reduce wave run-up, and minimize scouring action at the base. In cases where bulkheading is permitted, scientific information suggests a rock riprap design should be preferred. The cracks and openings in such a structure afford suitable habitats for certain forms of aquatic life.

At times bulkheads are built out into the water in conjunction with landfill for the purpose of creating new dry land areas. However, this is being discouraged at all levels of jurisdiction concerned with shorelines.

The following policies address shoreline stabilization.

**POLICIES**

1. Construction or repair of bulkheads should not extend into the Lake beyond the existing high water line, except as approved by a variance or in the case of approved land fill.

2. The use of vegetation for stabilizing the water’s edge from erosion should be encouraged with the use of bulkheads.

3. Bulkheads at the water’s edge should be designed to minimize the transmission of wave energy to other properties.

4. Bulkheads and landfill may be permitted to restore lands lost to erosion within one year of the date that erosion occurred. A one year extension for a reasonable cause may be granted by the local jurisdiction. The applicant is responsible for demonstrating the severity and extent of such erosion.

5. Breakwaters should generally be discouraged. In those limited instances where breakwaters are permitted, a floating design is preferred unless such a design is not technically or
ecologically practical.

6. There should be no construction of jetties, groins, or other protective structures unless there is a demonstrated need for such structures and no preferable alternatives are available.

RECOMMENDATIONS

1. Appropriate governmental agencies should be encouraged to undertake a study on the short-term and long-term effects of breakwaters, bulkheads, and other shoreline protective structures in order to develop suitable criteria or guidelines for their construction. It is recommended that bulkheads be of sloping rock riprap design.

3. It is recommended that policy be developed on the issuance of variances for bulkheads to cover such instances as those in which lands are lost to erosion where a suitable building site does not exist. Further, bulkheads or landfills may be permitted out to a line connecting existing immediately adjoining neighboring bulkheads through the variance procedures.

1. Non-structural stabilization measures are preferred over “soft” structural measures. Soft structural measures are preferred over hard structural measures.

PIERS AND MOORAGES

The following policies address piers and moorages. A majority of the single family properties on the shoreline have piers and/or moorages. The only multi-family areas, Shorewood, also has piers along its waterfront area. These waterfront components provide desirable facilities to the property owners but may, at some future date, if totally uncontrolled, result, in some undesirable consequences for the Lake and the community. Further, the Shoreline Management Act directs the Local Master Program to address itself to this possibility. Therefore, it is appropriate to consider additional piers and/or moorages in light of future as well as existing uses and patterns and further, to provide general guidelines and controls for issuing permits and reviewing new development proposals.

Existing City zoning codes contain sections on pier length and setbacks as well as moorages. These should be reviewed in light of the recommendations contained in this Master Program. In addition, any relevant data generated from local and regional studies on piers and moorages should be considered in the periodic updating of the Mercer Island Master Program.

POLICIES

1. New piers and docks shall be allowed only for water-dependent uses or public access. Piers and docks associated with single family residences are considered a water-dependent use.

2. Piers and docks shall be designed and constructed to avoid or, if that is not possible, to minimize and mitigate the impacts to ecological functions.
Construction of new or expanded piers should generally be regulated, and the following limitations shall apply:

Piers should be allowed only for moorage of pleasure craft, for water-dependent recreation, for water-dependent economic activities, for utility maintenance, or for required emergency vessels.

Temporary moorages may be permitted for vessels used in the construction of shoreline facilities.

Adjoining waterfront property owners should be encouraged to share a common pier.

The size and extent of a pier should not exceed that which is required for the water-dependent purposes for which it was constructed.

In multi-family or condominium developments the ratio of moorage berths to residential units should be equal to or some fraction less than one.

2. The use of buoys for moorage should be considered as an alternative to the construction of piers for this purpose. Such buoys should be placed as close to shore as possible in order to minimize hazards to navigation.

3. Exterior lighting utilized in conjunction with piers and waterfront structures should be directed away from adjacent property and the water wherever offensive.

RECOMMENDATIONS

1. Mercer Island should establish uniform standards governing the design of piers including criteria for length, width, location, density and floating versus pile construction. It should be noted that floating piers can be rearranged, removed or relocated as needs or regulations change.

2. Consideration should be given to revising Ordinance 15, the Zoning Code, to
reduce setbacks along property lines for piers from ten (10) feet to zero (0) feet.

3. Regulation of spacing between piers and total number of piers in a designated distance should be considered.

4. Study and consideration should be given to revising Ordinance 15, the Zoning Code, as it prescribes dock length at 100 feet. Dock length should be related to intended use and water depth which may be greater or less than that prescribed by the Code.

UTILITIES

The following policies address utilities. Utilities are services which produce or carry electric power, gas, sewage, water, communications or oil products. The potential exists for combining some of these uses with other shoreline uses, including public access.

Although the diversion of sewage away from Lake Washington has substantially improved water quality in the Lake, storm sewers continue to affect water quality. As rain and other waters pass over impervious land surfaces, these waters pick up large quantities of sediments, oil, litter, heat and other contaminants. The impact of surface runoff from construction sites is of particular concern. Excessive quantities of suspended solids and oil are carried away and may significantly affect the quality of the receiving waters and associated aquatic life.

It should be noted that the Federal Water Pollution Control Act of 1972 may apply to surface runoff if there is a recognizable source of contamination (for example, business districts, parking lots, major land developments, and others). But the issue is complicated by the fact that much contamination comes from numerous sources which are small and often very difficult to identify.

POLICIES

1. Utility facilities should be designed and located to assure no net loss of shoreline ecological functions, preserve the natural landscape, and minimize conflicts with present and planned land and shoreline uses while meeting the needs of future populations.

2. Transmission facilities for the conveyance of services, such as power lines, cables, and pipelines, shall be located outside of the shoreline area where feasible, and when necessarily located within the shoreline area, shall assure no net loss of shoreline ecological functions.

3. Utilities should be located in existing rights of way and corridors whenever possible.

4. Whenever possible, consolidation of utilities should be encouraged within rights of way.
2. These facilities should be placed underground, except where it is clearly technically and economically not feasible.

3. After completion of installation or maintenance of these facilities, the shoreline area should be restored to its pre-project condition. If the previous condition is identified as being undesirable, then landscaping and other improvements should be undertaken.

4. In all new developments, the developer should install means to control the entry of contaminants into the Lake within acceptable water quality standards.

5. Prior to construction of major new outfalls, water circulation studies should be conducted to determine the best shoreline location for such facilities.

6. Major shoreline outfalls should be designed and constructed to minimize damage to the lake’s edge and be placed below the surface of the Lake where feasible.

RECOMMENDATIONS

1. The proliferation of impervious surfaces in the drainage basins serving Lake Washington should be kept to a minimum.

2. Whenever possible contaminants should be removed from surface runoff at the source of contamination. Methods of removing contaminants include oil skimmers, sediment traps, and street sweeping.

3. When contemplating the construction of a major new outfall, Metro and other appropriate governmental agencies should be consulted regarding the appropriate location and design for the outfall.

PARKING

The following policies address parking. Whether for work or leisure time, many people reach the shoreline by automobile. The use of shoreline areas for parking, however, precludes other more appropriate uses of the land. Since landfill as a means of increasing dry land areas is to be discouraged, the storage space for automobiles is limited. Thus, the number of required parking spaces for new construction can severely restrict the density in many developments.

The use of the automobiles as the primary mode of transportation is expected to continue. Any reliable public transportation system may take years to develop. The problem of the automobile as a major waterfront land user may increase as the demand for various waterfront uses and activities increases.

POLICIES
Parking facilities for motor vehicles or boat trailers should be minimized in the shoreline area.

   a. Parking facilities should not be permitted along the water’s edge.

   b. Upland parking facilities for shoreline activities should provide adequate pedestrian access to the shoreline.

   c. Upland parking facilities should be designed and landscaped to minimize adverse impacts on the shoreline and adjacent lands.

   d. Parking facilities shall be planned, located and designed where they will have the least possible adverse effect on unique or fragile shoreline features, and will not result in a net loss of shoreline ecological functions or adversely impact existing or planned water-dependent uses.

   e. Parking facilities in shorelines shall minimize the environmental and visual impacts.

**BOAT LAUNCHING FACILITIES**

The following policies address boat launching facilities. Boating is a popular form of recreation in the Lake Washington area, and demand for boating is expected to increase as the population in the region grows. The use of boat launching facilities permits dry land storage of vessels and reduces the need for marinas and piers. At present there are 41 public boat launching ramps on Lake Washington; however, none exist on Mercer Island at present. The proposed Comprehensive Plan envisions two areas for boat launching and water-related recreation under the future I-90 bridge approaches.

**POLICIES**

1. Regional boat launching facilities should be provided which are adequate for the needs and carrying capacity of the Lake subject to other policies herein governing land and water use.

2. Boat launching facilities should not be constructed in unique and fragile areas.

3. Boat launching facilities should be separated from swimming areas wherever possible.

**RECOMMENDATIONS**

1. Mercer Island should consider the feasibility of developing one or two of their shoreline street ends for car-top boat launching.

2. Mercer Island and appropriate governmental agencies should join together in a
Lake-wide study which would optimize the number of boat-launching facilities on Lake Washington.

3. Boat launching ramps should only be provided after provisions for adequate parking, screening, and landscaping have been made.

SIGNS

Signs are public displays whose purpose is to provide information, direction, identification and advertising. Mercer Island has developed an Ordinance (No., 297) creating a Design Commission. The Ordinance enjoins the Commission to control all signs within the public and private sectors (except traffic control), to assure uniform application to achieve a desirable, balanced environment. Form, proportion, color, material, surface treatment, and position will be considered in each case. The criteria used for Design Commission sign review are the interim sign guidelines developed as a part of the Mercer Island Design Guidelines.

POLICIES

1. Off-premise and non-appurtenant signs are prohibited on the shoreline.

2. Illuminated or free standing signs or any signs extending above roof lines should be prohibited on the shoreline except for required navigational aids.

3. Advertising signs, when permitted, and approved by the Design Commission, should be limited to areas of high-intensity land use, and should be stationary, non-blinking, and a size commensurate with the structure to which it is fixed.

4. Signs advertising the sale of property are not prohibited provided they do not exceed 6 sq. ft. (e.g.: 2' x 3'), and are limited to one street side and one water side sign.

APPENDIX ‘A’

Mercer Island's Comprehensive Plan and Zoning Ordinance preclude economic uses of shorelines such as those permitted in Business, Planned Business, or Commercial-Office zones and community values have clearly shown an intent to perpetuate this land use pattern. However, the Regional Master Program, and, in particular, the Economic Element thereof, addresses potential development that may have a significant impact on the waters of Lake Washington and the shoreline. For these reasons the Regional Economic Element is contained herein to indicate Mercer Island’s concern for major developments that may affect the quality of Lake Washington and its tributaries.
SHORELINE CUMULATIVE IMPACTS ANALYSIS
for the City of Mercer Island
Shoreline Master Program

Prepared by:

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SHORELINE CUMULATIVE IMPACTS ANALYSIS
FOR CITY OF MERCER ISLAND SHORELINE MASTER PROGRAM

1 INTRODUCTION

The Shoreline Management Act guidelines require local shoreline master programs to regulate new development to “achieve no net loss of ecological function.” The guidelines (WAC 173-26-186(8)(d)) state that, “To ensure no net loss of ecological functions and protection of other shoreline functions and/or uses, master programs shall contain policies, programs, and regulations that address adverse cumulative impacts and fairly allocate the burden of addressing cumulative impacts.”

The guidelines further elaborate on the concept of net loss as follows:

“When based on the inventory and analysis requirements and completed consistent with the specific provisions of these guidelines, the master program should ensure that development will be protective of ecological functions necessary to sustain existing shoreline natural resources and meet the standard. The concept of “net” as used herein, recognizes that any development has potential or actual, short-term or long-term impacts and that through application of appropriate development standards and employment of mitigation measures in accordance with the mitigation sequence, those impacts will be addressed in a manner necessary to assure that the end result will not diminish the shoreline resources and values as they currently exist. Where uses or development that impact ecological functions are necessary to achieve other objectives of RCW 90.58.020, master program provisions shall, to the greatest extent feasible, protect existing ecological functions and avoid new impacts to habitat and ecological functions before implementing other measures designed to achieve no net loss of ecological functions.” [WAC 173-206-201(2)(c)]

In short, updated SMPs shall contain goals, policies and regulations that prevent degradation of ecological functions relative to the existing conditions as documented in that jurisdiction’s characterization and analysis report. For those projects that result in degradation of ecological functions, the required mitigation must return the resultant ecological function back to the baseline. This is illustrated in Figure 1 below. The jurisdiction must be able to demonstrate that it has accomplished that goal through an
analysis of cumulative impacts that might occur through implementation of the updated SMP. Evaluation of such cumulative impacts should consider:

(i) current circumstances affecting the shorelines and relevant natural processes;
(ii) reasonably foreseeable future development and use of the shoreline; and
(iii) beneficial effects of any established regulatory programs under other local, state, and federal laws.”

Figure 1. Department of Ecology Illustration to Achieve “no net loss”

As outlined in the Shoreline Restoration Plan prepared as part of this SMP update, the SMA also seeks to restore ecological functions in degraded shorelines. This cannot be required by the SMP at a project level, but Section 173-26-201(2)(f) of the Guidelines says: “master programs shall include goals and policies that provide for restoration of such impaired ecological functions.” See the Shoreline Restoration Plan for additional discussion of SMP policies and other programs and activities in Mercer Island that
contribute to the long-term restoration of ecological functions relative to the baseline condition.

The following information and analysis provided in this report provides an overview by proposed environment designation of existing conditions, anticipated development, relevant Shoreline Master Program (SMP) and other regulatory provisions, and the expected net impact on ecological function.

# 2 EXISTING CONDITIONS

The following summary of existing conditions is based on the Shoreline Analysis Report (The Watershed Company 2009a) and additional analysis needed to perform this assessment. As per the Shoreline Analysis Report, this discussion has been divided by proposed shoreline environment designations. As shown in Appendix A, these include Urban Residential, and Urban Park designations. The Shoreline Analysis Report includes an in-depth discussion of the topics below, as well as information about transportation, stormwater and wastewater utilities, impervious surfaces, and historical/archaeological sites, among others.

## 2.1 Urban Residential Environment

Approximately 90.4 percent of the City’s upland shoreline jurisdiction is in the Urban Residential environment.

### 2.1.1 Existing Land Use

The entire shoreline within the Urban Residential environment is zoned single-family residential (R-8.4, R-9.6, R-12, or R-15), while Comprehensive Plan designations include single-family residential and multi-family residential (R-8.4, R-9.6, R-12, R-15, and MF-3). Land uses are predominantly single-family residential, with one multi-family use, Covenant Shores (senior retirement facility), located along the north shore of the island. Mercerwood Shore Club and Mercer Island Beach Club, two private swimming, fitness, and tennis clubs, are also included in the Urban Residential environment designation.

In general, the land area designated as Urban Residential is fully developed. Out of 945 existing lots, only 57 (roughly 6% percent) are listed as vacant or undeveloped. Of these lots, only 10 have development potential, based on City G.I.S. analysis. Expansion, redevelopment or alteration to existing single-family units will occur over time, but the majority of this environment will remain unchanged. Since single-family residences are considered to be a preferred use along the shoreline, and thus, very few conflicts are anticipated.
Under the current SMP, the standard residential structure setback is 25 feet from the ordinary high water mark (OHWM). The actual median setback in the Urban Residential environment is 66.4 feet. Table 1 presents data on existing residential structure setbacks on parcels within the Shoreline Residential environment. As Table 1 shows, 44 (6.2%) of the 713 waterfront parcels are listed as vacant. A total of 126 (17.7%) lots have residential structures located less than 25 feet (non-conforming structures) from the OHWM. Of the remaining developed lots, 587 (82.3%) have residential structures greater than 25 feet from OHWM, 413 (58.2%) have residential structures greater than 50 feet from OHWM, 291 (40.8%) have residential structures greater than 75 feet from OHWM, and 206 (28.9%) have residential structures greater than 100 feet from OHWM.

While all areas of the City’s shoreline contain a wide variety of existing setbacks, it is fairly evident that the western shoreline contains a higher percentage of properties with smaller setbacks (those less than 50 feet), including quite a few with non-conforming structures (less than 25 feet). Conversely, areas along the north and eastern shoreline have a higher percentage of lots with structures greater than 50 feet from shore.

**Table 1. Existing shoreline residential structure setback data for the Urban Residential environment.**

<table>
<thead>
<tr>
<th>Measure of residential structure setback</th>
<th>Number of Waterfront Parcels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Waterfront Parcels</td>
<td>713</td>
</tr>
<tr>
<td>Vacant</td>
<td>44</td>
</tr>
<tr>
<td>Structures &lt; 25 ft from OHWM (non-conforming)</td>
<td>126</td>
</tr>
<tr>
<td>Structures ≥ 25 ft. from OHWM</td>
<td>587</td>
</tr>
<tr>
<td>≥ 50 ft. from OHWM</td>
<td>415</td>
</tr>
<tr>
<td>≥ 75 ft. from OHWM</td>
<td>291</td>
</tr>
<tr>
<td>≥ 100 ft. from OHWM</td>
<td>206</td>
</tr>
</tbody>
</table>

### 2.1.2 Parks and Open Space/Public Access

There are no formal public parks or open spaces within the Shoreline Residential environment.

### 2.1.3 Shoreline Modifications

The Urban Residential environment is heavily modified with just over 82 percent of the shoreline armored at or near the OHWM (Table 2) (see Figures 7.1-7.14 in the Shoreline Analysis Report) and a pier density of approximately 47 piers per mile (Table 3). This compares to 71 percent armored and 36 piers per mile for the entire Lake Washington shoreline (Toft 2001). Thus, for Mercer Island’s Urban Residential environment, pier
density is much higher and shoreline armoring is slightly higher than the lake-wide figures.

Table 2. Shoreline armoring in the Urban Residential environment.

<table>
<thead>
<tr>
<th>Shoreline Condition (feet / % of shoreline)</th>
<th>Armored1</th>
<th>Natural / Semi-Natural2</th>
</tr>
</thead>
<tbody>
<tr>
<td>57,934 (82%)</td>
<td>12,444 (18%)</td>
<td></td>
</tr>
</tbody>
</table>

1 “Armored” shorelines encompass angular or rounded granite or basalt boulder, concrete, and wood armoring types.
2 “Natural/Semi-Natural” shorelines captures those areas that are not solidly armored at the ordinary high water line; they may include some scattered boulders or woody debris at or near the ordinary high water line.

Table 3. In-water structures in the Urban Residential environment.

<table>
<thead>
<tr>
<th>Total Number of Piers</th>
<th>Average Number of Piers per Mile</th>
<th>Total Overwater Cover (square feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>678</td>
<td>47</td>
<td>532,008</td>
</tr>
</tbody>
</table>

It is not uncommon around Lake Washington for some historic fills to be associated with the original bulkhead construction, usually to create a more level or larger yard. Most of these shoreline fills occurred at the time that the lake elevation was lowered during construction of the Hiram Chittenden Locks.

2.2 Urban Park

Approximately 9.6 percent of the City’s shoreline jurisdiction is in the Urban Park environment and includes Luther Burbank Park, which has been re-designated from Conservancy to Urban Park under this update of the Shoreline Master Program. The following data includes Luther Burbank Park in the Urban Park environment.

2.2.1 Existing Land Use

As identified by the City’s Comprehensive Plan, the Urban Park environment is comprised of regional, community, neighborhood, and mini- parks. The entire shoreline within the Urban Park environment is zoned single-family residential (R-8.4, R-9.6, R-12, and R-15), while the Comprehensive Plan zones eight of the parks as “Park”, including Luther Burbank Park.
As with the other environment designations, the standard structure setback under the current SMP is 25 feet from OHWM. The actual median setback in the Urban Park environment is 115 feet, and the mean is 82 feet, based the four park properties that have structures.

### 2.2.2 Parks and Open Space/Public Access

The City parks discussed below provide public access to Lake Washington, as well as provide opportunities for water-dependent, water-related, and water-enjoyment recreational uses.

- **Clarke Beach** is an 8.8-acre grassy park with waterfront access, a swimming area, diving board, public docks, fishing access and picnicking and barbeque areas. It also provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Groveland Beach** is a 3.2-acre park with waterfront access, a swimming area, fishing access, public dock, playground, and picnicking and barbeque areas. This park also provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Slater Park** is a half-acre park with waterfront access, a swimming area, and a picnic area.

- **Mercer Island Boat Launch** is a public boat launch located at 3600 East Mercer Way. This park provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Park on the Lid** is a 20-acre park that provides visual access to the water, as well as a variety of recreational opportunities including: tennis, baseball/softball, soccer, basketball, walking trails, playgrounds, and picnic areas.

- **Calkins Landing** is a waterfront street-end park with a non-guarded public beach and picnicking space. It also provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Franklin Landing** is a street-end park with waterfront access and provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Forest Landing** is a street-end park with waterfront access.

- **Fruitland Landing** is a street-end park that provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Garfield Landing** is a street-end park with waterfront access.

- **Lincoln Landing** is a street-end park with a picnic area that provides a Lakes-to-Locks Water Trail Launch and Landing Site.

- **Luther Burbank Park** is approximately 78 acres in size and provides over three-quarters of a mile of shoreline for public access. A majority of the park has been left undeveloped and contains areas of natural shoreline. The park includes a swimming beach, public boat dock, off-leash dog area, public fishing pier, former
Luther Burbank School brick dormitory, steam plant and dairy ruins, trails and other groomed areas, wetlands, watercourses, and woodlands. A total of 2 parcels make up the shoreline environment within the park.

- **Miller Landing** is a street-end park with waterfront access.
- **Proctor Landing** is a street-end park with waterfront access, fishing access, and a public dock. It also provides a Lakes-to-Locks Water Trail Launch and Landing Site.
- **Roanoke Landing** is a street-end park with waterfront access.
- **77th Avenue SE Landing** is a street-end park with waterfront access.
- **SE 56th Street Landing** is a street-end park that is primarily undeveloped.
- **SE 72nd Street Landing** is a street-end park with waterfront access.
- **South Point** is a street-end park that provides a Lakes-to-Locks Water Trail Launch and Landing Site.

As funding allows, additional street-ends, other City rights-of-way, and other opportunities may also be formally added to the public access system.

### 2.2.3 Shoreline Modifications

The Mercer Island shoreline in the Urban Park environment has been modified with approximately 35 percent of the shoreline armored (Table 4) (see Figures 7.1-7.14 in the Shoreline Analysis Report) at or near the OHWM and a total of approximately 16 piers per mile (Table 5). As expected, pier density along Mercer Island’s Urban Park environment is significantly lower than the lake-wide figures. Shoreline armoring is also significantly lower than the lake-wide average of 71 percent.

#### Table 4. Shoreline armoring in the Urban Park environment.

<table>
<thead>
<tr>
<th>Shoreline Condition (feet / % of shoreline)</th>
<th>Armored¹</th>
<th>Natural / Semi-Natural²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,539 (35%)</td>
<td>4,716 (65%)</td>
</tr>
</tbody>
</table>

¹ “Armored” shorelines encompass angular or rounded granite or basalt boulder, concrete, and wood armoring types.

² “Natural/Semi-Natural” shorelines captures those areas that are not solidly armored at the ordinary high water line; they may include some scattered boulders or woody debris at or near the ordinary high water line.
Table 5. In-water structures in the Urban Park environment.

<table>
<thead>
<tr>
<th>Total Number of Piers</th>
<th>Average Number of Piers per Mile</th>
<th>Total Overwater Cover (square feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>16.6</td>
<td>15,861</td>
</tr>
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</table>

2.3 Biological Resources and Critical Areas

The shoreline zone itself is generally deficient in high-quality biological resources and critical areas, primarily because of the extensive residential development and its associated shoreline modifications. The highest-functioning shoreline area is within Luther Burbank Park, which has two distinct shoreline associate wetlands and a substantial amount of shoreline vegetation. Many of the parks and street-ends in the Urban Park environment have the potential for the improvement of ecological functions.

Geologically hazardous areas encumber almost the entire island. This is likely due to the steep topography of the island, as well as the crossing of the Seattle Fault along the I-90 corridor. As mentioned above, two wetlands have been inventoried within shoreline jurisdiction, both of which are located in Luther Burbank Park. There are a number of streams in Mercer Island that discharge into Lake Washington. According to a stream inventory completed by Adolfson Associates, Inc. (Adolfson Associates 2005), there are 37 perennial streams, 3 of which have documented fish use and an additional 12 which may have potential for fish use near their mouths at Lake Washington. These streams that are known to support fish use may include chinook (known juvenile use of the mouths of several streams), coho, and sockeye salmon and cutthroat trout. Many of the smaller tributaries to Lake Washington originate as hillside seeps or springs and flow seasonally or during periods of heavy rains. Many of these smaller systems are piped at some point and discharge directly to Lake Washington via a closed system.

3 Anticipated Development and Potential Effect on Function

3.1 Patterns of Shoreline Activity

The City reviewed its shoreline permitting records for the past eight years and found 200 issued Shoreline Exemptions and 86 issued Shoreline Substantial Development Permits. Table 6 presents the shoreline permitting history.

<table>
<thead>
<tr>
<th>Year</th>
<th># of Cases</th>
<th>Pier</th>
<th>Bulkhead Modification</th>
<th>Upland Structure</th>
<th>Permit Type</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>New</td>
<td></td>
<td></td>
<td>SDP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Exemption</td>
</tr>
<tr>
<td>2000</td>
<td>28</td>
<td>13</td>
<td>0</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>22</td>
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<tr>
<td>2001</td>
<td>42</td>
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<td>8</td>
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<tr>
<td>2002</td>
<td>43</td>
<td>26</td>
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<td>16</td>
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<tr>
<td>2003</td>
<td>43</td>
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<td>31</td>
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<td>2004</td>
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<td>2006</td>
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<td>2007</td>
<td>49</td>
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<td>6</td>
<td>10</td>
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<td></td>
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<td></td>
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<td>39</td>
</tr>
<tr>
<td>TOTAL</td>
<td>286</td>
<td>159</td>
<td>12</td>
<td>55</td>
<td>86</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200</td>
</tr>
</tbody>
</table>

As indicated by the data presented above, new piers are very infrequent, averaging less than two proposals per year. The most commonly proposed shoreline activities are pier modifications/replacements, averaging over 19 proposals per year.

### 3.2 Residences

With the possible exception of limited additional residential lands being acquired for public open space, land use in the Urban Residential environment is not expected to change over the next 20 years, although some re-builds and substantial remodels are anticipated. As mentioned above, there are only 57 (6%) vacant lots in the Urban Residential environment, 44 of which are listed as vacant waterfront lots. However, only 10 of those lots have any potential for development as the remainder of the vacant lots are either in permanent tracts, easements, public ownership, or simply too small for a single-family use.

Typically, development of vacant lots into residential uses would result in replacement of pervious, vegetated areas with impervious surfaces and a landscape management regime that often includes chemical treatments of lawn and landscaping. These actions can have multiple effects on shoreline ecological functions, including:

1. Increase in surface water runoff due to reduced infiltration area and increased impervious surfaces, which can lead to excessive soil erosion and subsequent in-lake sediment deposition. This can affect the following:
   - **Hydrologic Functions**
     - Storing water and sediment

2. Reduction in ability of site to improve quality of waters passing through the untreated vegetation and healthy soils. This can affect the following:
Hydrologic Functions
Removing excess nutrients and toxic compounds

Vegetation Functions
Water quality improvement

3. Potential contamination of surface water from chemical and nutrient applications. This can affect the following:

Vegetation Functions
Water quality improvement

4. Elimination of upland habitat occupied by wildlife that use riparian areas. This can affect the following:

Habitat Functions
Physical space and conditions for life history
Food production and delivery

Expansions and remodels of existing residences are likely to occur relatively frequently during the future. Many of these activities would not change the baseline condition of ecological function, although expansions that increase impervious surfaces may occur. Runoff from most expanded residences is clean, however, and water quantity is not an issue in the Lake Washington environment. The significance of impervious surfaces on a lake environment where water quantity is not really a factor is very diminished given the residential uses. Single-family or multi-family homes generally have clean roof and sidewalk runoff, and driveways whether 50 square feet or 5,000 square feet are typically pollution-generating surfaces only to the extent that vehicle-related pollutants are deposited on them. Most single-family homes have between two and four vehicles, regardless of the driveway area and thus the correlation between driveway area and amount of pollution is not strong. However, improperly managed runoff during and post construction could increase erosion, and could cause sediments and pollutants to enter the lake.

As mentioned above, the existing median setback in the Urban Residential environment is 66 feet. The SMP proposes a residential setback of 25 feet. Based on the City’s analysis of redevelopment potential, the resultant median setback in the Shoreline Residential environment would be approximately 59 feet. This reduction in the median setback results in a conversion of a maximum of 22 acres of space between the primary structure and the OHWM to a greater level of development. This conversion number is likely an overestimate, both in area and assumed corresponding function, as primary structures are never as wide as the lot. It also does not factor in that much of that “lost” space is already occupied by decks, paved surfaces, lawn or other improvements that have reduced or eliminated the function of that space. Finally, because of the staggered distribution of lot depths and primary structure locations, some of that space landward of a primary structure currently set back far from the water’s edge may be greatly impacted by activities on shallower adjacent lots where the structure is located closer to the water’s edge.
To address the other less direct losses to shoreline function resulting from reduction in the space between primary structures and their attendant activities and the water’s edge, the SMP contains vegetation requirements within 20 feet of Lake Washington’s ordinary high water mark for new development and redevelopment.

### 3.3 Overwater Structures

Piers can adversely affect ecological functions and habitat in the following ways:

1. Alter patterns of light transmission to the water column, affecting macrophyte growth and altering habitat for and behavior of aquatic organisms, including juvenile salmon. This can affect the following:
   - **Habitat Functions**
     - Physical space and conditions for life history
     - Food production and delivery

2. Interfere with long-shore movement of sediments, altering substrate composition and development. This can affect the following:
   - **Hydrologic Functions**
     - Attenuating wave energy

3. Contribute to contamination of surface water from chemical treatments of structural materials. This can affect the following:
   - **Hydrologic Functions**
     - Removing excess nutrients and toxic compounds

4. Pier lighting is known to affect fish movement and predation. This can affect the following:
   - **Habitat Functions**
     - Physical space and conditions for life

Overwater structures encompass a variety of uses, from in-water structures, such as fixed-pile piers and floating docks, to moorage covers, such as canopies and boathouses with associated boatlifts. It is difficult to determine exactly how many waterfront properties do not have a pier or pier access, particularly as many piers are located near property lines and thus it is possible that those may be shared with the adjacent property. In total, it is estimated that out of the 713 waterfront residential properties, approximately 60 (8%) parcels do not have a pier.

Given the current rate of new pier proposals, only about 30 new piers are likely over the next 20 years. If all of those properties add a pier, that would represent a 4.2 percent increase in the total number of piers in the Shoreline Residential environment, with a final density of 49 piers per mile.
Under the proposed SMP, new piers will be smaller than piers approved under the current SMP. New and replacement piers will also include light-transmitting decking material, which will reduce the impact of the overwater cover. Nevertheless, if new piers were the only pier-related activity, ecological function would still decline. The decline would be due to an unavoidable net increase in the number of in-water structures and overwater cover that can be minimized but not entirely mitigated.

However, pier repair and pier maintenance activities are more common, and it is anticipated that pier replacement proposals may become even more common as existing piers degrade or do not meet the property owner’s needs in their current configuration or location. Under the proposed SMP, replacement piers are considered new moorage structures and must meet the dimensional criteria for new private piers or be otherwise approved by State and Federal agencies (Washington Department of Fish and Wildlife and the U.S. Army Corps of Engineers). Any pier repair which involves the replacement of more than 40 percent of the pier support piles must also meet the dimensional criteria of new private piers.

A summary of the quantitative analysis is provided below (Table 7, full analysis provided in Appendix B, based on City trends and assumptions. Based on the trends and assumptions made regarding new piers, pier replacement, pier repairs, and pier additions, the total area of effective overwater cover would decline by 2.8 percent over a 20-year time period.

Table 7. Summary of Pier Analysis

<table>
<thead>
<tr>
<th>Existing Overwater Coverage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total existing overwater coverage - single-family</td>
<td>683,697</td>
</tr>
<tr>
<td>Total existing overwater coverage - semi-private</td>
<td>15,183</td>
</tr>
<tr>
<td>Total existing overwater coverage - public</td>
<td>15,861</td>
</tr>
<tr>
<td><strong>Total existing overwater coverage (square footage)</strong></td>
<td><strong>714,741</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effective Overwater Coverage in 20 years</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total overwater cover in 20 years - single-family</td>
<td>664,759</td>
</tr>
<tr>
<td>Total overwater cover in 20 years - semi-private</td>
<td>15,010</td>
</tr>
<tr>
<td>Total overwater cover in 20 years - public</td>
<td>14,858</td>
</tr>
<tr>
<td><strong>Total effective overwater coverage in 20 years (square footage)</strong></td>
<td><strong>694,627</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Change in Effective Overwater Coverage in 20 years</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Net change in overwater cover - single-family</td>
<td>-18,938</td>
</tr>
<tr>
<td>Net change in overwater cover - semi-private</td>
<td>-173</td>
</tr>
<tr>
<td>Net change in overwater cover - public</td>
<td>-1,003</td>
</tr>
<tr>
<td><strong>TOTAL CHANGE IN EFFECTIVE OVERWATER COVER IN 20 YEARS</strong></td>
<td><strong>-20,115</strong></td>
</tr>
<tr>
<td><strong>PERCENTAGE DECREASE IN OVERWATER COVER IN 20 YEARS</strong></td>
<td><strong>-2.8%</strong></td>
</tr>
</tbody>
</table>

1 Note: “Effective” overwater cover is a measure of the actual solid footprint that shades the water, rather than the structure’s total footprint. Use of grated decking with a minimum of 40% open space reduces the adverse impacts of the overwater structure, even though the traditional structure footprint may increase.
The proposed regulations (MICC 19.07.110) have specifically been crafted to avoid and minimize the following specific potential impacts as outlined below:

1. Growth of aquatic vegetation: Overwater cover is minimized through size and height restrictions for new piers restricting size of replacement structures and requiring grated decking (MICC 19.07.110(D)(1) Table B).

2. Sediment movement. Boatlifts are restricted in the nearshore area (MICC 19.07.110(D)(1) Table B) The use of jetties or breakwaters are prohibited in all environments.

3. Chemical contamination: Piers and other structures shall be constructed of materials that will not adversely affect water quality (MICC 19.07.110(D)(3)b)).

3.4 Shoreline Stabilization

Bulkheads typically have the following effects on ecological functions:

1. Reduction in nearshore habitat quality for juvenile salmonids and other aquatic organisms. Specifically, shoreline complexity and emergent vegetation that provides forage and cover may be reduced or eliminated. Elimination of shallow-water habitat may also increase vulnerability of juvenile salmonids to aquatic predators. This can affect the following:

   - Habitat Functions
     - Physical space and conditions for life history
     - Food production and delivery

2. Reduction of natural sediment recruitment from the shoreline. This recruitment is necessary to replenish substrate and preserve shallow water conditions. This can affect the following:

   - Habitat Functions
     - Physical space and conditions for life history

3. Increase in wave energy at the shoreline if shallow water is eliminated, resulting in increased nearshore turbulence that can be disruptive to juvenile fish and other organisms. This can affect the following:

   - Hydrologic Functions
     - Attenuating wave energy

   - Habitat Functions
     - Physical space and conditions for life history

Repairs and replacements of existing bulkheads perpetuate those conditions. There have been 55 bulkhead modification proposals in the last eight years, and future proposals are likely to be repairs and replacements (based on trends observed in other Lake Washington jurisdictions with similar shoreline activity). Applications for new
bulkheads are likely to be infrequent as the majority of the shoreline has already been developed with 82 percent arming in the Urban Residential environment.

The updated SMP states that new shoreline stabilization would only be allowed when “conclusive evidence, documented by a geotechnical analysis, is provided that the structure is in danger from shoreline erosion caused by waves…” It must be demonstrated in a study prepared by a qualified professional that the proposed stabilization is the least harmful method to the environment. Replacement bulkheads must generally be installed in the same location as the existing bulkhead, or farther landward, and must also demonstrate that a loss of ecological functions will not occur. Replacement bulkheads would not be allowed to encroach farther waterward, except that soft shoreline stabilization measures that provide restoration of shoreline ecological functions may be permitted waterward of the ordinary high water mark. Finally, all shoreline stabilization proposals must ensure that there will be no net loss of ecological functions.

Over time, the combined effects of the City’s proposed SMP will likely result in a reduction over time of the net amount of hardened shoreline at the ordinary high water mark and an increase in shallow-water habitat.

4 PROTECTIVE SMP PROVISIONS

4.1 Environment Designations

The first line of protection of the City’s shorelines is the environment designation assignments. Table 8 below identifies the prohibited and allowed uses and modifications in each of the shoreline environments, and clearly shows a hierarchy of higher-impacting uses and modifications being allowed in the already highly altered shoreline environments. This strategy helps to minimize cumulative impacts by concentrating development activity in lower functioning areas that are not likely to experience function degradation with incremental increases in new development.

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE</td>
<td>Categorically Exempt</td>
</tr>
<tr>
<td>SEP</td>
<td>Shoreline Exemption Permit</td>
</tr>
<tr>
<td>SDP</td>
<td>Substantial Development Permit</td>
</tr>
<tr>
<td>SEPA</td>
<td>Required Review under the State Environmental Policy Act</td>
</tr>
<tr>
<td>NP</td>
<td>Not Permitted Use</td>
</tr>
</tbody>
</table>
### Designated Environments

<table>
<thead>
<tr>
<th>Shoreline Use</th>
<th>Designated Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Park Environment</td>
<td>Urban Residential Environment</td>
</tr>
<tr>
<td>Single-family residential and associated appurtenances</td>
<td>NP</td>
</tr>
<tr>
<td>Multifamily residential</td>
<td>NP</td>
</tr>
<tr>
<td>Public and private recreational facilities and parks</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Moorage facilities (including piers, docks, piles, lift stations, or buoys)</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Commercial marinas, moorage and storage of commercial boats and ships</td>
<td>NP</td>
</tr>
<tr>
<td>Bulkheads and shoreline protective structures</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Breakwaters and jetties</td>
<td>NP</td>
</tr>
<tr>
<td>Utilities</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Dredging</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Alterations over 250 cubic yards – outside the building footprint</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Boating Facilities</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Transportation and Parking</td>
<td>SDP, SEPA</td>
</tr>
<tr>
<td>Light Rail Transit Facilities</td>
<td>SDP, SEPA</td>
</tr>
</tbody>
</table>

If a use is not listed in this matrix, it shall be considered as a conditional use, pursuant to WAC 173-26-160.

### 4.2 General Goals, Policies and Regulations

The SMP contains numerous general policies, with supporting regulations (see SMP), intended to protect the ecological functions of the shoreline and prevent adverse cumulative impacts. These policies are summarized below.
• All activities, development and redevelopment within the City’s shoreline jurisdiction should be designed to ensure no net loss of shoreline ecological functions.
• Standards for density or minimum frontage width, setbacks, lot coverage limitations, buffers, shoreline stabilization, vegetation conservation, critical area protection, and water quality shall be set to assure no net loss of shoreline ecological functions, taking into account the environmental limitations and sensitivity of the shoreline area, the level of infrastructure and services available, and other comprehensive planning considerations.
• Standards should be established for shoreline stabilization measures, vegetation conservation, water quality, and shoreline modifications. These standards shall ensure that new development does not result in a net loss of shoreline ecological functions or further degrade other shoreline values.
• Existing natural resources should be conserved, consistent with private property rights.
• Existing and future activities on Lake Washington and its shoreline should be designed to minimize adverse effects on the natural systems.
• Public access to and along the water’s edge should be consistent with the public safety, private property rights, and conservation of unique or fragile areas.
• Develop efficient circulation systems in a manner that assures the safe movement of people and goods while minimizing adverse effects on shoreline use, developments and shoreline ecological functions
• Fills shall be located, designed, and constructed to protect shoreline ecological functions and ecosystem-wide processes, including channel migration.
• Piers and docks shall be designed and constructed to avoid or, if that is not possible, to minimize and mitigate the impacts to ecological functions.

• Utility facilities should be designed and located to assure no net loss of shoreline ecological functions, preserve the natural landscape, and minimize conflicts with present and planned land and shoreline uses while meeting the needs of future populations.
• Critical areas within shoreline jurisdiction will be regulated per MICC 19.07.
5 Effect of Other Development and Restoration Activities/Programs

5.1 Washington Department of Fish and Wildlife
The Washington Department of Fish and Wildlife has jurisdiction over in- and over-water activities up to and including the ordinary high water mark, as well as any other activities that could “use, divert, obstruct, or change the bed or flow of state waters” (http://www.wdfw.wa.gov/hab/hpapage.htm). Practically speaking, these activities in the City of Mercer Island include, but are not limited to, installation or modification of shoreline stabilization measures, piers and accessory structures such as boatlifts, culverts, and bridges and footbridges. These types of projects must obtain a Hydraulic Project Approval from WDFW, which will contain conditions intended to prevent damage to fish and other aquatic life, and their habitats. In some cases, the project may be denied if significant impacts would occur that could not be adequately mitigated.

5.2 Washington Department of Ecology
The Washington Department of Ecology may review and condition a variety of project types in Mercer Island, including any project that needs a permit from the U.S. Army Corps of Engineers (see below), any project that requires a shoreline Conditional Use Permit or Shoreline Variance, and any project that disturbs more than 1 acre of land. Project types that may trigger Ecology involvement include pier and shoreline modification proposals and wetland or stream modification proposals, among others. Ecology’s three primary goals are to: 1) prevent pollution, 2) clean up pollution, and 3) support sustainable communities and natural resources (http://www.ecy.wa.gov/about.html). Their authority comes from the State Shoreline Management Act, Section 401 of the Federal Clean Water Act, the Federal Water Pollution Control Act, the Federal Coastal Zone Management Act of 1972, the State Environmental Policy Act, the Growth Management Act, and various RCWs and WACs of the State of Washington.

5.3 U.S. Army Corps of Engineers
The U.S. Army Corps of Engineers has jurisdiction over any work in or over navigable waters (including Lake Washington) under Section 10 of the Federal Rivers and Harbors Act of 1899, and discharges of dredged or fill material into waters of the United States (including Lake Washington, streams, and non-isolated wetlands) under Section 404 of the Federal Clean Water Act.

As a federal agency, any activity within Corps jurisdiction that could affect species listed under the Federal Endangered Species Act must be consulted on with the National...
Marine Fisheries Service and the U.S. Fish and Wildlife Service. These agencies ensure that the project includes impact minimization and compensation measures for protection of listed species and their habitats. Since salmon were first listed in Puget Sound, the Corps and the other federal agencies have been working closely to streamline the permitting process, particularly for new pier and pier modification projects. The result of those efforts for Lake Washington has culminated in Regional General Permit (RGP) 3.

### 6 Restoration Opportunities

As discussed above, one of the key objectives that the SMP must address is “no net loss of ecological shoreline functions necessary to sustain shoreline natural resources” (Ecology 2004). However, SMP updates seek not only to maintain conditions, but to improve them:

“...[shoreline master programs] include planning elements that when implemented, serve to improve the overall condition of habitat and resources within the shoreline area of each city and county (WAC 173-26-201(c)).”

The guidelines state that “master programs shall include goals, policies and actions for restoration of impaired shoreline ecological functions. These master program provisions should be designed to achieve overall improvements in shoreline ecological functions over time, when compared to the status upon adoption of the master program” (WAC 173-26-201(2)(f)). Pursuant to that direction, the City has prepared a Shoreline Restoration Plan (The Watershed Company 2009b).

Practically, it is not always feasible for shoreline developments and redevelopments to achieve no net loss at the site scale, particularly for those developments on currently undeveloped properties or a new pier or bulkhead. The Restoration Plan, therefore, can be an important component in making up that difference in ecological function that would otherwise result just from implementation of the SMP. The Restoration Plan represents a long-term vision for restoration that will be implemented over time, resulting in incremental improvement over the existing conditions.

The Shoreline Restoration Plan identifies a number of project-specific opportunities for restoration on both public and private properties inside and outside of shoreline jurisdiction, and also identifies ongoing City programs and activities, non-governmental organization programs and activities, and other recommended actions consistent with the Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan.
7 ASSESSMENT OF CUMULATIVE IMPACTS

The following table (Table 9) summarizes for each environment designation the existing conditions (Chapter 2 above), anticipated development (Chapter 3 above), relevant Shoreline Master Program (SMP) and other regulatory provisions, and the expected net impact on ecological function. The complete assessment of overwater structure impacts is presented in Section 3.3, organized by pier type rather than environment designation. The discussion of existing conditions is based on the Final Shoreline Analysis Report (The Watershed Company 2009a), and additional analysis conducted to perform this assessment. The Analysis Report includes a more in-depth discussion of the topics below, as well as information about transportation, stormwater and wastewater utilities, impervious surfaces, and historical/archaeological sites, among others.
### Table 9. Qualitative Assessment of Cumulative Impacts

<table>
<thead>
<tr>
<th>Likely Development / Functions or Processes Potentially Impacted</th>
<th>Effect of SMP Provisions</th>
<th>Effect of Other Regulatory Programs and Non-Regulatory Restoration Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urban Residential</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Existing Conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FUTURE DEVELOPMENT</strong> in the Urban Residential environment will likely be restricted to remodeled or expanded residences since only ten vacant waterfront lots (&lt;1 percent) have development potential. Based on permit data from 2000 – 2007, the City anticipates that approximately 25 percent of existing developed lots will likely redevelop over the next 20 years. No change in uses is anticipated.</td>
<td>Several facets of the SMP development standards for the Urban Residential environment are aimed at minimizing potential impacts to shoreline ecological functions that are discussed in Sections 3.2, 3.3, and 3.4. Residential setbacks are one of the key components to assess overall impacts to ecological function as they relate to many of the items listed below. Structure setbacks are regulated under MICC 19.07.100(B)(1). Under these scenarios and an anticipated redevelopment of up to 167 lots, the median residential setback would change from 66 feet to 59 feet. 1. Impervious surface increases: Expansions and remodels of existing residences are likely to occur relatively frequently during the future. Many of these activities would not change the baseline condition of ecological function, although expansions that increase impervious surfaces may occur. The significance of impervious surfaces on a lake environment where water quantity is not really a factor is diminished given the residential uses. Single-family or multi-family homes generally have clean roof and sidewalk runoff. Driveways are typically pollution-generating surfaces only to the extent that vehicle-related pollutants are deposited on them. Most single-family homes typically have between two and four vehicles, regardless of the driveway area and thus the correlation between driveway area and amount of pollution is not strong. However, improperly managed runoff during and post construction could increase erosion, and could cause sediments and pollutants to enter the lake.</td>
<td><strong>Other Regulatory Programs:</strong> Any in- or over-water proposals, primarily piers and shoreline reconstruction, would require review not only by the City of Mercer Island, but also by the WDFW, the U.S. Army Corps of Engineers (Corps), and/or Ecology. Each of these agencies is charged with regulating and/or protecting streams, lakes, and wetlands, and would impose certain design or mitigation requirements on applicants. Due to Endangered Species Act consultation requirements with the U.S. Fish and Wildlife Service and National Marine Fisheries Service, the Corps has developed recommendations to minimize project impacts. These include Regional General Permit 3 (RGP-3) for overwater structures and a Programmatic Biological Evaluation for shoreline stabilization. WDFW also follows similar design standards as the Corps. The City of Mercer Island has included some of these design elements within the proposed SMP. These agencies would also impose certain design and mitigation requirements on a proposed project to minimize adverse impacts. Outside of the immediate shoreline zone, short- and long-term stormwater management per the latest Ecology Stormwater Manual would minimize/eliminate construction-related stormwater runoff impacts and may slowly improve the quality of any waters reaching the shoreline.</td>
</tr>
<tr>
<td><strong>FUNCTIONS/PROCESSES IMPACTED:</strong> As described in Section 3.2, new and re-development may be accompanied by: 1. Impervious surface increases 2. Vegetation removal 3. Chemical contaminant increases Additional impacts could occur with associated new pier development and shoreline modification; these are cumulatively discussed in Sections 3.3 and 3.4. These impacts may affect: 4. Growth of aquatic vegetation 5. Juvenile salmon migration and behavior 6. Sediment movement 7. Chemical contamination 8. Shoreline complexity 9. Wave attenuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Non-Regulatory Restoration Actions</strong> Although no specific restoration projects have been identified in the Urban Residential environment, the City’s Shoreline Restoration Plan (The Watershed Company 2009b) does include goals and objectives with an emphasis on public education and involvement intended to promote voluntary shoreline enhancement and restoration on private land. Examples of specific items include:  • Encourage salmon friendly shoreline design during new construction or redevelopment  • Offer incentives for voluntary removal of bulkheads, beach improvement, riparian revegetation  • Encourage low impact development through regulations, incentives, education/training, and demonstration projects  • Through grant funding sources, restoration opportunities may be available to multiple contiguous shoreline properties, including residential lots that are interested in improving shoreline function.</td>
</tr>
</tbody>
</table>

Shoreline Cumulative Impacts Analysis 21
<table>
<thead>
<tr>
<th>Existing Conditions</th>
<th>Likely Development / Functions or Processes Potentially Impacted</th>
<th>Effect of SMP Provisions</th>
<th>Effect of Other Regulatory Programs and Non-Regulatory Restoration Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Vegetation Removal</td>
<td>Mercer Island’s shoreline is largely developed with single family residences, many of which contain lawn areas abutting the shoreline. As redevelopment occurs, on a whole, structures may move closer to the shoreline, which will result in some vegetation removal. Since lawn areas provide little ecological function, and are a source for water polluting fertilizers, reduction of these areas will have little negative effect. To address any ecological impact that may occur, the SMP requires new development and redevelopment to provide vegetation as follows: 25% of the 20 feet closest to the OHW shall contain vegetation coverage. The five feet nearest the OHW shall contain at least 25% native coverage. A shoreline vegetation plan shall be submitted to the City for approval. A variety of ground cover, shrubs, and trees that provides lake shading is encouraged. This regulation, along with the City’s Restoration Plan, a no-net loss of shoreline functions and values related to vegetation should be met.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Chemical contaminant increases</td>
<td>It is anticipated that new development and re-development will not likely increase the level of potential chemical applications, such as fertilizers, to the shoreline jurisdiction area.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Urban Park**

This segment contains land areas in shoreline jurisdiction generally dominated by City parks, street-ends, and open spaces. The three largest City parks include FUTURE DEVELOPMENT in the Urban Park environment will be limited. There will be a number of park improvements, including restoration work at Groveland and Clarke beach parks, which may Similar to the Shoreline Residential environment described above, SMP development standards for the Urban Park environment are also aimed at minimizing potential impacts to shoreline ecological functions that result from shoreline structures, armoring, and overwater cover. **Other Regulatory Programs:** Any in- or over-water proposals, primarily piers and shoreline reconstruction, would require review not only by the City of Mercer Island, but also by the WDFW, the Corps, and/or Ecology. Each of these agencies is charged with regulating and/or protecting streams, lakes, and wetlands, and would impose certain design or mitigation requirements on applicants. Due to Endangered Species Act consultation requirements with the U.S. Fish and Wildlife Service and National Marine
### Existing Conditions

<table>
<thead>
<tr>
<th>Groveland Beach Park, Clarke Beach Park, and Luther Burbank Park</th>
</tr>
</thead>
</table>

- Include improvements to shoreline armoring and overwater cover. No change in use is anticipated in Clarke Beach Park and Groveland Park.

  Recent shoreline restoration activities in Luther Burbank Park took place in 2008 as part of mitigation for future sewer lake line repairs expected to occur in 2009/2010. Other restoration activities are expected as part of implementation of the Park Master Plan, including extensive re-vegetation of shoreline areas. No modification to existing shoreline armoring is anticipated. Any future modifications to the three existing pier structures would likely involve installation of grated decking which would improve light transmission.

  No change in use is anticipated in Luther Burbank Park.

### FUNCTIONS/ PROCESSES IMPACTED:

- The anticipated alterations to parks are expected to alter, in most cases beneficially, the following upland functions.
  1. Impervious surface
  2. Vegetation/habitat

  Additional impacts could occur with associated overwater structure development and shoreline modification; these are cumulatively discussed in Sections 3.3 and 3.4. These impacts may affect:
  3. Growth of aquatic vegetation
  4. Juvenile salmon migration and behavior
  5. Sediment movement
  6. Chemical contamination
  7. External lighting impacts on overwater structures
  8. Shoreline complexity

### Effect of SMP Provisions

- These are regulated under MICC 19.07.110

  As already mentioned, new developments within the parks are not anticipated and redevelopment is not likely to result in structures being located closer to the water’s edge than the current condition, so the existing average setback would not change.

  Several of the parks, street-ends, and open spaces also include watercourses, which have additional protections under MICC 19.07.070.

  Luther Burbank Park also includes watercourses and wetlands, which have additional protections under MIIC 19.07.070 and MIIC 19.07.080.

  **1. Impervious surface**
  - It is anticipated that little change in impervious surface in the Urban Park environment will occur.

  **2. Vegetation/habitat**
  - As previously mentioned, many of the activities in the parks are intended to improve ecological functions, and would be conducted voluntarily beyond the SMP requirements for mitigation tied to any development.

### Effect of Other Regulatory Programs and Non-Regulatory Restoration Actions

- Fisheries Service, the Corps has developed recommendations to minimize project impacts. These include Regional General Permit 3 (RGP-3) for overwater structures and a Programmatic Biological Evaluation for shoreline stabilization. While these recommendations are intended for single-family property, many of the same guidelines are also applicable to public and commercial property. WDFW also follows similar design standards as the Corps and the City of Mercer Island has included some of these design elements within the proposed SMP. These agencies would also impose certain design and mitigation requirements on a proposed project to minimize adverse impacts.

  Outside of the immediate shoreline zone, short- and long-term stormwater management per the latest Ecology Stormwater Manual would minimize/eliminate construction-related stormwater runoff impacts and may slowly improve the quality of any waters reaching the shoreline.

### Non-Regulatory Restoration Actions

- The City’s Shoreline Restoration Plan (The Watershed Company 2009b) includes goals and objectives with an emphasis on public education and involvement intended to promote voluntary shoreline enhancement and restoration. The Restoration Plan includes two specific projects. One at Groveland Beach Park to remove invasive vegetation, replace worn playground elements, and prepare shoreline improvements. The second at Clarke Beach Park to remove a concrete retaining wall/bulkhead along the shoreline.

  Other priorities listed in the Restoration Plan include: invasive vegetation species management, reductions in overwater cover and in-water structure, reductions in shoreline armoring, and improvements in stormwater discharges. These measures would improve shoreline processes and ecological functions for fish and wildlife.

  The City’s Parks Department also has a number of other partnerships or efforts that will likely result in additional improvements to parks that improve ecological function, including Forest Stewardship, Adopt-a-Park, and EarthCorps.
<table>
<thead>
<tr>
<th>Existing Conditions</th>
<th>Likely Development / Functions or Processes Potentially Impacted</th>
<th>Effect of SMP Provisions</th>
<th>Effect of Other Regulatory Programs and Non-Regulatory Restoration Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9. Wave attenuation</td>
<td></td>
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</tbody>
</table>


8 NET EFFECT ON ECOLOGICAL FUNCTION

Table 12 above examines development and redevelopment potential by environment designation, except for piers and shoreline armoring which are addressed collectively in Section 3.3 and 3.4. It is clear from Table 9 that the City is already highly developed, and has limited potential for new development on a small number of vacant lots. Most of the ten vacant lots with development potential have a mixture of lawn and vegetation, including some trees. Development of these lots would increase impervious surfaces, and may reduce vegetation and alter existing shoreline functions in those specific areas.

Collectively, the redevelopment potential may shift development closer to the water’s edge, but the condition of the remaining space between the water and structures will be improved overall through vegetation requirements within 20 feet of Lake Washington’s ordinary high water mark for new development and redevelopment, the City-wide tree retention requirements under MICC 19.10, and the City’s Restoration Plan.

In the long term, impervious surfaces currently located in the existing and proposed setbacks may be removed.

The effective overwater coverage (but not the actual footprints) should also decrease over the next 20 years, even with installation of new piers and pier additions due to the required installation of grated decking during redevelopment of existing docks and the relatively small number of new docks.

Because of the increased requirements to demonstrate need for new shoreline armoring and the requirements to consider soft solutions for new and replacement shoreline armoring, the City’s overall shoreline hardening condition will at worst remain the same, and realistically will improve over time.

Potential for improvement of shoreline ecological functions is currently greatest on City park properties, with installation of native vegetation and removal of invasive vegetation and enhancement of currently armored shoreline.

Even without implementation of the Restoration Plan, the proposed Shoreline Master Program should result in maintenance of the current level of ecological function, and possibly even improvements over time. However, when paired with the Restoration Plan, ecological function of the City’s Lake Washington shoreline is certain to improve.

Therefore, no net loss of shoreline ecological functions is anticipated.
9 REFERENCES


City of Mercer Island. 2007. City of Mercer Island Capital Improvement Program.


10 LIST OF ACRONYMS AND ABBREVIATIONS

CIP ............................... Capital Investment Program
Corps ............................. U.S. Army Corps of Engineers
Ecology ......................... Washington Department of Ecology
OHWM ............................ ordinary high water mark
SMP ............................... Shoreline Master Program
WDFW ............................. Washington Department of Fish and Wildlife
APPENDIX A

Shoreline Environment Designation Map
Appendix F - Proposed Shoreline Environment Designations
Shoreline Master Program - City of Mercer Island

All areas within shoreline jurisdiction that are not mapped and/or designated are automatically assigned the "Urban Residential" designation until the shoreline can be redesignated through a master program amendment. In the event of a mapping error, the City of Mercer Island shall rely upon common boundary descriptions and the criteria contained in RCW 90.58.030(2) and Chapter 173-22 WAC pertaining to determinations of shorelands, as amended, rather than the incorrect or outdated map.

1. Waterward extent of Shoreline Management Area is measured 200 ft landward of the Ordinary High Water Mark.

2. Waterward extent of City jurisdiction is measured to the middle of Lake Washington, pursuant to RCW 35.11.018.

3. Landward extent of Shoreline Management Area is measured 200 ft landward of the Ordinary High Water Mark.
<table>
<thead>
<tr>
<th>New Single-Family Overwater Structures</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # of new single-family piers possible</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Total square footage allowed for a new single-family pier (fully grated)</td>
<td>1,000</td>
<td>Number of new piers is based upon 8 year permit history from 2000 to 2007 in which 12 applications for new piers occurred</td>
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<tr>
<td>Total # of new joint-use piers possible</td>
<td>2</td>
<td>NOTE Joint-use applications are fairly rare.</td>
</tr>
<tr>
<td>Total square footage allowed for new joint-use pier (fully grated)</td>
<td>1,000</td>
<td>Total number is 60 lots without piers</td>
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<tr>
<td>Total new square footage for new piers</td>
<td>32,000</td>
<td>Number of new covered moorage structures expected based on permit history</td>
</tr>
<tr>
<td>Total # of new covered moorages possible</td>
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<tr>
<td>Total square footage allowed for a new covered moorage</td>
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<tr>
<td>Total new square footage for new covered moorage</td>
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<td></td>
</tr>
<tr>
<td>Total new effective overwater square footage (see open space value)</td>
<td>37,200</td>
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</tr>
<tr>
<td>Total effective overwater cover (s.f.) for new piers</td>
<td>37,200</td>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>Replacement of Single-Family Overwater Structures</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Total # of existing single-family piers</td>
<td>678</td>
<td></td>
</tr>
<tr>
<td>Percentage of piers to be replaced</td>
<td>20%</td>
<td>NOTE Based on 8 year permit history, 398 piers will be repaired or replaced in next 20 years =~60%. Assume 20% replacements, 30% repairs, and 10% additions</td>
</tr>
<tr>
<td>Total # of piers to be replaced</td>
<td>136</td>
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<tr>
<td>Average replacement pier size (assumes piers to be rebuilt at same size as existing, but fully grated)</td>
<td>828</td>
<td></td>
</tr>
<tr>
<td>Total square footage fully grated</td>
<td>828</td>
<td></td>
</tr>
<tr>
<td>Total square footage of replacement piers (same as existing footage)</td>
<td>112,277</td>
<td></td>
</tr>
<tr>
<td>Total replacement square footage with grating</td>
<td>112,277</td>
<td>Average existing pier size comes from shoreline inventory. 678 existing piers with approximately 532,000 square feet of overwater cover</td>
</tr>
<tr>
<td>Effective overwater coverage of replacement piers (see open space value)</td>
<td>67,366</td>
<td></td>
</tr>
<tr>
<td>Effective reduction in coverage from replacement</td>
<td>44,911</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Repair of Single-Family Overwater Structures</th>
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</thead>
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<tr>
<td>Total # of existing single-family structures</td>
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<tr>
<td>Percentage of existing piers to be replaced with grated decking in nearshore 30 feet (area assumption to right)</td>
<td>30%</td>
<td>Average pier width in nearshore 30 feet</td>
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<tr>
<td>Total # of piers to be repaired</td>
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<td>9.6</td>
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<td>Total square footage of decking to be replaced with grating</td>
<td>58,579</td>
<td>Based on City GIS Data</td>
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<td>Effective overwater coverage of replaced decking (see open space value)</td>
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<tr>
<td>Effective reduction in coverage from repair</td>
<td>23,432</td>
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<table>
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<th>Additions to Single-Family Overwater Structures</th>
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<td>Estimated average length of new additions</td>
</tr>
<tr>
<td>Percent of existing piers expected to propose additions</td>
<td>10%</td>
<td>Estimated average width of new additions</td>
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<tr>
<td>Total # of piers with additions</td>
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<tr>
<td>Total square footage estimated for new additions</td>
<td>20,340</td>
<td>Calculated approximate area of new additions</td>
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<tr>
<td>Description</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------</td>
<td>--------</td>
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</tr>
<tr>
<td>Total square footage fully grated</td>
<td>20,340</td>
<td></td>
</tr>
<tr>
<td>Total new effective overwater cover (see open space value)</td>
<td>12,204</td>
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<tr>
<td>Effective increase in coverage from additions</td>
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<tr>
<td>Total square footage of existing piers</td>
<td>560,236</td>
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<tr>
<td>Total square footage of existing covered moorage</td>
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<td>Increase in effective overwater cover based on new piers</td>
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<td>Reduction in effective overwater cover based on replacements</td>
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<td>Reduction of effective overwater cover based on repairs</td>
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<tr>
<td>Increase in effective overwater cover based on pier additions</td>
<td>12,204</td>
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<tr>
<td><strong>TOTAL FINAL EFFECTIVE OVERWATER COVER</strong></td>
<td><strong>664,759</strong></td>
<td></td>
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<tr>
<td><strong>NET CHANGE IN EFFECTIVE OVERWATER COVER</strong></td>
<td><strong>-18,938</strong></td>
<td></td>
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<tr>
<td>---</td>
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<tr>
<td><strong>Repair of Semi-private Overwater Structures</strong></td>
<td></td>
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<tr>
<td>4</td>
<td>Total # of existing semi-private structures</td>
<td>9</td>
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<tr>
<td>5</td>
<td>Total square footage of structures</td>
<td>15,183</td>
</tr>
<tr>
<td>6</td>
<td>Average square footage of semi-private structures</td>
<td>1,687</td>
</tr>
<tr>
<td>7</td>
<td>Percentage of existing piers to be replaced with grated decking in nearshore 30 feet (area assumption to right)</td>
<td>20%</td>
</tr>
<tr>
<td>8</td>
<td>Total square footage of decking to be replaced with grating</td>
<td>432</td>
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<td>9</td>
<td>Average pier width in nearshore 30 feet</td>
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<td></td>
<td>Effective overwater coverage of replaced decking (see open space value)</td>
<td>259</td>
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<tr>
<td>10</td>
<td>Effective reduction in coverage from repair</td>
<td>173</td>
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<tr>
<td><strong>Total Cover Calculation for Semi-Private Structures</strong></td>
<td></td>
<td></td>
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<tr>
<td>14</td>
<td>Total square footage of existing semi-private piers</td>
<td>15,183</td>
</tr>
<tr>
<td>15</td>
<td>Reduction of effective overwater cover based on repairs</td>
<td>-173</td>
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<tr>
<td><strong>TOTAL FINAL EFFECTIVE OVERWATER COVER</strong></td>
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<td>-173</td>
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<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Total # of existing public structures</strong></td>
<td>12</td>
<td></td>
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<tr>
<td><strong>Total square footage of structures</strong></td>
<td>15,861</td>
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</tr>
<tr>
<td><strong>Average square footage of public structures</strong></td>
<td>1,322</td>
<td></td>
</tr>
<tr>
<td><strong>Percentage of existing decking to be replaced with grated decking</strong></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td><strong>Total square footage of decking to be replaced</strong></td>
<td>4,758</td>
<td></td>
</tr>
<tr>
<td><strong>Effective overwater coverage of replaced decking (see open space value)</strong></td>
<td>2,855</td>
<td></td>
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<tr>
<td><strong>Effective reduction in coverage from repair</strong></td>
<td>1,903</td>
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<tr>
<td><strong>Total # of additions to piers possible</strong></td>
<td>2</td>
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<tr>
<td><strong>Total square footage estimated for new additions</strong></td>
<td>1,500</td>
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<td><strong>Total new effective overwater cover (see open space value)</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Effective increase in coverage from additions</strong></td>
<td>900</td>
<td></td>
</tr>
<tr>
<td><strong>Total square footage of existing public piers</strong></td>
<td>15,861</td>
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<tr>
<td><strong>Reduction of effective overwater cover based on repairs</strong></td>
<td>-1,903</td>
<td></td>
</tr>
<tr>
<td><strong>Increase in effective overwater cover based on additions</strong></td>
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<tr>
<td><strong>TOTAL FINAL EFFECTIVE OVERWATER COVER</strong></td>
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<td><strong>NET CHANGE IN EFFECTIVE OVERWATER COVER</strong></td>
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<tr>
<td></td>
<td>Existing Overwater Coverage</td>
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<tr>
<td>---</td>
<td>---------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Total existing overwater coverage - single-family</td>
<td>683,697</td>
</tr>
<tr>
<td>3</td>
<td>Total existing overwater coverage - semi-private</td>
<td>15,183</td>
</tr>
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<td>4</td>
<td>Total existing overwater coverage - public</td>
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<td><strong>Total existing overwater coverage (square footage)</strong></td>
<td><strong>714,741</strong></td>
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<td></td>
<td>Effective Overwater Coverage in 20 years</td>
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<td>8</td>
<td>Total overwater cover in 20 years - single-family</td>
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<td>9</td>
<td>Total overwater cover in 20 years - semi-private</td>
<td>15,010</td>
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<td>10</td>
<td>Total overwater cover in 20 years - public</td>
<td>14,858</td>
</tr>
<tr>
<td>11</td>
<td><strong>Total effective overwater coverage in 20 years (square footage)</strong></td>
<td><strong>694,627</strong></td>
</tr>
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</tr>
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<td>13</td>
<td>Change in Effective Overwater Coverage in 20 years</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Net change in overwater cover - single-family</td>
<td>-18,938</td>
</tr>
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<td>15</td>
<td>Net change in overwater cover - semi-private</td>
<td>-173</td>
</tr>
<tr>
<td>16</td>
<td>Net change in overwater cover - public</td>
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</tr>
<tr>
<td>17</td>
<td><strong>TOTAL CHANGE IN EFFECTIVE OVERWATER COVER IN 20 YEARS</strong></td>
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</tr>
<tr>
<td>18</td>
<td><strong>PERCENTAGE DECREASE IN OVERWATER COVER IN 20 YEARS</strong></td>
<td><strong>-2.8%</strong></td>
</tr>
</tbody>
</table>
SHORELINE RESTORATION PLAN

for the City of Mercer Island
Shoreline Master Program

Prepared by:

City of Mercer Island
Development Services Group
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The Watershed Company Reference Number:
070613

The Watershed Company Contact Person:
Dan Nickel and Christa H. Strickwerda

Cite this document as:
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1 INTRODUCTION

A jurisdiction’s Shoreline Master Program applies to activities in the jurisdiction’s shoreline zone. Activities that have adverse affects on the ecological functions and values of the shoreline must provide mitigation for those impacts. By law, the proponent of that activity is not required to return the subject shoreline to a condition that is better than the baseline level at the time the activity takes place. How then can the shoreline be improved over time in areas where the baseline condition is severely, or even marginally, degraded?

Section 173-26-201(2)(f) WAC of the Shoreline Master Program Guidelines\(^1\) says:

“master programs shall include goals and policies that provide for restoration of such impaired ecological functions. These master program provisions shall identify existing policies and programs that contribute to planned restoration goals and identify any additional policies and programs that local government will implement to achieve its goals. These master program elements regarding restoration should make real and meaningful use of established or funded nonregulatory policies and programs that contribute to restoration of ecological functions, and should appropriately consider the direct or indirect effects of other regulatory or nonregulatory programs under other local, state, and federal laws, as well as any restoration effects that may flow indirectly from shoreline development regulations and mitigation standards.”

However, degraded shorelines are not just a result of pre-Shoreline Master Program activities, but also of unregulated activities and exempt development. The new Guidelines also require that “[l]ocal master programs shall include regulations ensuring that exempt development in the aggregate will not cause a net loss of ecological functions of the shoreline.” While some actions within shoreline jurisdiction are exempt from a permit, the Shoreline Master Program should clearly state that those actions are

---

not exempt from compliance with the Shoreline Management Act or the local Shoreline Master Program. Because the shoreline environment is also affected by activities taking placed outside of a specific local master program’s jurisdiction (e.g., outside of city limits, outside of the shoreline zone within the city), assembly of out-of-jurisdiction actions, programs and policies can be essential for understanding how the City fits into the larger watershed context. The latter is critical when establishing realistic goals and objectives for dynamic and highly inter-connected environments.

As directed by the Guidelines, the following discussions provides a summary of baseline shoreline conditions, lists restoration goals and objectives, and discusses existing or potential programs and projects that positively impact the shoreline environment. Finally, anticipated scheduling, funding, and monitoring of these various comprehensive restoration elements are provided. In total, implementation of the Shoreline Master Program (with mitigation of project-related impacts) in combination with this Restoration Plan (for restoration of lost ecological functions that occurred prior to a specific project) should result in a net improvement in the City of Mercer Island’s shoreline environment in the long term.

In addition to meeting the requirements of the Guidelines, this Restoration Plan is also intended to support the City’s or other non-governmental organizations’ applications for grant funding, and to provide the interested public with contact information for the various entities working within the City to enhance the environment.

# 2 SHORELINE INVENTORY SUMMARY

## 2.1 Introduction

The City conducted a comprehensive inventory of its Lake Washington shoreline in 2008. The purpose of the shoreline inventory was to facilitate the City of Mercer Island’s compliance with the State of Washington’s Shoreline Management Act (SMA) and updated Shoreline Master Program Guidelines. The inventory describes existing physical and biological conditions in the Lake Washington shoreline zone within City limits, including recommendations for restoration of ecological functions where they are degraded. The full Final Shoreline Analysis Report is included as an appendix to the Shoreline Master Program, and is summarized below.

## 2.2 Shoreline Boundary

As defined by the Shoreline Management Act of 1971, shorelines include certain waters of the state plus their associated “shorelands.” Shorelands are defined as:
“those lands extending landward for 200 feet in all directions as measured on a horizontal plane from the ordinary high water mark; floodways and contiguous floodplain areas landward 200 feet from such floodways; and all wetlands and river deltas associated with the streams, lakes, and tidal waters which are subject to the provisions of this chapter...Any county or city may determine that portion of a one-hundred-year-floodplain\(^2\) to be included in its master program as long as such portion includes, as a minimum, the floodway and the adjacent land extending landward two hundred feet therefrom (RCW 90.58.030)”

Shorelands in the City of Mercer Island include only areas within 200 feet of the ordinary high water mark, as established by the U.S. Army Corps of Engineers for Lake Washington, and any associated wetlands within shoreline jurisdiction. As part of the shoreline jurisdiction assessment, there were two wetlands identified in Luther Burbank Park that extend the shoreline jurisdiction beyond 200 feet from the Lake Washington ordinary high water mark (Figure 1). Lake Washington does not have a floodway or floodplain.

Figure 1: Mercer Island Shoreline Jurisdiction Including Associated Wetlands (inset)

\(^2\) According to RCW 173-220-030, 100-year floodplain is “that land area susceptible to being inundated by stream derived waters with a one percent chance of being equaled or exceeded in any given year. The limit of this area shall be based upon flood ordinance regulation maps or a reasonable method which meets the objectives of the act;”
2.3 Inventory

The shoreline inventory is divided into five main sections: Introduction, Current Regulatory Framework Summary, Shoreline Inventory, Analysis of Ecological Functions and Ecosystem-wide Processes, Land Use Analysis and Shoreline Management Recommendations. The City’s shoreline jurisdiction is divided into two segments: Urban Residential, and Urban Park. These segments are based on existing land use and zoning, as well as the City’s current environment designations.

2.3.1 Land Use and Physical Conditions

Existing Land Use

In general, the City of Mercer Island shoreline area is fully developed. The few areas not occupied by single or multi-family residential uses are either private recreation clubs, vacant lots, City parks or landings. With the possible exception of limited additional residential lands being acquired for public open space, land uses along the shoreline are not expected to change over the next 20 years, although re-builds, substantial remodels and some redevelopment of single-family residential are anticipated. The City’s shoreline is predominately zoned single-family residential (R-8.4, R-9.6, R-12 and R-15). Residential and private club uses (Urban Residential designation) comprise 90.4 percent of the City’s shoreline area, Luther Burbank Park (Urban Park designation) comprises 6 percent, and public recreation and open space (Urban Park designation) comprise the remaining 3.6 percent of the shoreline area. There are five City parks, one City boat launch, two private recreational clubs, and one private retirement facility on the waterfront. There are also 13 City-owned street ends (“landings”) located within the shoreline area. The Mercerwood Shore Club and Mercer Island Beach Club are private waterfront recreation clubs that include clubhouses, picnic areas, swimming beaches, tennis and fitness facilities, boat moorage, and other amenities. Covenant Shores retirement center includes private boat moorage and other similar private recreational opportunities. There are 57 privately owned lots (roughly 6%) within the shoreline jurisdiction that are considered vacant or undeveloped, 44 of which are along the shoreline. Of those 44 properties, only 10 have development potential.

Parks and Open Space/Public Access

There are a number of opportunities to access the Mercer Island waterfront, whether at public parks, landings or the City boat launch. Luther Burbank Park is the City’s largest multi-use park and is considered the crown jewel of the park system (Figure 2). The park is 77 acres and includes a swimming beach, public boat
dock, public fishing pier, former Luther Burbank School brick dormitory, steam plant and dairy ruins, trails, off-leash dog area, and other groomed and wooded areas. Calkins Point, located on the north end of the park, has been slowly eroding away and has been identified by the City as a high-priority for shoreline restoration.

Other parks located along the shoreline include Clarke Beach (Figure 3), Groveland Beach, Slater Park, and Park on the Lid. These parks provide multiple opportunities for water-related recreational uses, including swimming, fishing, picnicking, and active and passive recreation. Mercer Island Boat Launch is located along the City’s northeast shore and provides a Lakes-to-Locks Water Trail Launch and Landing Site.

There are 13 street-end public rights-of-way into public spaces and parks that provide access to the waterfront. The landings, which vary in the level of development, include swimming and fishing areas, boat launch facilities and docks. A few of the landings remain undeveloped and provide opportunities for future restoration or improvements.

Figure 3: Clark Beach Park

**Shoreline Modifications**

The Mercer Island shoreline is heavily modified with close to 78 percent of the shoreline armored at or near the ordinary high water mark and a pier density of approximately 47.5 overwater structures per mile. This compares to 71 percent armored and 36 piers per mile for the entire Lake Washington shoreline. Thus, for Mercer Island, both pier density and shoreline armoring are slightly higher than the lake-wide figures. Many of the piers have one or more boatlifts.

As expected, the Urban Residential segment has the most altered shoreline, with 82 percent armored with either vertical or boulder bulkheads. The Urban Park segment is 35 percent armored. It is not uncommon around Lake Washington for some historic fills to be associated with the original bulkhead construction, usually to create a more level or larger yard. Most of these shoreline fills occurred at the time that the lake elevation was lowered during construction of the Hiram Chittenden Locks.

Also as expected, the highest amount of overwater cover per lineal foot of shoreline can be found in the Urban Residential segment. This can be attributed to the presence of a
number of residential homes within this segment, as well as two beach clubs which have marinas.

The full shoreline inventory includes a more in-depth discussion of the above topics, as well as information about transportation, stormwater and wastewater utilities, impervious surfaces, and historical/archaeological sites, among others.

2.3.2 Biological Resources and Critical Areas

With the exception of some portions of the shoreline along Luther Burbank Park (Urban Park), the shoreline zone itself is generally deficient in high-quality biological resources and critical areas, primarily because of the extensive residential development and its associated shoreline modifications. There are a number of City parks along the shoreline, but a majority of these are mostly well manicured and include extensive shoreline armoring or pier and dock structures. The highest-functioning shoreline area is Luther Burbank Park, which contains a majority of the City’s last unaltered shoreline. There are also a few City-owned landings which are undeveloped, but these are surrounded by residential development and do not cover an extensive area of the shoreline area. Virtually all of the Mercer Island shoreline is encumbered by geologically hazard areas, including seismic, erosion and landslide areas. According to City data, there are two wetlands inventoried within shoreline jurisdiction, both of which are located in Luther Burbank Park. There are a number of streams that discharge into Lake Washington, including 39 perennial streams, 13 of which have been identified as having potential for fish use near their mouth to Lake Washington. These streams are used by Chinook, coho, and sockeye salmon, as well as cutthroat trout. Many of the smaller tributaries to Lake Washington originate as hillside seeps or springs and flow seasonally or during periods of heavy rains. Many of these smaller systems are piped at some point and discharge directly to Lake Washington via a closed system. These streams have been impacted extensively by basin development, resulting in increased peak flows, unstable and eroding banks, loss of riparian vegetation, and fish and debris passage barriers. These changes have altered their contributions of sediment, organic debris, and invertebrates into Lake Washington.

WDFW mapping of Priority Habitat and Species (WDFW 2008) also indicates the presence of other Fish and Wildlife Habitat Conservation Areas within and adjacent to the shoreline zone. These include historic and current bald eagle nest locations, wetlands, and urban natural open space (parks and other green spaces). Segments B and C, Urban Park and Urban Residential respectively, generally do not contain any significant fish or other wildlife habitats other than Lake Washington. Extensive residential and park development, which includes landscaping and shoreline modifications, has removed much of the potential for riparian habitat.
3 RESTORATION GOALS AND OBJECTIVES

According to the Lake Washington/Cedar/Sammamish Watershed (WRRA) Near-Term Action Agenda For Salmon Habitat Conservation, Lake Washington suffers from “Altered trophic interactions (predation, competition), degradation of riparian shoreline conditions, altered hydrology, invasive exotic plants, poor water quality (phosphorus, alkalinity, pH), [and] poor sediment quality” (WRRA 8 Steering Committee 2002). Mercer Island’s Final Shoreline Analysis Report (The Watershed Company 2009) provides supporting information that validates these claims specifically in the City’s shoreline jurisdiction. The WRRA 8 Action Agenda established four “ecosystem objectives,” which are intended to guide development and prioritization of restoration actions and strategies. The objectives are as follows:

- “Maintain, restore, or enhance watershed processes that create habitat characteristics favorable to salmon.
- Maintain or enhance habitat required by salmon during all life stages and maintain functional corridors linking these habitats.
- Maintain a well-dispersed network of high-quality refuge habitats to serve as centers of population expansion.
- Maintain connectivity between high-quality habitats to allow for population expansion into recovered habitat as degraded systems recover.”

The WRRA 8 restoration objectives, in combination with the results of the City’s Final Shoreline Analysis Report, the direction of Ecology’s Shoreline Master Program Guidelines, and the City’s commitment (Appendix A) to support the Final Lake Washington/Cedar/Sammamish Watershed (WRRA 8) Chinook Salmon Conservation Plan, are the foundation for the following goals and objectives of the City of Mercer Island’s restoration strategy. Although the WRRA 8 Action Agenda and the Final Lake Washington/Cedar/Sammamish Watershed (WRRA 8) Chinook Salmon Conservation Plan are salmon-centered, pursuit of ecosystem-wide processes and ecological functions performance that favors salmon generally captures those processes and functions that benefit all fish and wildlife.

**Goal 1** – Maintain, restore or enhance watershed processes, including sediment, water, wood, light and nutrient delivery, movement and loss.

**Goal 2** – Maintain or enhance fish and wildlife habitat during all life stages and maintain functional corridors linking these habitats.

**Goal 3** – Contribute to conservation and recovery of chinook salmon and other anadromous fish, focusing on preserving, protecting and restoring habitat with the intent to recover listed species, including sustainable, genetically diverse, harvestable populations of naturally spawning chinook salmon.
System-wide restoration objectives

- Continue to work collaboratively with other jurisdictions and stakeholders in WRIA 8 to implement the Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan.

- Use the scientific foundation and the conservation strategy as the basis for local actions recommended in the Chinook Salmon Conservation Plan and as one source of best available science for future projects, ordinances, and other appropriate local government activities.

- Use the comprehensive list of actions, and other actions consistent with the Chinook Salmon Conservation Plan, as a source of potential site-specific projects and land use and public outreach recommendations.

- Use the start-list to guide priorities for regional funding in the first ten years of Chinook Salmon Conservation Plan implementation, and implementing start-list actions through local capital improvement projects, ordinances, and other activities.

- Seek funding for various restoration actions and programs from local sources and by working with other WRIA 8 jurisdictions and stakeholders to seek federal, state, grant and other funding opportunities.

- Develop a public education plan to inform private property owners in the shoreline zone and in the remainder of the City about the effects of land management practices and other unregulated activities (such as vegetation removal, pesticide/herbicide use, car washing) on fish and wildlife habitats.

Lake Washington restoration objectives


- Improve Lake Washington tributary stream health by eliminating man-made barriers to anadromous fish passage, preventing the creation of new barriers, and providing for transport of water, sediment and organic matter at all stream crossings.

- Improve Lake Washington and Lake Washington tributary stream health by identifying hardened and eroding lakeshores and streambanks, and correcting to the extent feasible with bioengineered stabilization solutions.

- Improve Lake Washington and Lake Washington tributary stream health by increasing large woody debris recruitment potential through plantings of
trees in the riparian corridors, particularly conifers. Where feasible, install large woody debris to meet short-term needs.

- Increase quality, width and diversity of native vegetation in protected corridors adjacent to stream and lake habitats to provide safe migration pathways for fish and wildlife, food, nest sites, shade, perches, and organic debris. Strive to control non-indigenous plants or weeds that are proven harmful to native vegetation or habitats.

- Reconnect and enhance small creek mouths as juvenile rearing areas.

- Habitat in small Lake Washington tributaries, such as those in the City of Mercer Island, should be restored for coho so that production of cutthroat trout, which prey on juvenile chinook salmon in Lake Washington, is reduced.

- Decrease the amount and impact of overwater and in-water structures through minimization of structure size and use of innovative materials such as grated decking.

- Participate in lake-wide efforts to reduce populations of non-native aquatic vegetation.

4 List of Existing and Ongoing Projects and Programs

The following series of existing projects and programs are generally organized from the larger watershed scale to the City-scale, including City projects and programs and finally non-profit organizations that are also active in the Mercer Island area.

4.1 Water Resource Inventory Area (WRIA) 8 Participation

Mercer Island has taken advantage of outreach and education offered by WRIA 8 staff on salmon-friendly shoreline landscape design. Mercer Island continues to be involved in the Forum at both the elected official and staff level. The City was one of 27 members of the WRIA 8 Forum, which participated in financing and developing the Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. The Chinook Salmon Conservation Plan includes the City of Mercer Island’s implementation commitment in the form of City Council Resolution 1347, approved September 6, 2005 (Appendix A).

The City’s preparation of the Shoreline Analysis Report Including Shoreline Inventory and Characterization of the City of Mercer Island’s Lake Washington Shoreline (The Watershed Company 2009) and this Shoreline Restoration Plan are important steps
toward furthering the goals and objectives of the WRISA 8 Chinook Salmon Conservation Plan. The City’s Shoreline Master Program update products rely heavily on the science included in the WRISA 8 products, and incorporate recommended actions from the WRISA 8 products (Table 1).

To review, the WRISA 8 Steering Committee’s mission and goal statements state that the Plan shall: 1) recognize that local governments are key implementing entities for the plan, because of their responsibilities for land use, 2) direct most future population growth to already urbanized areas, because new development has greater negative effects on hydrology and ecological health of streams in rural than in urban areas, 3) create incentives for behavior that would support Plan goals, and 4) be coordinated with the Growth Management Act, local and regional responses to the Clean Water Act, other environmental laws and past/current planning efforts.

The Plan presents an Action Start-List that attempts to compile the land use, site-specific habitat protection and restoration projects, and public outreach and education recommendations into a single strategy list which focuses watershed priorities yet also provides a manageable number of actions. Conservation priority actions identified for WRISA 8 chinook salmon habitat within Lake Washington included in the Plan are as follows:

- Reduce predation on juvenile migrants in Lake Washington by providing increased rearing and refuge opportunities.
- Restore shallow water habitats and creek mouths for juvenile rearing and migration.

Table 1. The Final Lake Washington/Cedar/Sammamish Watershed (WRISA 8) Chinook Salmon Conservation Plan Action Start-List for Lake Washington and Status of Implementation in the City of Mercer Island

<table>
<thead>
<tr>
<th>Action Item</th>
<th>Mercer Island Implementation</th>
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<tbody>
<tr>
<td><strong>Reduce predation to outmigrating juvenile chinook by: reducing bank hardening, restoring overhanging riparian vegetation, replacing bulkhead and rip-rap with sandy beaches with gentle slopes, and use of mesh dock surfaces and/or community docks.</strong></td>
<td>The proposed SMP includes provisions that ensure salmon friendly shoreline design for new construction and redevelopment, including requirements for grated decking and shoreline vegetation…</td>
</tr>
<tr>
<td>Encourage salmon friendly shoreline design during new construction or redevelopment by offering incentives and regulatory flexibility to improve bulkhead and dock design and revegetate shorelines.</td>
<td>The City has done two projects demonstrating these techniques at public Right of Way street ends on the</td>
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<tr>
<td>Action Item</td>
<td>Mercer Island Implementation</td>
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<td>---------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>Increase enforcement and address nonconforming structures over long run by</td>
<td>Code enforcement is responsible for enforcing regulations which address public health and safety issues, including regulations related to rubbish, garbage, specific nuisances, removal of vegetation, zoning, housing, dangerous buildings, and inoperable and unlicensed vehicles on private property. Enforcement actions are taken both proactively and in response to requests for action received from citizens. The City has not recently updated its code enforcement.</td>
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<td>requiring that major redevelopment projects meet current standards.</td>
<td></td>
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<tr>
<td>Discourage construction of new bulkheads; offer incentives (e.g., provide</td>
<td>The proposed SMP includes provisions that discourage construction of new bulkheads by limiting new bulkheads to only those properties that can show a demonstrated need through a geotechnical analysis.</td>
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<td>expertise, expedite permitting) for voluntary removal of bulkheads,</td>
<td></td>
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<tr>
<td>beach improvement, riparian revegetation.</td>
<td></td>
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<tr>
<td>Support joint effort by NOAA Fisheries and other agencies to develop</td>
<td>The City has been coordinating on a regular basis with state and federal agencies to help develop consistent pier and bulkhead design standards, including coordination with adjacent jurisdictions.</td>
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<td>dock/pier specifications to streamline federal/state/local permitting;</td>
<td></td>
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<tr>
<td>encourage similar effort for bulkhead specifications.</td>
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<tr>
<td>Promote value of light-permeable docks, smaller piling sizes, and</td>
<td>The City has hosted workshops for lakeshore owners which has highlighted the value of eco-friendly pier construction. This includes King County Lakeshore Living and Greenshorelines workshops.</td>
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<tr>
<td>community docks to both salmon and landowners through direct mailings to</td>
<td></td>
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<tr>
<td>lakeshore landowners or registered boat owners sent with property tax</td>
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<td>notice or boat registration tab renewal.</td>
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<tr>
<td>Develop workshop series specifically for lakeshore property owners on</td>
<td>King County has led this effort. As mentioned above, the City has hosted workshops on this topic in the past (Lakeshore Living and Greenshorelines). This work is expected to continue in the near future.</td>
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<tr>
<td>lakeside living: natural yard care, alternatives to vertical wall</td>
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<tr>
<td>bulkheads, fish friendly dock design, best management practices for</td>
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<tr>
<td>aquatic weed control, porous paving, and environmentally friendly methods</td>
<td></td>
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<tr>
<td>of maintaining boats, docks, and decks.</td>
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*Protect and restore water quality in tributaries and along shoreline. Restore coho runs in smaller tributaries as control mechanism to reduce the cutthroat population.*

*Reconnect and enhance small creek mouths as juvenile rearing areas.*
### Action Item

Address water quality and high flow impacts from creeks and shoreline development through NPDES Phase 1 and Phase 2 permit updates, consistent with Washington Department of Ecology’s 2001 Stormwater Management Manual, including low impact development techniques, on-site stormwater detention for new and redeveloped projects, and control of point sources that discharge directly into the lakes.

### Mercer Island Implementation

The City currently implements Ecology’s 2005 *Stormwater Management Manual for Western Washington* through its NPDES Phase 2 permit. The NPDES Phase II permit is required to cover the City’s stormwater discharges into regulated lakes and streams. Under the conditions of the permit, the City must protect and improve water quality through public education and outreach, detection and elimination of illicit non-stormwater discharges (e.g., spills, illegal dumping, wastewater), management and regulation of construction site runoff, management and regulation of runoff from new development and redevelopment, and pollution prevention and maintenance for municipal operations.

Encourage low impact development through regulations, incentives, education/training, and demonstration projects.

The Comprehensive Plan and the proposed SMP contain provisions which promote LID, including allowance of storm water strategies that minimize the creation of impervious surfaces, and measures to minimize the disturbance of native soils and vegetation. The City has already identified a short list of good candidates for LID demonstration projects at City facilities that will be completed in the future.

Protect and restore water quality and other ecological functions in tributaries to reduce effects of urbanization and reduce conditions which encourage cutthroat. Protect and restore forest cover, riparian buffers, wetlands, and creek mouths by revising and enforcing critical areas ordinances and Shoreline Master Programs, incentives, and flexible development tools.

The City updated the Critical Areas Ordinance in 2005. Management of the City’s critical areas using these regulations should help insure that ecological functions and values are not degraded, and impacts to critical areas are mitigated. The City also coordinates ongoing Maintenance activities, specifically with drainage basins, with open spaces improvements on adjoining properties. The City currently implements the 2004 Open Space Vegetation Plan (City of Mercer Island 2004) which promotes
<table>
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<th>Action Item</th>
<th>Mercer Island Implementation</th>
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<tbody>
<tr>
<td>Promote through design competitions and media coverage the use of “rain gardens” and other low impact development practices that mimic natural hydrology.</td>
<td>The City actively promotes rain garden and LID education through local news media and support for ongoing workshops.</td>
</tr>
</tbody>
</table>

### 4.2 Comprehensive Plan Policies

The City updated its Comprehensive Plan on July 5, 2005. The updated Comprehensive Plan, specifically the Conservation Element of the Shoreline Goals and Policies, contains a number of general and specific goals and policies that direct the City to permit and condition development in such a way that the natural environment is preserved and enhanced. The specific goals and policies include:

**Goal:** The resources and amenities of Lake Washington are to be protected and preserved for use and enjoyment by present and future generations.

- **Policy 1:** Existing natural resources should be conserved, consistent with private property rights.
- **Policy 2:** Existing and future activities on Lake Washington and its shoreline should be designed to minimize adverse effects on the natural systems.
- **Policy 3:** Uses or activities within all drainage basins related to Lake Washington should be considered as an integral part of shoreline planning.
- **Policy 4:** Shoreline areas having historical, cultural, educational or scientific value should be protected and restored.

Techniques suggested by the various policies to protect the natural environment include requiring setbacks from sensitive areas, preserving habitats for sensitive species, preventing adverse alterations to water quality and quantity, promoting low impact development, preserving existing native vegetation, educating the public, and mitigating necessary sensitive area impacts, among others.

### 4.3 Critical Areas Regulations

The City of Mercer Island critical areas regulations are found in Mercer Island City Code Chapter 19.07 Environment. The City completed its last critical areas regulations update
on 2005. The updated regulations are based on best available science, and provide protection to critical areas in the City, particularly for streams and wetlands. All activities which require a substantial development permit, conditional use or variance under the SMP are reviewed under the City’s CAO for consistency. As stated above, if there is a conflict between the CAO and SMP, the regulations that offer the greatest environmental protection apply.

Some of the basic components of the critical areas regulations include a four-tiered watercourse typing system with standard buffers ranging between 25 and 75 feet, and Ecology’s four-tiered wetland rating system with standard buffers ranging from 35 to 100 feet. Management of the City’s critical areas using these regulations should help insure that ecological functions and values are not degraded, and impacts to critical areas are mitigated. These critical areas regulations are one important tool that will help the City meet its restoration goals.

4.4 Stormwater Management and Planning

Although much of the City of Mercer Island’s Storm and Surface Water Utility’s jurisdiction is outside of the shoreline zone, all of the regulated surface waters, both natural and piped, are discharged ultimately into Lake Washington and thus affect shoreline conditions. According to the City’s GIS data, there are 208 known stormwater outfalls, 187 of which are located within the shoreline jurisdiction area (see Figures 5.1 - 5.3). The City’s Utilities section of the Comprehensive Plan contains the following stormwater policies:

4.1 The City shall continue to implement programs and projects designed to meet the goals and requirements of the Puget Sound Water Quality Management Plan.

4.2 The City shall actively promote and support education efforts focusing on all facets of stormwater management.

4.3 The City shall maintain and enforce land-use plans and ordinances requiring stormwater controls for new development and re-development. The ordinances shall be based on standards developed by the state Department of Ecology and shall be consistent with the policies in the Land-Use Element of this plan and the goals and policies of the City’s Development Services Group.

The City received its National Pollutant Discharge Elimination System (NPDES) Phase II Municipal Stormwater Permit in January 2007 from Ecology. The NPDES Phase II permit is required to cover the City’s stormwater discharges into regulated lakes and streams. Under the conditions of the permit, the City must protect and improve water quality through public education and outreach, detection and elimination of illicit non-stormwater discharges (e.g., spills, illegal dumping, wastewater), management and regulation of construction site runoff, management and regulation of runoff from new
development and redevelopment, and pollution prevention and maintenance for municipal operations (City of Mercer Island website).

In 2007, the Department of Ecology published information about toxics levels in fish, including fish sampled in Lake Washington (Department of Ecology 2007). Lake Washington ranked second only to the Wenatchee River near Leavenworth for a site contaminant score. Although this report does not identify specific point sources, it represents a clear need to better understand contaminant sources and control.

The City’s 2004 Open Space Vegetation Plan (City of Mercer Island 2004) was prioritized by multiple factors including storm water buffering and erosion control. It directs work to sites where it would most likely improve storm water buffering and erosion control.

4.5 Public Education

The City of Mercer Island’s Comprehensive Plan identifies various policy statements based on the goal of environmental public involvement (excerpted below). These items help guide City staff and local citizen groups in developing mechanisms to educate the public and broaden the interest in protecting and enhancing local environmental resources.

4.5.1 Land Use Element

Natural Environment Policies

Goal 10: The protection of the natural environment will continue to be a priority in all Island development. Protection of the environment and private property rights will be consistent with all state and federal laws.

Policy 10.1 The City of Mercer Island shall protect environmentally sensitive lands such as watercourses, geologic hazard areas, steep slopes, shorelines, wildlife habitat conservation areas, and wetlands. Such protection should continue through the implementation and enforcement of critical areas and shoreline regulations.

Policy 10.2 Land use actions, storm water regulations and basin planning should reflect intent to maintain and improve the ecological health of watercourses and Lake Washington water quality.

Policy 10.3 New development should be designed to avoid increasing risks to people and property associated with natural hazards.
Policy 10.4  The ecological functions of watercourses, wetlands, and habitat conservation areas should be maintained and protected from the potential impacts associated with development.

Policy 10.5  The City shall consider best available science during the development and implementation of critical areas regulations. Regulations will be updated periodically to incorporate new information and, at a minimum, every seven years as required by the Growth Management Act.

4.5.2 Utilities Element

Water Quality Policies

Policy 2.8  The City shall aggressively promote and support water conservation on Mercer Island and shall participate in regional water conservation activities. The goal of the City’s efforts shall be a significant and lasting reduction in Mercer Island’s peak water consumption. In 1999 the City decided to participate in SPU’s 1% Water Conservation Initiative, and continues to receive information and assistance in reducing water consumption in City facilities and in the community.

Stormwater Policies

Policy 4.2  The City shall actively promote and support education efforts focusing on all facets of stormwater management.

4.5.3 Shoreline Goals and Policies

Conservation Element

Policy 4.a.  Public and private cooperation should be encouraged in site preservation and protection.

As part of the City of Mercer Island’s efforts to abide by these goals and policies, the City supports several volunteer efforts, such as Mountains to Sound Greenway sponsored events, Open Space Conservancy Trust, Forest Stewardship, Forest Stewardship training, Adopt-a-Park and EarthCorps.

4.6 Open Space Conservancy Trust

The Open Space Conservancy Trust, established by Mercer Island City Council in 1992, “was created for the express purpose of receiving and holding such real property, as transferred for open space purposes; for protecting, maintaining and preserving the
Open Space Properties; and insuring that the development and use of the Open Space Properties are both consistent and compatible with the intent and purpose of the Trust and the guidelines and polices enacted.” The trust is led by a seven member volunteer board consisting of six citizens appointed by the Mayor and one City Council member. The trust currently holds Pioneer Park as its sole property.

Contact Information: http://www.ci.mercer-island.wa.us/ccbindex.asp?ccbid=12

4.7 Mountains to Sound Greenway Trust
Mountains to Sound (MTS) Greenway Trust, a nonprofit organization founded in 1991, assists local, state, and federal agencies to acquire open space lands for permanent protection in order to create a 100-mile connected green corridor along Interstate 90.

Within the City of Mercer Island, MTS organizes and leads volunteers to improve City parks by removing invasive plants (primarily ivy) and planting native trees and shrubs. Mercer Island Parks and Recreation has teamed up with MTS and a number of other groups and organizations to host several volunteer events throughout the year.

Contact Information: http://www.miparks.org/, http://www.mtsgreenway.org/

4.8 Forest Stewardship and Adopt-A-Park Programs
Citizens of Mercer Island donate countless hours to maintain the City’s open spaces and parks through picking up litter, cutting ivy, planting and trail maintenance and repair. Forest Stewardship provides opportunities for citizens to be active with City-sponsored projects or work individually with other volunteers. Forest Stewardship training provides the skills to become Forest Stewards who are qualified to run volunteer projects on the island on behalf of the Parks and Recreation Department.

The City’s Adopt-a-Park program allows local schools or services groups to adopt a City park. The program benefits schoolchildren, who learn valuable stewardship skills, and the public who benefit from the restoration efforts.

Contact Information: miparks@mercergov.org, http://www.ci.mercer-island.wa.us/Page.asp?NavID=1515

4.9 EarthCorps
EarthCorps is a non-profit organization that provides environmental restoration service programs for young adults. These one-year programs provide opportunities to learn conservation and develop skills in leading volunteers. EarthCorps works with Mercer Island Parks and Recreation to organize and lead restoration projects, such as removing invasive plants and planting native species.
5 LIST OF ADDITIONAL PROJECTS AND PROGRAMS TO ACHIEVE LOCAL RESTORATION GOALS

The following series of additional projects and programs are generally organized from the larger watershed scale to the City-scale, including City projects and programs and finally non-profit organizations that are also active in the Mercer Island area.

5.1 Unfunded WRIA 8 Projects

The 2005 Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan does not identify any specific projects along the Mercer Island shoreline, but does include the following general recommendations to reduce predation on outmigrating juvenile chinook salmon in its “Action Start-List for Migratory Areas”:

- Encourage salmon friendly shoreline design during new construction or redevelopment by offering incentives and regulatory flexibility to improve bulkhead and dock design and revegetate shorelines. Increase enforcement and address nonconforming structures over long run by requiring that major redevelopment projects meet current standards.
- Discourage construction of new bulkheads; offer incentives (e.g., provide expertise, expedite permitting) for voluntary removal of bulkheads, beach improvement, riparian revegetation.
- Support joint effort by NOAA Fisheries and other agencies to develop dock/pier specifications to streamline federal/state/local permitting; encourage similar effort for bulkhead specifications.
- Promote value of light-permeable docks, smaller piling sizes, and community docks to both salmon and landowners through direct mailings to lakeshore landowners or registered boat owners sent with property tax notice or boat registration tab renewal. Offer financial incentives for community docks in terms of reduced permit fees, loan fees/percentage rates, taxes, and permitting time, in addition to construction cost savings.
- Develop workshop series specifically for lakeshore property owners on lakeside living: natural yard care, alternatives to vertical wall bulkheads, fish friendly dock design, best management practices for aquatic weed control, porous paving, and environmentally friendly methods of maintaining boats, docks, and decks. Related efforts include creation of a website to convey workshop material, an awareness campaign, “Build a Beach,” to illuminate impact of bulkheads on development of sandy beaches.
• Restore shoreline in Lake Washington Section 1: work with private property owners to restore shoreline in Section 1. Use interpretive signage where possible to explain restoration efforts.

5.2 Recommended Projects - Public

The following is developed from a list of opportunity areas identified within the Final Shoreline Analysis Report (The Watershed Company 2009) and is intended to contribute to improvement of impaired functions on public property. The list of recommended projects was created after reviewing the City’s CIP list and assessing field conditions during the shoreline inventory and characterization phase.

* Luther Burbank Park*

Two restoration projects listed in the City’s CIP include:

• Luther Burbank Shoreline Restoration (Summer 2008): removing non-native plant species, replant native vegetation, create recreation access beaches, develop habitat and maintain trail opportunities, stabilize soft banks.

• Luther Burbank Off-Leash Area (OLA) (2008): design and construct minor drainage, surfacing, shoreline, landscaping and fencing improvements in OLA.

Restoration opportunities not included in the City’s CIP include:

• In October 2005, Anchor Environmental, LLC. prepared a Shoreline Habitat Inventory that identified a number of restoration opportunities along the shoreline. Many of these have been completed or are included in the City’s CIP. However, the inventory contains several items not included in the CIP, which represent future opportunities. These include restoration of several stretches (18, 20, 21) along the shoreline. Restoration would include placement of beach nourishment, removal of invasive plants, and planting of native plants to increase overhanging vegetation.

* Street-Ends (Landings) and Residential Shoreline Properties*

There are two projects listed in the City’s 2007-2008 6-Year Capital Improvement Program. Both projects are currently planned for implementation in 2013.

• Groveland Beach Park: Remove invasive vegetation, replace worn playground elements, and prepare shoreline improvements.

• Clarke Beach Park: Removal of up to 300 linear feet of concrete retaining wall/bulkhead/barrier at Clarke Beaches.

• Many of the parks, street-ends and residential shoreline properties along the shoreline have the potential for improvement of ecological functions through: 1)
reduction or modification of shoreline armoring, 2) reduction of overwater cover and in-water structures (grated pier decking, pier size reduction, pile size and quantity reduction, moorage cover removal), 3) improvements to nearshore native vegetative cover, and/or 4) reductions in impervious surface coverage.

Open Space – Vegetation Management

Many parks located on Mercer Island are heavily invaded by non-native invasive species that will eventually damage and destroy forest canopies. Opportunities exist to provide vegetation and property management in existing open space areas. This will improve shoreline and upland habitat areas within the City.

5.3 Recommended Projects - Private

Generally, restoration opportunities which have been identified are focused on City property, including parks, open spaces, and street-ends. Many other restoration opportunities exist throughout the City on private property. These opportunities would include many of the same issues as listed above, but would likely occur only through voluntary means or through re-development proposals.

General: Many shoreline properties have the potential for improvement of ecological functions through: 1) reduction or modification of shoreline armoring, 2) reduction of overwater cover and in-water structures (grated pier decking, pier size reduction, pile size and quantity reduction, moorage cover removal), 3) improvements to nearshore native vegetative cover, and/or 4) reductions in impervious surface coverage. Similar opportunities would also apply to undeveloped lots which may be used as community lots for upland properties or local street-ends and utility corridors. Other opportunities may exist to improve either fish habitat or fish passage for those properties which have streams discharging to Lake Washington.

An example of how shoreline armoring might be reduced on some lots along the City’s residential areas is depicted below (Figure 4). This example displays before and after images of a lot in which the existing bulkhead is partially pulled back to create a shallow cove beach combined with natural materials. This example combines the effort to improve habitat conditions with improved access and aesthetics.

Restoration of Multiple Contiguous Properties: Through grant funding sources, restoration opportunities may be available to multiple contiguous shoreline properties, including residential lots that are interested in improving shoreline function. Restoring shoreline properties that are connected to one another would provide significantly more benefits than a more piecemeal approach. Therefore, priority should be given to restoration projects which involve multiple lots (such as accelerated permit processes).

5.4 Public Education/Outreach

The Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan includes a table outlining 53 “Outreach and Education Actions” with target audiences for each action ranging from the general public, to shoreline property
owners in general, to lakeshore property owners specifically, to businesses, to youth, and others. The complete list of WRIA 8 “Outreach and Education Actions” is included as Appendix B.

Figure 4: Partial bulkhead removal example project
6 PROPOSED IMPLEMENTATION TARGETS AND MONITORING METHODS

As previously noted, the City’s shoreline zone is occupied by single- and multi-family residences, and public recreation/open spaces. Therefore, efforts should be made to improve shoreline ecological function through the promotion of restoration and healthy practices at all levels, from large-scale marina users to single-family property owners. The City of Mercer Island already has a very active environmental community with a restoration and education focus. Continued improvement of shoreline ecological functions on the shoreline requires a more comprehensive watershed approach, which combines upland and shoreline projects and programs.

The following table (Table 2) outlines a possible schedule and funding sources for implementation of a variety of efforts that could improve shoreline ecological function, and are described in previous sections of this report.

Table 2. Implementation Schedule and Funding for Restoration Projects, Programs and Plans.

<table>
<thead>
<tr>
<th>Restoration Project/Program</th>
<th>Schedule</th>
<th>Funding Source or Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 WRIA 8 Participation</td>
<td>Ongoing</td>
<td>The City is an active member of the WRIA 8 Forum. Membership at this time entails a commitment of staff and elected official time.</td>
</tr>
<tr>
<td>4.2 Comprehensive Plan Policies</td>
<td>Ongoing</td>
<td>The City makes a substantial commitment of staff time in the course of project and program reviews to determine consistency and compliance with the recently updated Comprehensive Plan. The next Comprehensive Plan update will occur in 2010.</td>
</tr>
<tr>
<td>4.3 Critical Areas Regulations</td>
<td>Ongoing</td>
<td>The City makes a substantial commitment of staff time in the course of project and program reviews to determine consistency and compliance with their recently updated Critical Areas Regulations.</td>
</tr>
<tr>
<td>4.4 Stormwater Planning</td>
<td>Ongoing</td>
<td>Currently, staff time and materials are the only City resource commitments. The City currently follows its 2008 Stormwater Management Program which implements the City’s Phase II NPDES permit and reports annually to Ecology. The City is also involved in the implementation of the 2005 Surface Water Master Plan, which goals includes flood reduction, water quality improvements and aquatic habitat improvements. The City also is in full compliance with NPDES permit requirements for Phase II cities.</td>
</tr>
<tr>
<td>4.5 Public Education</td>
<td>Ongoing</td>
<td>Currently, staff time and materials are provided in</td>
</tr>
<tr>
<td>Restoration Project/Program</td>
<td>Schedule</td>
<td>Funding Source or Commitment</td>
</tr>
<tr>
<td>----------------------------</td>
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<tr>
<td></td>
<td></td>
<td>developing public education and outreach efforts, which are highlighted in the Comprehensive Plan policy statement based on the goal of natural resource protection. These items help guide City staff and local citizen groups in developing mechanisms to educate the public and broaden the interest in protecting and enhancing local environmental resources.</td>
</tr>
<tr>
<td>4.6 Open Space Conservancy Trust</td>
<td>Ongoing</td>
<td>Currently, staff time and materials to support these groups are part of the City’s resource commitments. The Mountains to Sound Greenway Trust also has a contractual agreement with the City for Volunteer Management Services. These groups consist of volunteers appointed by the Mayor.</td>
</tr>
<tr>
<td>4.7 Mountains to Sound Greenway Trust</td>
<td>Ongoing</td>
<td>Currently, staff time and materials to support these groups are the only City resource commitments. These groups consist of volunteers and are supported by the City’s Parks and Recreation Department.</td>
</tr>
<tr>
<td>4.8 Forest Stewardship and Adopt-A-Park</td>
<td>Ongoing</td>
<td>Currently, staff time and materials to support this group is part of the City’s resource commitments. EarthCorps also has a contractual agreement with the City for Volunteer Management Services. These groups consist of volunteers and are supported by the City’s Parks and Recreation Department.</td>
</tr>
<tr>
<td>4.9 EarthCorps</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>5.1 Unfunded WRIA 8 Projects</td>
<td>As funds and opportunity allow</td>
<td>The City Council passed a resolution in 2005 expressing its approval and support for the Lake Washington/Cedar/Sammamish Watershed Chinook Salmon Conservation Plan. Projects will be funded by the City, partnering agencies and non-profit organizations, and grants as projects and funding opportunities arise.</td>
</tr>
<tr>
<td>5.2 Recommended Projects - Public</td>
<td>As funds and opportunity allow</td>
<td>Projects identified in this section would likely be implemented either when grant funds are obtained, when partnerships are formed between the City and other agencies or non-profit groups, or as may be required by the critical areas regulations and the Shoreline Master Program during project-level reviews by the City.</td>
</tr>
<tr>
<td>5.3 Recommended Projects - Private</td>
<td>As funds and opportunity allow</td>
<td></td>
</tr>
<tr>
<td>5.4 Public Education/Outreach</td>
<td>As funds and opportunity allow</td>
<td>On-going and future education efforts should be coordinated with the City and partnering agencies, including funding sources (grant funding, monetary donations, volunteer hours)</td>
</tr>
</tbody>
</table>

The Watershed Company
April 2010

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City planning staff will track all land use and development activity, including exemptions, within shoreline jurisdiction, and will incorporate actions and programs of the Parks and Utilities departments as well. A report will be assembled that provides basic project information, including location, permit type issued, project description, impacts, mitigation (if any), and monitoring outcomes as appropriate. Examples of data categories might include square feet of non-native vegetation removed, square feet of native vegetation planted or maintained, reductions in chemical usage to maintain turf, linear feet of eroding bank stabilized through plantings, linear feet of shoreline armoring removed, or number of fish passage barriers corrected. The report would also update Tables 1 and 4 above, and outline implementation of various programs and restoration actions (by the City or other groups) that relate to watershed health.

The staff report will be assembled to coincide with Comprehensive Plan updates and will be used, in light of the goals and objectives of the Shoreline Master Program, to determine whether implementation of the SMP is meeting the basic goal of no net loss of ecological functions relative to the baseline condition established in the Shoreline Analysis Report (The Watershed Company 2009). In the long term, the City should be able to demonstrate a net improvement in the City of Mercer Island’s shoreline environment.

Based on the results of this assessment, the City may make recommendations for changes to the SMP.

7 RestoratIon PRIORITIES

The process of prioritizing actions that are geared toward restoration of Mercer Island’s shoreline areas involves balancing ecological goals with a variety of site-specific constraints. Briefly restated, the City’s environmental protection and restoration goals include 1) protecting watershed processes, 2) protecting fish and wildlife habitat, and 3) contributing to chinook conservation efforts. Constraints that are specific to Mercer Island include a highly developed residential shoreline along Lake Washington with several large areas of public open space/access. While some areas may already offer fairly good ecological functions (e.g. portions of Luther Burbank Park shoreline), they tend to include some additional opportunities to further enhance ecological functions. These goals and constraints were used to develop a hierarchy of restoration actions to rank different types of projects or programs associated with shoreline restoration. Programmatic actions, like continuing WRIA 8 involvement and conducting outreach programs to local residents, tend to receive relatively high priority opposed to restoration actions involving private landowners. Other factors that influenced the hierarchy are based on scientific recommendations specific to WRIA 8, potential funding sources, and the projected level of public benefit. Restoration projects on public property, such as those identified in Section 5.2, have received a high priority ranking.
due to their availability to be funded by a variety of sources, such as CIP program, Parks Department, local grants, and non-profit groups.

Although restoration project/program scheduling is summarized in the previous section (Table 2), the actual order of implementation may not always correspond with the priority level assigned to that project/program. This discrepancy is caused by a variety of obstacles that interfere with efforts to implement projects in the exact order of their perceived priority. Some projects, such as those associated with riparian planting, are relatively inexpensive and easy to permit and should be implemented over the short and intermediate term despite the perception of lower priority than projects involving extensive shoreline restoration or large-scale capital improvement projects. Straightforward projects with available funding should be initiated immediately for the worthwhile benefits they provide and to preserve a sense of momentum while permitting, design, site access authorization, and funding for the larger, more complicated, and more expensive projects are under way.

7.1 Priority 1 – Continue Water Resource Inventory Area (WRIA) 8 Participation

Of basic importance is the continuation of ongoing, programmatic, basin-wide programs and initiatives such as the WRIA 8 Forum. Continue to work collaboratively with other jurisdictions and stakeholders in WRIA 8 to implement the Final Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. This process provides an opportunity for the City to keep in touch with its role on a basin-wide scale and to influence habitat conditions beyond its borders, which, in turn, come back to influence water quality and quantity and habitat issues within the City.

7.2 Priority 2 – Public Education and Involvement

Public education and involvement has a high priority in the City of Mercer Island due to the predominance of residential development along the shoreline. Recent outreach efforts by other jurisdictions, such as the handbook Green Shorelines: Bulkhead Alternatives for a Healthier Lake Washington (City of Seattle 2008), have begun to change the perception of shoreline aesthetics, use, and ecological health. This and other outreach efforts (i.e. workshops, websites, example projects) are clear motivating and contributing factors for restoration activities on private property.

While many opportunities for shoreline restoration exist within City parks (see Section 5.2), multiple other opportunities also exist along community-owned properties and private marinas. Whether the focus is on single-family residential, community-owned, or marina properties, providing education opportunities and involving the public is key to success, and would possibly entail coordinating the development of a long-term Public Education and Outreach Plan (Section 5.2). This could also include focusing on gaining public support for restoration along City parks.
Specific projects from the Action Start List include developing a workshop series and website that is tailored to lakeshore property owners, and that promotes natural yard care, alternatives to vertical bulkheads, fish-friendly dock design, best management practices for aquatic weed control, porous paving, and environmentally friendly methods of maintaining boats, docks, and decks. Collaborative efforts with other jurisdictions (i.e., City of Seattle) could be completed to meet the Action Start List goals. Additionally, design competitions and media coverage could be used to promote the use of “rain gardens” and other low impact development practices that mimic natural hydrology. A home/garden tour or “Street of Dreams” type event might serve to showcase these landscape/engineering treatments.

7.3 Priority 3 – Reduce Shoreline Armoring along Lake Washington, Create or Enhance Natural Shoreline Conditions

The preponderance of shoreline armoring and its association with impaired habitat conditions, specifically for juvenile chinook salmon, has been identified as one of the key limiting factors along Lake Washington (Kerwin 2001). Nearly 78 percent of the shoreline within the City of Mercer Island is armored at or below the ordinary high water mark (The Watershed Company 2009). While there are no specifically identified projects in the Final Lake Washington/ Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan that are located within Mercer Island, there are many opportunities listed in this Restoration Plan which focus on the potential reduction in shoreline armoring and subsequent restoration and enhancement of shoreline ecological functions.

However, emphasis should also be given to future project proposals that involve or have the potential to restore privately-owned shoreline areas to more natural conditions. The City should explore ways in which to assist local property owners, whether through financial assistance, permit expedition, or guidance, to team together with restoration of multiple contiguous lots.

Recommendations from the Action Start List reflect this focus and encourage salmon friendly shoreline design during new construction or redevelopment by offering incentives and regulatory flexibility to improve bulkhead and dock design and revegetate shorelines. Other recommendations from the List that support this priority include: 1) increasing enforcement that addresses nonconforming structures over the long run by requiring that major redevelopment projects meet current standards; 2) discouraging construction of new bulkheads and offer incentives (e.g., provide expertise, expedite permitting) for voluntary removal of bulkheads, beach improvement, riparian revegetation; 3) utilizing interpretive signage where possible to explain restoration efforts.
7.4 Priority 4 – Reduction of In-water and Over-water Structures

Similar to Priority 3 listed above, in-water and over-water structures, particularly piers, docks, and covered moorages, have been identified as one of the key limiting factors in Lake Washington (Kerwin 2001). Pier density along the City’s shoreline is 48 piers per mile – slightly higher than the lake-wide average of 36 piers per mile (Toft 2001), but inline with other jurisdictions around Lake Washington. The density of residential development along the City’s lakeshore is the main reason for the slightly higher-than-average pier density. While the pier density along residential shorelines is much higher than what is typically found along City-owned park property, the overall footprint of each public pier is generally much greater than is found along single-family residential sites. Opportunities exist for reduction in pier size and overall shading impacts through pier modifications on public sites.

Although no specific privately-owned project sites to reduce in-water and over-water structures within residential areas are identified here, future project proposals involving reductions in the size and/or quantity of such structures should be emphasized. Such future projects may involve joint-use pier proposals or pier reconstruction and may be allowed an expedited permit process.

Action Start List Recommendations in support of Priority 4 include: 1) supporting the joint effort by NOAA Fisheries and other agencies to develop dock/pier specifications that streamline federal/state/local permitting; 2) promoting the value of light-permeable docks, smaller piling sizes, and community docks to both salmon and landowners through direct mailings to lakeshore landowners or registered boat owners sent with property tax notice or boat registration tab renewal; and 3) offering financial incentives for community docks in terms of reduced permit fees, loan fees/percentage rates, taxes, and permitting time, in addition to construction cost savings. Similarly, the WRIA 8 Salmon Conservation Plan identified a future project (C302) to explore opportunities to reduce the number of docks by working with private property owners.

7.5 Priority 5 – Restore Mouths of Tributary Streams, Reduce Sediment and Pollutant Delivery to Lake Washington

Although most of the watercourses and their basins located within the City are outside of shoreline jurisdiction, their impacts to shoreline areas should not be discounted. Several of these streams have the potential to provide fish and wildlife habitat. For juvenile chinook, once they enter Lake Washington, they often congregate near the mouths of tributary streams, and prefer low gradient, shallow-water habitats with small substrates (Tabor and Piaskowski 2002; Tabor et al. 2004; Tabor et al. 2006). Chinook fry entering Lake Washington early in the emigration period (February and March) are still relatively small, typically do not disperse far from the mouth of their natal stream, and are largely dependent upon shallow-water habitats in the littoral zone with overhanging
vegetation and complex cover (Tabor and Piaskowski 2002; Tabor et al 2004). The mouths of creeks entering Lake Washington (whether they support salmon spawning or not), as well as undeveloped lakeshore riparian habitats associated with these confluence areas, attract juvenile chinook salmon and provide important rearing habitat during this critical life stage (Tabor et al. 2004; Tabor et al. 2006).

Later in the emigration period (May and June), most chinook juveniles have grown to fingerling size and begin utilizing limnetic areas of the Lake more heavily (Koehler et al. 2006). As the juvenile chinook salmon mature to fingerlings and move offshore, their distribution extends throughout Lake Washington. Although early emigrating chinook fry from the Cedar River and North Lake Washington tributaries (primary production areas) initially do not disperse around all of Mercer Island, some salmon fry from the Cedar River are known to depend on nearshore habitats along the southern shore of Mercer Island. Later in the spring (May and June), however, juvenile chinook are known to be well distributed throughout both limnetic and littoral areas of Lake Washington, and certainly utilize the shoreline habitats along Mercer Island.

Action Start List Recommendations in support of Priority 5 include: 1) addressing water quality and high flow impacts from creeks and shoreline development through NPDES Phase 1 and Phase 2 permit updates, consistent with Washington Department of Ecology’s 2001 Stormwater Management Manual, including low impact development techniques, on-site stormwater detention for new and redeveloped projects, and control of point sources that discharge directly into the lakes; and 2) Protecting and restoring water quality and other ecological functions in tributaries to reduce effects of urbanization. This involves protecting and restoring forest cover, riparian buffers, wetlands, and creek mouths by revising and enforcing critical areas ordinances and Shoreline Master Programs, incentives, and flexible development tools.

7.6 Priority 6 –Improve Water Quality and Reduce Sediment and Pollutant Delivery

Although most of the City’s watercourses and their basins are located outside of shoreline jurisdiction, their impacts to shoreline areas should not be discounted. Several of these watercourses have the potential to provide fish habitat in their lower sections and wildlife habitat throughout. They are also a common receiving body for non-point source pollution, which in turn delivers those contaminants ultimately to Lake Washington. Mercer Island started a Water Quality Monitoring effort in 2001 with technical assistance from the King County Water and Land Resources Division that analyzes a variety of water quality factors affecting Lake Washington.

Many actions provided in the WRIA 8 Salmon Conservation Plan focus on addressing water quality and stormwater controls, including:

- Implement Phase 2 NPDES permit requirements
• Address stormwater impacts from transportation projects involving new or expanded roadways

• Encourage low impact development through regulations, incentives, education and training, and demonstration projects

• Improve Enforcement of Existing Land Use and Other Regulations

These recommendations emphasize the use of low impact development techniques, on-site stormwater detention for new and redeveloped projects, and control of point sources that discharge directly into surface waters. They involve protecting and restoring vegetative cover, riparian buffers, wetlands, and creek mouths by revising and enforcing critical areas ordinances and Shoreline Master Programs, incentives, and flexible development tools.

7.7 Priority 7 – Improve Riparian Vegetation, Reduce Impervious Coverage

Similar to the priority listed above to improve water quality and reduce sediment and pollutant delivery, improved riparian vegetation and reduction in impervious surfaces are emphasized throughout the WRIA 8 Salmon Conservation Plan. These factors correspond directly to the emphasis to increase use of Low Impact Development techniques. Actions which involve improvements to riparian vegetation and reductions in impervious surface coverage are likely to take place on both public and private development. The City’s Parks and Recreation Department is committed to providing improved shoreline landscapes by incorporating areas of native riparian vegetation. Private development should be encouraged to utilize low impact development techniques such as the planting of native trees and use of porous paving.

7.8 Priority 8 – Reduce Aquatic Non-Native Invasive Weeds

While not specifically listed in the WRIA 8 Salmon Conservation Plan, reduction of aquatic invasive weeds from Lake Washington, particularly Eurasian watermilfoil and white water lily, is of particular concern across many jurisdictions with Lake Washington shoreline. Not only are aquatic weeds a problem for boats and swimmers, but they also tend to reduce dissolved oxygen to lethal levels for fish, hampering foraging opportunities. Long-term control of aquatic non-native invasive plants in Lake Washington will be very difficult to achieve without coordinated inter-jurisdictional collaboration.

7.9 Priority 9 – Acquisition of Shoreline Property for Preservation, Restoration, or Enhancement Purposes

The City should explore opportunities to protect natural areas or other areas with high ecological value or restoration potential via property acquisition. Mechanisms to purchase property would likely include collaboration with other stakeholder groups.
including representatives from local government, businesses and the general public in order to develop a prioritized list of actions. Properties throughout the more developed shoreline areas within the City may be available for acquisition both for preservation but also to act as a showcase for restoration potential.

7.10 Priority 10 – City Zoning, Regulatory, and Planning Policies

City Zoning, Regulatory, and Planning Policies are listed as being of lower priority in this case simply because they have been the subject of a thorough review and have recently been updated accordingly. Notably, the City’s Critical Areas Ordinance was updated (November 2005) consistent with the Best Available Science for critical areas, including those within the shoreline area. However, as noted in the WRIA Implementation Monitoring Report (WRIA 8 2008a), both Shoreline Master Programs and Critical Areas Ordinances are highly linked to the implementation of plan recommendations. For the time being, it is considered more important to capitalize on this Restoration Plan by focusing on implementing projects consistent with the updated SMP policies. Unimplemented or unused policies, by themselves, will not improve habitat. As time goes by, further review and potential updating of these policies may increase in priority. Policy-related items in this category as listed in previous sections include Comprehensive Plan Policies (Section 4.2), Critical Areas Regulations (Section 4.3), and Stormwater Planning (Section 4.4).

The City received its final NPDES Phase II permit in February 2007 from Ecology. The NPDES Phase II permit is required to cover the City’s stormwater discharges into regulated lakes and streams. Under the conditions of the permit, the City must protect and improve water quality through public education and outreach, detection and elimination of illicit non-stormwater discharges (e.g., spills, illegal dumping, wastewater), management and regulation of construction site runoff, management and regulation of runoff from new development and redevelopment, and pollution prevention and maintenance for municipal operations.

The City conducts all of the above at some level already, but significant additional effort may be needed to document activities and to alter or upgrade programs. The City has various programs to control stormwater pollution through maintenance of public facilities, inspection of private facilities, water quality treatment requirements for new development, source control work with businesses and residents, and spill control and response. Monitoring may be required as part of an illicit discharge detection and elimination program, for certain construction sites, or in waterbodies with a Total Maximum Daily Load (TMDL) Plan for particular pollutants. General water quality monitoring concerns include: a) stormwater quality; b) effectiveness of best management practices; and c) effectiveness of the stormwater management program.
8 REFERENCES

Anchor Environmental LLC. 2005. Draft Shoreline Habitat Inventory Memorandum

City of Mercer Island. 2007. City of Mercer Island Capital Improvement Program.


9 LIST OF ACRONYMS AND ABBREVIATIONS

AASF............................ Adopt-A-Stream Foundation

cfs............................. cubic feet per second

CIP............................... Capital Investment Program

GMA............................... Growth Management Act

NGPA............................. Native Growth Protection Area

NGPE............................. Native Growth Protection Easement

OHWM......................... ordinary high water mark

WDFW............................. Washington Department of Fish and Wildlife
APPENDIX A

CITY OF MERCER ISLAND
RESOLUTION 1347
RATIFYING THE WRIA 8 CHINOOK SALMON CONSERVATION PLAN
WHEREAS, in March 1999, the National Oceanic and Atmospheric Administration (NOAA) Fisheries listed the Puget Sound Chinook salmon evolutionary significant unit as a threatened species under the Endangered Species Act (ESA); and

WHEREAS, in November 1999, the United States Fish and Wildlife Service (USFWS) listed the Puget Sound bull trout distinct population segment as a threatened species under the ESA; and

WHEREAS, under the ESA, it is illegal to take a listed species, and the ESA defines the term “take” to include actions that could harm listed species or their habitat; and

WHEREAS, under the ESA, Section 4(f), NOAA Fisheries (for Chinook salmon) and USFWS (for bull trout) are required to develop and implement recovery plans to address the recovery of the species; and

WHEREAS, an essential ingredient for the development and implementation of an effective recovery program is coordination and cooperation among federal, state, and local agencies, tribes, businesses, researchers, non-governmental organizations, landowners, citizens, and other stakeholders as required; and

WHEREAS, Shared Strategy for Puget Sound, a regional non-profit organization, has assumed a lead role in the Puget Sound response to developing a recovery plan for submittal to NOAA Fisheries and the USFWS; and

WHEREAS, local jurisdictions have authority over some habitat-based aspects of Chinook survival through land use and other policies and programs; and the state and tribes, who are the legal co-managers of the fishery resource, are responsible for addressing harvest and hatchery management in WRIA 8; and

WHEREAS, in WRIA 8, habitat actions to significantly increase Chinook productivity trends will be helpful, in conjunction with other recovery efforts, to avoid extinction in the near term and restore WRIA 8 Chinook to viability in the long term; and

WHEREAS, Mercer Island supports cooperation at the WRIA level to set common priorities for actions among partners, efficient use of resources and investments, and distribution of responsibility for actions and expenditures;

WHEREAS, 27 local governments in WRIA 8 jointly funded development of The WRIA 8 Steering Committee Proposed Lake Washington/Cedar/Sammanish Watershed Chinook Resolution No. 1347
Salmon Conservation Plan (the Plan), published February 25, 2005 following public input and review; and

WHEREAS, while the Plan recognizes that salmon recovery is a long-term effort, it focuses on the next 10 years and includes a scientific framework, a start-list of priority actions and comprehensive action lists, an adaptive management approach, and a funding strategy; and

WHEREAS, Mercer Island has consistently implemented habitat restoration and protection projects, and addressed salmon habitat through its land use and public outreach policies and programs over the past five years; and

WHEREAS, it is important to provide jurisdictions, the private sector and the public with certainty and predictability regarding the course of salmon recovery actions that the region will be taking in the Lake Washington/Cedar/Sammamish Watershed, including the Puget Sound nearshore; and

WHEREAS, if insufficient action is taken at the local and regional level, it is possible that the federal government could list Puget Sound Chinook salmon as an endangered species, thereby decreasing local flexibility.

NOW, THEREFORE, BE IT RESOLVED BY THE MERCER ISLAND CITY COUNCIL AS FOLLOWS:

Section A: The Mercer Island City Council hereby ratifies The WRIA 8 Steering Committee Proposed Lake Washington/Cedar/Sammamish Watershed Chinook Salmon Conservation Plan, dated February 25, 2005, a copy of which is on file with the Mercer Island City Clerk (the Plan). Ratification is intended to convey the city’s approval of the Plan.

Section B: Mercer Island recognizes that negotiation of commitments and assurances/conditions with appropriate federal and state agencies will be an iterative process. Full implementation of this Plan is dependent on the following:

1. NOAA Fisheries will adopt the Plan, as an operative element of its ESA Section 4(f) recovery plan for Puget Sound Chinook salmon.

2. NOAA Fisheries and USFWS will:
   a) take no direct enforcement actions against Mercer Island under the ESA for implementation of actions recommended in or consistent with the Plan,
   b) endorse the Plan and its actions, and defend Mercer Island against legal challenges by third parties, and
   c) reduce the regulatory burden for Mercer Island activities recommended in or consistent with the Plan that require an ESA Section 7 consultation.
3. Federal and state governments will:
   a) provide funding and other monetary incentives to support Plan actions and monitoring activities,
   b) streamline permitting for projects implemented primarily to restore salmonid habitat or where the actions are mitigation that further Plan implementation,
   c) offer programmatic permitting for local jurisdiction actions that are consistent with the Plan,
   d) accept the science that is the foundation of the Plan and support the monitoring and evaluation framework,
   e) incorporate actions and guidance from the Plan in future federal and state transportation and infrastructure planning and improvement projects, and
   f) direct mitigation resources toward Plan priorities.

Section C: This resolution does not obligate the Mercer Island City Council to future appropriations beyond current authority set forth in its 2005-2006 biennial budget. All future appropriations are subject to review and approval by the then seated City Council.


Bryan Cairns, Deputy Mayor

ATTEST:

Allison Spietz, City Clerk
APPENDIX B

PROPOSED OUTREACH AND EDUCATION ACTIONS
## Draft Proposed Outreach & Education Actions for the Cedar Population (Tier 1 and 2 Subareas)
(by WRIA 8 Public Outreach Committee)

<table>
<thead>
<tr>
<th>Proj #</th>
<th>Habitat Condition</th>
<th>Desired Outcome</th>
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<tbody>
<tr>
<td>C701</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics; water quality compromised by garden chemicals, metals, sediment.; higher water use at times when flows lowest.</td>
<td>Protect &amp; restore riparian vegetation to provide sources of large woody debris/pools/riffles; protect &amp; restore water quality, maintain instream flows</td>
<td>Shoreline property owners and general public</td>
<td>Update and distribute streamside living materials such as Streamside Savvy, Salmon Friendly Gardening Practices, or Going Native. Distribute to all shoreline property owners and make available at City Hall, libraries, and retail establishments such as home &amp; garden centers.</td>
<td>High</td>
<td>Ongoing or have been distributed in past.</td>
<td>Low-Medium</td>
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<tr>
<td>C702</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics; water quality compromised by landscape practices; higher water use at times when flows lowest.</td>
<td>Protect &amp; restore riparian vegetation to provide sources of large woody debris/pools/riffles; protect &amp; restore water quality, maintain instream flows</td>
<td>Shoreline property owners</td>
<td>Offer shoreline property owners a workshop in streamside living. Include tips on landscape design/maintenance appropriate for riverside properties and shoreline stabilization (alternatives to vertical wall bulkhead design). Feature designers and contractors who have both experience and recognition in salmon friendly design.</td>
<td>High</td>
<td>Seattle Public Utilities and Snohomish County Streamside Stewardship Courses, Issaquah’s Creekside Living workshops</td>
<td>Low</td>
</tr>
<tr>
<td>C703</td>
<td>Smaller parcels lost to development or possible habitat degradation without financial incentives to conserve that are offered to owners of larger parcels</td>
<td>Protect good salmon habitat that could provide source of shelter, pools, riffles, food</td>
<td>Shoreline property owners</td>
<td>Expand use tax credit incentives to encourage protection of smaller properties not currently eligible for existing programs.</td>
<td>High</td>
<td>Public Benefits Rating System, Open Space Current Use Tax (CUT)</td>
<td>Variable (Low budget)</td>
</tr>
<tr>
<td>C704</td>
<td>Channel confinement from bulkheads, levees, and armoring; loss of riparian vegetation</td>
<td>Soften shorelines, restore floodplain connectivity and channel complexity</td>
<td>Shoreline property owners</td>
<td>Reduce permit fees for shoreline stabilization if design is salmon friendly (employing alternatives to dikes, levees, revetments, and vertical wall bulkheads). Also reduce permit fees (where applicable) for streamside restoration and removal &amp; replacement of non-native vegetation.</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
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<td>C705</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics; water quality compromised by garden chemicals, metals, sediment. Higher water use at times when flows lowest.</td>
<td>Protect &amp; restore riparian vegetation; protect &amp; restore water quality, maintain instream flows, stabilize slopes with native riparian vegetation. Increase likelihood of achieving these goals by bringing on board industry with a large influence over the landscapes within watershed.</td>
<td>Landscape Contractors</td>
<td>Offer educational opportunities to landscape designers/contractors on riparian design/naturescaping, local plant sourcing, proper installation techniques, invasive species, efficient watering techniques and use of compost to build healthy soils, control erosion and reduce need for supplemental irrigation. Augment training to accommodate English as Second Language participants.</td>
<td>High</td>
<td>Washington Assoc. of Landscape Professionals (WALP) trainings</td>
<td>Low - Medium (industry supported)</td>
</tr>
<tr>
<td>C706</td>
<td>Reduced forest cover; increased impervious areas/lack of infiltration/ground water recharge</td>
<td>Protect forest cover, reduce impervious surface area, increase infiltration back into soil and ground water recharge, decrease water use.</td>
<td>Design &amp; Building Professionals</td>
<td>Provide education to architects, landscape architects, engineers, and developers on sustainable building/design practices. Work with professional associations to highlight building practices that maintain watershed health. Include Low Impact Development, importance of maintaining canopy cover and limiting impervious surfaces.</td>
<td>High</td>
<td>City of Seattle Business &amp; Industry Venture, King County Green Building, LEEDS, Construction Works and other Solid Waste Division outreach programs</td>
<td>Low – Medium</td>
</tr>
<tr>
<td>C707</td>
<td>Reduced forest cover; increased impervious areas/lack of infiltration/ground water recharge</td>
<td>Control stormwater runoff to more closely mimic natural hydrology, reduce paving and impervious areas, increase infiltration, protect forest cover</td>
<td>Design &amp; Building Professionals</td>
<td>Use recognition as a means to encourage more salmon sustainable designs and construction. In addition to professional association awards, expand recognition to include merit awards celebrated by popular magazines read by a broader sector of the general public. Promote through design competitions and media coverage the use of “rain gardens” and other low impact development practices that mimic natural hydrology. Combine a home/garden tour or “Street of Dreams” type event featuring these landscape</td>
<td>High</td>
<td>AIA, ASLA, Sunset Magazine, and Seattle Times Home and Garden awards, King County EnviroStars</td>
<td>Low – Medium</td>
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<td>C708</td>
<td>Insufficient flow</td>
<td>Maintain instream flows</td>
<td>High-end water users, general public</td>
<td>Extend availability of water conservation incentive programs (such as rebates for efficient toilets, appliances, free indoor conservation kits, or free landscape irrigation audits) to decrease household and commercial water consumption.</td>
<td>High</td>
<td>Smart &amp; Healthy Landscapes, Water Cents</td>
<td>Low</td>
</tr>
<tr>
<td>C709</td>
<td>Water quality compromised by garden chemicals, metals, sediment. Higher water use at times when flows lowest.</td>
<td>Protect water quality from degradation by pesticides and soil erosion, maintain instream flows by reducing water used for irrigation, increase organic content in soils to increase water holding capacity</td>
<td>General public</td>
<td>Target Natural Yardcare Neighborhoods Program to include more communities in the Cedar sub-basin. Expand curricula to offer more landscaping guidelines specific to shoreline residences.</td>
<td>High</td>
<td>Ongoing program</td>
<td>Medium - High</td>
</tr>
<tr>
<td>C710</td>
<td>Water quality degraded by cleaners, oils, grit, and paint; stream flows reduced by excessive water use</td>
<td>Protect and restore water quality and maintain flows</td>
<td>General Public</td>
<td>Coordinate with local business community to encourage the use of commercial car washes. (Water quality and salmon conservation could provide a new marketing angle; car dealerships could offer car wash coupons as bonus with car purchase.). Require that car kits be used for all parking lot fund raiser car washes, or offer carwash coupons or as more eco-friendly alternative funding source.</td>
<td>High</td>
<td>Puget Sound CarWash Association Coupon Program.</td>
<td>Variable - Low</td>
</tr>
<tr>
<td>C711</td>
<td>All conditions listed above Water quality degraded by toxics and garden chemicals; channel confinement; loss of riparian buffer; use of large woody debris, pools, riffles, reduced channel complexity; riparian vegetation displaced by lawn; high water use when flows lowest.</td>
<td>Increase public watershed literacy awareness of effects on water quality and habitat conditions.</td>
<td>General Public, but in particular, residents of Cedar sub-basin who may not be aware of existence of salmon right within urban area</td>
<td>Support and encourage efforts of Cedar River Naturalist Program to promote voluntary stewardship by focusing on education, monitoring, and maintenance of restoration sites (e.g. Cavanaugh Pond). Continue and expand messaging about how everyday personal actions affect salmon, the Cedar River, and entire watershed.</td>
<td>High</td>
<td>Ongoing program with successful track record since 1998</td>
<td>Low-Medium</td>
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<td>C712</td>
<td>Water quality degraded by toxics</td>
<td>Keep toxics out of water by providing safer alternative</td>
<td>General Public</td>
<td>Increase outreach about availability and locations of Hazardous Waste Collection sites and special collection events.</td>
<td>High</td>
<td>King County Local Hazardous Waste Management Program</td>
<td>Low (cheaper than dealing with illegal dumping)</td>
</tr>
<tr>
<td>C713</td>
<td>Water quality degraded by toxics, pesticides, metals, increased nutrient loads, sediments, loss of riparian buffer</td>
<td>Protect and restore water quality</td>
<td>General Public</td>
<td>Publicize emergency call numbers for public to report water quality and quantity problems, non-permitted vegetation clearing, non-permitted in-stream grading, and wood removal incidents.</td>
<td>High</td>
<td>Seattle Public Utilities Surface Water Pollution Prevention Hotline and website</td>
<td>Low</td>
</tr>
<tr>
<td>C714</td>
<td>Riparian vegetation displaced by lawn, invasives, and exotics, providing little food value, no source of LWD, or soil stability (sedimentation of gravel beds). Increased water use when flows lowest; increased use of pesticides on less resistant exotics</td>
<td>Restore native riparian vegetation to provide cover and terrestrial food source, reduce soil erosion and sedimentation in gravel beds, protect and restore water quality, maintain instream flows</td>
<td>Shoreline Property Owners and Community</td>
<td>Increase number of native plant salvages. Integrate these salvage opportunities into naturscaping classes; class participants can take home native plants for immediate use both within and surrounding sensitive areas.</td>
<td>High</td>
<td>King and Snohomish County Native Plant Salvage Programs, WSU Cooperative Extension Native Plant Salvage Project partnership with Puget Sound Action Team, Thurston &amp; Mason Counties.</td>
<td>Low</td>
</tr>
<tr>
<td>C715</td>
<td>Channel confinement and loss of channel complexity from bulkheads, levees, and armoring; loss of riparian vegetation</td>
<td>Reduce channel confinement, restore riparian vegetation, and floodplain connectivity and channel complexity</td>
<td>Shoreline property owners, general Public</td>
<td>Demonstration Project. Locate property owner in publicly accessible (or viewable) area willing to remove bulkhead, levee, or stream bank armoring and replace it with more ecologically friendly design. Publicize efforts through various means. Demonstration project should contain elements that can be done by average shoreline property owner. Provide information on costs and advantages of alternate treatments.</td>
<td>High – Medium-</td>
<td></td>
<td>Variable</td>
</tr>
<tr>
<td>C716</td>
<td>Lack of large woody debris</td>
<td>Overcome public fear and resistance to providing and</td>
<td>Shoreline property owners,</td>
<td>Increase public awareness about the value of large woody debris and native vegetation for flood protection, salmon habitat, and healthy streams. Convey through</td>
<td>High-Medium</td>
<td>Existing King County and US Forest</td>
<td>Low</td>
</tr>
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<td>maintaining woody debris along shorelines and subsequent source of cover, pools, riffles</td>
<td>general public</td>
<td>media (local newspapers, community newsletters); signage along publicly accessible “model” shoreline; and brochures such as King County’s <em>Large Woody Debris and River Safety</em> and US Forest Service <em>Large Woody Material: The Backbone of a Stream</em>. Distribute to all shoreline property owners and to more of general public, especially recreational boaters. Brochures on LWD and boater safety could be made available at appropriate locations such as: the Renton Community Center (where some tubers put in or pull out), the Henry Moses Pool and Water Park, the Renton Public Library (also on the river), and retail locations where inner-tubes, canoes, and kayaks are sold or rented. Where there is right-of-way or permission from private owners, consider installing kid-friendly signage which addresses the potential dangers that LWD can pose to boaters – along with the value it provides to salmon and the health of the river. Where possible, locate signs at popular “put-in” and “take-out” spots along the river.</td>
<td>Service brochures</td>
<td></td>
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<tr>
<td>C717</td>
<td>All conditions listed above.</td>
<td>Reduce channel confinement, restore riparian vegetation, and floodplain connectivity and channel complexity</td>
<td>Shoreline property owners</td>
<td>Explore possibility of adding a disclosure to Real Estate Sales Agreement describing shorelines as sensitive areas, subject to rules and regulations of City and County. Look to model set by King County.</td>
<td>High – Medium</td>
<td>King County Dept. of Development and Environmental Services</td>
<td>Medium</td>
</tr>
<tr>
<td>C718</td>
<td>Water quality compromised by toxics, pesticides, metal fines, and nutrient overloads</td>
<td>Protect and restore water quality.</td>
<td>General Public</td>
<td>Work with auto parts retailers and gas stations to increase potential for collection of used motor oil/transmission fluids. Distribute Water Quality poster series which depicts impacts of everyday practices: washing car, driving car without maintenance, leaving pet wastes unattended, and improperly using lawn chemicals. Promote</td>
<td>High-Medium</td>
<td>Yes, King County Local Hazardous Waste Management <em>EnviroStars</em> program</td>
<td>Medium</td>
</tr>
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<tr>
<td>C719</td>
<td>Channel confinement reduced channel complexity, loss of riparian vegetation</td>
<td>Increase public watershed literacy awareness of effects on water quality and habitat conditions,</td>
<td>Community</td>
<td>Increase citizen involvement in voluntary stewardship programs, focusing on restoration projects to meet the needs of the conservation plan through restoration, education, monitoring and restoration site maintenance</td>
<td>High – Medium</td>
<td>Various: Cedar River Naturalists, Sammamish ReLeaf, Stream Team; Water Tenders</td>
<td>Medium</td>
</tr>
<tr>
<td>C720</td>
<td>Water quality degraded by sediment, diminished ground water recharge, flashiness of floods and resultant bed scour</td>
<td>Protect and restore forest cover, increase infiltration, decrease intensity of flood conditions, protect water quality from sediment</td>
<td>General public</td>
<td>Increase outreach efforts about the benefits of trees and basin-wide forest coverage to protect water quality. Clarify issues about hazard trees. Offer seedlings (perhaps provided by a timber company) to replant after potentially hazardous trees are removed. Enlist the help of nurseries/home &amp; garden centers on this education campaign. (Potential new Fathers’ Day gift idea: Buy and plant a tree each year for a dad who loves salmon).</td>
<td>High in rural areas; Medium in urban/suburban areas.</td>
<td>Yes, Sammamish ReLeaf; Mountains-to-Sound Greenway; City tree ordinances.</td>
<td>Variable - Medium</td>
</tr>
<tr>
<td>C721</td>
<td>All conditions listed.</td>
<td>Protect forest cover, wetlands, headwaters, critical salmon habitat; increase public support for land acquisition and restoration projects, as well as land use policies.</td>
<td>Shoreline property owners, general public</td>
<td>Identify and encourage shoreline neighborhood and community stewardship associations to foster the ethic of voluntary stewardship. Use these groups to build a bridge between property owners, agencies, and locals governments. Promote watershed health through grassroots messaging. Increased potential for media coverage when efforts initiated at community level.</td>
<td>Medium</td>
<td>Friends of Rock Creek Valley, Friends of Cedar River Watershed, Cedar River Council, Lake Forest Park Stewardship Foundation,</td>
<td>Low</td>
</tr>
<tr>
<td>C722</td>
<td>Loss of forest cover, organic content in soils, increase in impervious areas and increased run-off, degraded water quality flashiness during flood conditions.</td>
<td>Protect forest cover, reduce impervious area and runoff, increase infiltration, protect and restore water quality, maintain instream flows</td>
<td>Design/ Build Industry</td>
<td>Create a campaign that tracks demand among community residents for purchasing green homes and remodeling with green building strategies.</td>
<td>Medium</td>
<td>Green Car Program</td>
<td>Low</td>
</tr>
<tr>
<td>C723</td>
<td>Degraded water</td>
<td>Cultivate ethic of</td>
<td>Youth</td>
<td>Link education and community service stewardship</td>
<td>Medium</td>
<td>Environmental</td>
<td>Low</td>
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<tr>
<td>C724</td>
<td>quality, instream flows, habitat quality</td>
<td>environmental stewardship; increase watershed awareness and links between manmade habitat and environmental health.</td>
<td>General public</td>
<td>Encourage neighborhood garden tours of salmon friendly gardens. Help residents visualize alternatives to traditional (and often less eco-friendly) landscape treatments. Offer neighbors assistance with publicity, signage, and volunteer docents. Coordinate with neighborhood garden clubs.</td>
<td>Medium</td>
<td>Portal Seattle, Mercer Slough Interns, N. Shore Utility Tour, Water Tenders.</td>
<td>Low</td>
</tr>
<tr>
<td>C725</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics, providing little food value, source of large woody debris, or soil stability. Water quality compromised by garden chemicals, metals, sediment. Higher water use at times when flows lowest.</td>
<td>Replace lawn and other lower ecological value plantings with riparian buffers and native plants</td>
<td>General public, but in particular Shoreline property owners</td>
<td>Create local informational TV spots that could run on the government cable channels. Focus on those habitat conditions threatening salmon that are affected by our daily personal practices, landscape design and management practices. Showcase good designs to provide models to emulate.</td>
<td>Medium – Low</td>
<td>Salmon Information TV, C-TV,</td>
<td>Variable</td>
</tr>
<tr>
<td>C726</td>
<td>All conditions discussed above.</td>
<td>Increase awareness about effects of habitat on salmon and watershed health; increase support for land acquisition and restoration efforts as well as landuse policies; inspire shoreline property owners to make changes on their own property.</td>
<td>Design &amp; Building Professionals</td>
<td>Use recognition as a means to encourage more salmon sustainable designs and construction. Coordinate with professional association awards in addition to popular magazine merit awards. Continue to recognize businesses that carry out procedures or use products</td>
<td>Medium – Low</td>
<td>American Institute of Architects, American Society of</td>
<td>Low</td>
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<tr>
<td>C727</td>
<td>All conditions discussed above</td>
<td>Increase watershed literacy and understanding of effects of habitat on salmon</td>
<td>Business Community and General Public</td>
<td>Coordinate with businesses along Cedar that can help with outreach goals. For example, Ivar’s Seafoods could promote key messages about salmon conservation on their menus or though game cards. This seafood chain also has other restaurants located within WRIA 8 so it could be cost effective for them to do such a promotion.</td>
<td>Medium</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>C728</td>
<td>Water quality degraded by toxics and metal fines.</td>
<td>Reinforce to students and the community the relationship between what goes down storm drain and watershed health via an affordable and easily implemented program.</td>
<td>General Public</td>
<td>Expand storm-drain stenciling program locally and basin-wide. Track locations and dates in a Cedar Basin database.</td>
<td>Medium</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>C729</td>
<td>Channel confinement, loss of riparian buffer: sources of large woody debris, pools, riffles; reduced channel complexity,</td>
<td>Inspire shoreline property owners to make changes on their own property by providing good examples; increase public support for land acquisition and restoration efforts as well as landuse policies.</td>
<td>Shoreline property owners and general public</td>
<td>Use government cable channels to follow progress of the site specific restoration projects. Use of video to document projects before, during, and after restoration. Distribute resulting programs to libraries, schools, and communities groups.</td>
<td>Low</td>
<td>Salmon Information TV</td>
<td>Variable</td>
</tr>
<tr>
<td>C730</td>
<td>All conditions discussed above.</td>
<td>Improve watershed awareness and</td>
<td>Youth</td>
<td>Focus environmental/science curricula on local watershed issues, with particular emphasis on key</td>
<td>Low-Future</td>
<td>Yes</td>
<td>Medium</td>
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<td>possibly prevent future habitat degradation by instilling a better understanding of interrelationship between habitat, daily actions, and watershed health.</td>
<td>factors limiting the Cedar Chinook population.</td>
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### Draft Proposed Outreach & Education Actions for Lake Washington
**(by WRIA 8 Public Outreach Committee)**

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<tr>
<td>C729</td>
<td>Shoreline hardening, riparian vegetation displaced by lawn, invasives, or exotics with low ecological value, overwater structures creating sharp light contrast, water quality degraded by effects of landscape practices</td>
<td>Increase awareness that the lakeshore is also a nursery for juvenile salmon. It’s possible to make “home improvements” that can benefit both property owner and salmon. [people pets, and planet]</td>
<td>Lakeshore property owners</td>
<td>Promote concept of living with the lake, instead of just on it through public messaging. Foster idea of sharing the shoreline with other species that inhabit the lakeshore. Carry out through workshops, literature, and development of education and marketing campaigns</td>
<td>High</td>
<td>Lakeside Living Workshop Series; King County Lake Stewardship Program</td>
<td>Variable</td>
</tr>
<tr>
<td>C730</td>
<td>Shoreline hardening, riparian vegetation displaced by lawn, invasives, or exotics with low ecological value, overwater structures creating sharp light contrast, water quality degraded by effects of landscape practices</td>
<td>Reduce conditions favored by predator species; protect &amp; restore water quality.</td>
<td>Lakeshore property owners</td>
<td>Offer lakeshore property owners a series of workshops on lakeshore living: natural yard care; reduction of lawn size, shoreline buffer planting design/noxious weed management; alternatives to vertical wall bulkheads; salmon friendly dock design; aquatic weed management; environmentally friendly methods of maintaining boats, docks, decks; porous paving options</td>
<td>High</td>
<td>WRIA 8/KCD Lakeside Living Lakeshore Property Owner Workshops, Seattle Public Utilities and Snohomish County Creek Stewardship Programs, City of Issaquah’s Creekside Living Program, Natural Yard Care Neighborhoods</td>
<td>Medium-High</td>
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<td>C731</td>
<td>Forested parcels threatened by development, (even though difficult to build on); creek mouths degraded or unrecognizable (culverted); riparian vegetation replaced by invasives infested along shoreline</td>
<td>Protect and/or restore forest land, critical areas such as wetlands and shallow water rearing habitat. Promote watershed health through grassroots messaging.</td>
<td>Community, but especially lakeshore property owners.</td>
<td>Identify and encourage shoreline neighborhood and community stewardship associations. Use to foster the ethic of voluntary stewardship, set examples for other neighbors to follow, enlist community support to acquire and restore habitat, and to build a bridge between property owners, agencies, and local governments. Increase potential for media coverage when efforts initiated at community level.</td>
<td>High</td>
<td>Lake Forest Park Stewardship Foundation, Save Lake Sammamish, Denny Creek Neighborhood Association</td>
<td>Low</td>
</tr>
<tr>
<td>C732</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics; water quality compromised by garden chemicals, metals, sediment; elevated water temperatures due to increased water use at times when flows lowest.</td>
<td>Protect and improve rearing and migratory habitat; protect and restore water quality</td>
<td>Lakeshore property owners, general public</td>
<td>Update where necessary salmon-friendly educational materials such as <em>Salmon Friendly Gardening Practices</em>, <em>Going Native</em>, <em>Watershed Waltz and Sammamish Swing</em> booklets. Print and distribute to the following prioritized audiences: 1) lakeshore property owners 2) Public places such as libraries, city halls, community centers and where permitted, at home improvement centers and other major retail establishments.</td>
<td>Medium - High</td>
<td>Yes</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>C733</td>
<td>Riparian vegetation displaced by lawn, invasives, or exotics; water quality compromised by garden chemicals, metals, sediment.; elevated water temperatures due to increased water use at times when flows lowest.</td>
<td>Protect &amp; restore shoreline buffer plantings to provide source of food &amp; shelter; protect &amp; restore water quality, maintain baseflows of feeder streams in order to provide source of cooler water</td>
<td>Lakeshore property owners</td>
<td>Modify more for “lakeshore living” the existing “Streamside Living Welcome Wagon” program in which residents welcome new homeowners to the neighborhood and provide information concerning “salmon friendly” yard care, lakeshore planting tips, water-wise gardening.</td>
<td>Medium</td>
<td>WaterTenders Streamside Living Welcome Wagon</td>
<td>Low-Medium</td>
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<tr>
<td>C734</td>
<td>Solid overwater surfaces that create sharp light contrast and dark shadows,</td>
<td>Reduce severity of predation on juveniles</td>
<td>Lakeshore property owners</td>
<td>Explain about mutual value of mesh docks, smaller piling sizes, and community docks to salmon and property owners: Reduced predation for fish; reduced maintenance for homeowners, opportunity to watch small fish.</td>
<td>High</td>
<td></td>
<td>Medium</td>
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<td>conditions favored by predators.</td>
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<td>fish swimming under the dock, and architectural interest provided by new salmon-friendly elevated dock bridges. Outreach could be carried out, for example, by creating a boat owner education campaign. Mailings could be sent with boat registration tab renewal or with property tax notice for shoreline property owners; by literature at marine, sporting goods and hardware stores, at boat shows; and through workshops to homeowners and marine construction industry. Coordinate outreach through appropriate licensing agencies.</td>
<td></td>
<td>High</td>
<td>low</td>
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<tr>
<td>C735</td>
<td>Sharp light contrast and dark hiding spots created by overwater structures, conditions favored by predators</td>
<td>Reduce severity of predation on juveniles by reducing number of docks.</td>
<td>Lakeshore property owners</td>
<td>Offer financial incentives for community docks in terms of reduced: permit fees, loan fees/percentage rates, taxes and permitting time, in addition to reduced construction costs</td>
<td>High</td>
<td>Pro Bono advertising campaign development – The Coalition for Drug Free America ad campaign. Bert the Salmon ads.</td>
<td>Variable, but low able to get Pro Bono assistance.</td>
</tr>
<tr>
<td>C736</td>
<td>Steep shoreline gradient with coarse aggregate caused by wave action on vertical wall bulkheads</td>
<td>Create sandy, shallow water habitat needed by juveniles.</td>
<td>Lakeshore property owners</td>
<td>Utilize niche marketing to promote a “Build a Beach” campaign. Clarify how hardened shorelines prevent the development of shallow, sandy beaches and how alternative treatments can provide these amenities. Of benefit to salmon and to homeowners desiring more easily accessible shallow beach and aesthetics of a cove. Work with media (including design and lifestyle magazines) and real estate community (articles in real estate sections of papers) as well as construction, and design industry professionals</td>
<td>High</td>
<td>Various Bert the Salmon Ad campaigns</td>
<td></td>
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<tr>
<td>C737</td>
<td>Lack of shelter provided by large and small woody debris due to lack of shoreline vegetation; steep dropoffs from shoreline hardening</td>
<td>Reduce conditions favored by predator species.; increase shoreline buffer vegetation and sources for large and small woody debris.</td>
<td>Lakeshore property owners</td>
<td>Alternative marketing campaign: work with advertising industry and media. Do a play on “Child Haven” promotion. <em>Fry Haven?</em> Contrast picture of a sandy shallow shoreline containing woody debris hiding Chinook juveniles with that of a deep gravelly shoreline with evil looking predator species lurking, gobbling up young Chinook. [A “Chinook need safe places too” idea]. Possibly graphics in style of <em>Finding Nemo.</em> Create a marketing niche with landscape related industries to inform property owners about feeding requirements of out-migrating salmon off their beach. Validate need for native vegetation along the shoreline in</td>
<td>High</td>
<td>Various Bert the Salmon Ad campaigns</td>
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<tr>
<td>C738</td>
<td>Lack of appropriate shoreline vegetation, shoreline hardening by vertical wall bulkheads and rip rap walls; docks that create stark light contrast and hiding spots for predators</td>
<td>Reduce conditions favored by predator species by “softening” shoreline; increase shoreline buffer vegetation and sources for large and small woody debris, replace the many docks with more salmon friendly designs</td>
<td>Lakeshore property owners</td>
<td>Demonstration Project. Locate property owner in publicly accessible (or viewable) area willing to remove bulkhead, or shoreline armoring and replace it with more ecologically friendly design. Similarly, renovate existing dock with more salmon-friendly design. Publicize efforts through various means. Demonstration project should contain elements that can be done by average shoreline property owner. Provide information on costs and advantages of alternate treatments.</td>
<td>Medium – High</td>
<td>Redmond River Walk, Juanita Beach, Classic Nursery, Lark Forest Park Stewardship projects</td>
<td>Medium</td>
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<tr>
<td>C739</td>
<td>Coarse substrate, steep slope, dark hiding spots for predators caused by bulkheads and solid surface docks.</td>
<td>Reduce conditions favored by predator species; increase shoreline buffer vegetation and sources for large and small woody debris</td>
<td>Lakeshore property owners, general public</td>
<td>Document video progress on a range of restoration projects from planning to post-construction. Air on government cable channels, in shoreline property owner classes and for libraries, schools, communities groups.</td>
<td>Medium</td>
<td></td>
<td>Variable</td>
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<tr>
<td>C740</td>
<td>Coarse substrate, steep slope, dark hiding spots for</td>
<td>Overcome resistance of shoreline property</td>
<td>Lakeshore property owners,</td>
<td>Combine recreation and education. Organize a Bulkhead Alternatives and Salmon Friendly Dock Design tour to see good examples of design on a residential scale.</td>
<td>Low</td>
<td>King County and People for Puget Sound</td>
<td>Variable</td>
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<td>predators caused by bulkheads and solid surface docks.</td>
<td>owners to make such drastic changes to their shorelines by offering local examples of alternative treatments. Ultimate goal is to reduce conditions favored by predator species.</td>
<td>general public</td>
<td>Organize as boat tour so properties can be viewed from water (less invasive to property owner). Alternatively, create a self-guided water tour (most shoreline property owners have their own boats) with GPS coordinates to help locate example property.</td>
<td></td>
<td>shoreline homeowner workshops (pilot programs)</td>
<td></td>
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<tr>
<td>C741</td>
<td>Shoreline hardening, riparian vegetation displaced by lawn, invasives, or exotics with low ecological value, overwater structures creating sharp light contrast, water quality degraded by effects of landscape practices</td>
<td>Protect and improve water quality; habitat quality - or - Protect &amp; restore riparian vegetation to provide terrestrial food source and shelter; protect &amp; restore water quality, maintain instream flows upstream to provide source of cooler water</td>
<td>Landscape Contractors</td>
<td>Offer professional workshops to landscape designers &amp; contractors on environmentally-friendly lakeshore landscaping. Include topics such as shoreline buffer function and design, native plant selection, installation techniques, use of compost to build healthy soils, and noxious weed control. Determine need for training for non-English speaking participants</td>
<td>Medium – High</td>
<td>Washington Assoc of Landscape Professionals (WALP) Trainings by King County Local Hazardous Waste Management Program</td>
<td>Low</td>
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<tr>
<td>C742</td>
<td>Riparian vegetation displaced by lawn. Water quality compromised by garden chemicals, metals, sediment.</td>
<td>Increase shoreline planting; reduce lawn size to at least have buffer between lawn and shore.</td>
<td>Lakeshore property owners</td>
<td>Work with landscape, design, and real estate industries to sell benefit of “privacy” to homeowners. With restoration of shoreline buffer planting homeowners can increase privacy without sacrificing views. Promote idea of “framed views” as a more sophisticated landscape aesthetic.</td>
<td>Medium - High</td>
<td>1998 Lake Sammamish Shoreline Prop owners workshop Pilot Program</td>
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<tr>
<td>C743</td>
<td>Lack of shoreline buffer vegetation, increased water use when levels lowest;</td>
<td>Increase native vegetation and source of shelter and food for fish;</td>
<td>Lakeshore property owners, Community</td>
<td>Increase number of native plant salvages where landowners can take plants back to their yards. Publicize opportunity to drop off unwanted native plants at various parks surrounding the lake.</td>
<td>Low – Lake Washington</td>
<td>King County Native Plant Salvage Program</td>
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<tr>
<td>C744</td>
<td>Lack of appropriate shoreline vegetation</td>
<td>Increase shoreline vegetation and reduce non-native vegetation &amp; spread of invasives</td>
<td>Lakeshore property owners</td>
<td>Reduce permit fees (where applicable) for shoreline restoration, removal &amp; replacement of non-native vegetation</td>
<td>Medium</td>
<td>Low-Med Sammamish</td>
<td>Low</td>
</tr>
<tr>
<td>C745</td>
<td>Water quality degraded by toxics, pesticides, increased nutrient loads, sediment from construction sites; loss of riparian vegetation</td>
<td>Protect and improve water quality</td>
<td>General Public</td>
<td>Publicize emergency call numbers for public to report water quality problems, water diversion from lake for irrigation, non-permitted vegetation clearing, or tree overspray (pesticide) related incidents.</td>
<td>High</td>
<td>King County Water &amp; Land Division, Seattle Public Utilities Hotlines</td>
<td>Low</td>
</tr>
<tr>
<td>C746</td>
<td>Reduced forest and canopy cover; increased impervious areas, decreased infiltration; more flashiness of floods due to intensity of runoff</td>
<td>Protect and improve water quality; reduce quantity of water entering lake: during flood conditions can mix with sanitary sewer flows and enter lake.</td>
<td>General public, but property owners in particular</td>
<td>Increase outreach concerning the benefits of trees and basin-wide forest coverage to protect water quality. Include such actions as significant tree ordinance and information that links canopy cover to storm water issues. Provide clarification on hazardous tree issues. Offer seedlings to replant after hazard trees are removed. Coordinate with commercial nurseries to expand outreach about benefits of trees to salmon.</td>
<td>Medium-High</td>
<td>Sammamish ReLeaf; Mountains-to-Sound Greenway; City tree ordinances, King County Forestry Program</td>
<td>Low</td>
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<tr>
<td>C747</td>
<td>Elevated lake temperatures, lack of cool water sources from feeder streams, insufficient flows in feeder streams to provide source of cooler water, lack of ground water recharge, water</td>
<td>Protect forest cover, reduce paving and impervious areas, increase infiltration and conditions that mimic natural hydrology, protect water quality</td>
<td>Design, engineering, and construction industries</td>
<td>Provide education to architects, landscape architects, engineers, and developers on sustainable building/design practices. Work with professional associations to highlight building practices that maintain watershed health, importance of maintaining canopy cover and limiting impervious surfaces. Provide incentives to builders that demonstrate a use ecologically sensitive designs and/or techniques. Provide professional workshop and tours focusing on</td>
<td>Medium-High</td>
<td>WALP Trainings by King County Local Hazardous Waste Management Program. Stoneway</td>
<td>Variable</td>
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<td>quality, habitat quality</td>
<td>Protect and improve water quality and quantity to more closely mimic natural hydrology</td>
<td>Developers, Architects, Engineers Building Professionals</td>
<td>Use recognition as a means to encourage more salmon sustainable designs and construction. Coordinate with professional association awards, in addition to popular magazine merit awards. Continue to recognize businesses that carry out procedures or use products that protect watershed health. Promote through design competitions and media coverage the use of “rain gardens” and other low impact development practices that mimic natural hydrology. Combine a home &amp; garden tour or “Street of Dreams” type event featuring these landscape and engineering treatments.</td>
<td>Medium</td>
<td>Concrete Council for Sustainable Development outreach on pervious pavement. Port Blakely Communities, Issaquah partnerships, Built Green, Sustainable Seattle, LEEDS</td>
<td>Low</td>
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<tr>
<td>C748</td>
<td>Reduced forest cover, increased impervious area, decreased infiltration and ground water recharge, water quality degraded by runoff</td>
<td>Protect and improve water quality and quantity to more closely mimic natural hydrology</td>
<td>Developers, Architects, Engineers Building Professionals</td>
<td>Use recognition as a means to encourage more salmon sustainable designs and construction. Coordinate with professional association awards, in addition to popular magazine merit awards. Continue to recognize businesses that carry out procedures or use products that protect watershed health. Promote through design competitions and media coverage the use of “rain gardens” and other low impact development practices that mimic natural hydrology. Combine a home &amp; garden tour or “Street of Dreams” type event featuring these landscape and engineering treatments.</td>
<td>Medium</td>
<td>AIA, ASLA, Sunset Magazine, and Seattle Times Home and Garden awards, King County Enviro Stars.</td>
<td>Low</td>
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<tr>
<td>C749</td>
<td>Water quality degraded by metals, toxins, pesticides, and nutrient overloads</td>
<td>Protect and improve water quality</td>
<td>General Public</td>
<td>Create a program that addresses impact of car maintenance and offers alternatives that help protect watershed health and water quality. More actively distribute – poster series developed by multi-jurisdictional Water Quality Consortium. Series depict water quality implications of everyday activities such as car washing, ignoring car maintenance, pet wastes. Work with auto parts retailers and gas stations to increase potential for collection of used motor oil/transmission fluids.</td>
<td>Medium</td>
<td>King County Local Hazardous Waste Mgmt Program Water Quality Consortium, Businesses for Clean Water</td>
<td>variable</td>
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<td>C750</td>
<td>Water Quality degraded by toxics and metal fines</td>
<td>Protect and restore water quality</td>
<td>General Public</td>
<td>Make outreach materials available to non-English speakers.</td>
<td>Medium</td>
<td>Commute Trip Reduction Programs</td>
<td>Low - Medium</td>
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<tr>
<td>C751</td>
<td>Water Quality degraded by toxics and metal fines degraded by metals and toxins</td>
<td>Protect and restore water quality</td>
<td>General Public, schools/non-profits and Charity groups – and business that offer to host a carwash.</td>
<td>Coordinate with local business community to encourage the use of commercial car washes over washing at home on street or in parking lots. Encourage alternatives to charity cash washes via commercial car wash coupon books or extend car wash kits throughout entire watershed. Make requirement that all charity car washes use coupons or car wash storm drain kit. Distribute “alternative community fundraising idea” brochure to volunteer fundraisers.</td>
<td>Medium - High</td>
<td>Yes, various cities’ car wash kit programs. Puget Sound Carwash Association</td>
<td>Low</td>
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<tr>
<td>C752</td>
<td>Water quality degraded by metals and toxins</td>
<td>Protect and restore water quality</td>
<td>Businesses, property management companies, homeowners associations.</td>
<td>Educate and support retail business and homeowner associations on stormwater best management practices specifically related to parking lot cleaning, storm drain maintenance, and boat cleaning.</td>
<td>Medium</td>
<td>Ongoing programs by various jurisdictions within WIRA, e.g. Issaquah, Redmond</td>
<td>Low</td>
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<td>C753</td>
<td>Reduced baseflows from streams that feed into lake and subsequent elevated water temperatures in lake</td>
<td>Protect and restore sources of cool water</td>
<td>High end water users and general public</td>
<td>Extend availability of water conservation incentive programs such as rebates for efficient toilets, appliances, soaker hoses, free indoor conservation kits, or free landscape irrigation audits to decrease household and commercial water consumption.</td>
<td>High</td>
<td>Smart &amp; Healthy Landscapes, Water Cents, and other utility incentive programs</td>
<td>Low</td>
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<td>Docks</td>
<td>Setbacks and Vegetation</td>
<td>Bulkheads</td>
<td>Science</td>
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<td>1. Open grated decking is a safety issue. - Staff response: The Commission was presented with a commonly used gated decking material and manufacturer’s product data sheet on 7/1/09. The subject material is marketed as “barefoot friendly” and ADA compliant. One person testifying they have grating decking and is safer as it doesn’t grow moss, thus, is not as slick in wet weather, and does not splinter.</td>
<td>1. Setbacks and vegetation standards are inadequate. – Staff response: WAC 173-26 does not provide prescriptive vegetation or setback standards. Mercer Island’s shoreline is largely developed with single-family residences, many of which contain lawns abutting the shoreline. (Lawn areas provide little ecological function.) Over time, the proposed vegetation standards should help to meet the “No Net Loss” standard.</td>
<td>1. Concern that repair of existing bulkheads will not be permitted. – Staff response: The draft SMP states that trees and shrubs are “encouraged”, not mandatory.</td>
<td>1. There is a contradiction in information regarding lake shading; deck shading versus vegetation shading - Staff response: The Commission has reviewed the effect of dock shading on salmon. On 8/5/09, the Department of Ecology (DOE) presented information to the Commission that demonstrated how sharp contrast in light created by docks affects salmon eye physiology, which may create confusion, making the salmon more susceptible to being preyed on. Vegetation shading was discussed as filtered shading that would not have the same effect on the salmon eye physiology. Vegetation was also discussed as important for lake input, which is beneficial for salmon as a food source. Docks were presented as providing resource for bass, which are salmon predators.</td>
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<td>2. Cost of grating decking is expensive. – Staff response: The Commission reviewed a cost analysis on 7/15/09. Material cost for a grated decking is approximately $6.75 per sq. ft.; material cost for wood decking is approximately $2.79 per sq. ft. The typical cost to convert from wood to grated material is approximately $40.00 per sq. ft. for labor and materials, according to one local shoreline contractor.</td>
<td>2. Concern that trees are required as part of vegetation plan – Staff response: The draft SMP states that trees and shrubs are “encouraged”, not mandatory. 3. 50 feet moorage facility setback from properties designated as “Urban Park” is too much. It should be consistent with residential setbacks, which is 10 feet. – Staff response: The Commission reviewed this concern on 3/17/10 and concluded that this provision would provide appropriate separation for park uses, which have the potential to be higher in depth.</td>
<td>2. Opposing science has not been presented. – Staff response: Dr. Gill Pauley agreed to provide addition to Planning Commission for review. The Commission has reviewed related science throughout the process, along with presentations by the City’s science consultant, the</td>
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commonly sees applicants using “stilts” to support a boatlift, or the attachment of a boatlift to a dock. It is uncommon to see boatlifts approved by the Army Corp of Engineers (ACOE) within 30 feet of the shoreline.

4. 100 feet maximum length may not be long enough. – Staff response: The draft SMP allows for up to a maximum length of 150 feet where water is less than 10 feet deep (mean low water)

5. Proposed covered moorage triangle would create non-conformity. – Staff response: The Commission reviewed this concern on 3/17/10 and concluded that the proposed moorage triangle would help to address the intent of having a moorage triangle (lake views). Any non-conforming docks would be allowed to continue normal repair and maintenance.

6. Mooring piles are not considered part of the adjacent moorage structure, and if non-conforming for setbacks, would not be allowed to be replaced. – Staff response. By definition, a moorage pile is considered a moorage facility and would have the same setback requirements as a dock. If non-conforming, the repair would need to fall under the draft definition of normal intensity.

Department of Ecology, and the Washington State Department of Fish and Wildlife (WDFW). The White Papers referenced by WDFW at the hearing are listed in the Washington State Office of Community Development’s Recommended Sources of Best Available Science.
repair and maintenance. The 5/5/10 version of the draft SMP allows for normal maintenance and repair of such features. The Commission reviewed this concern on 3/17/10.

7. Dock standard should not be the same as the Army Corps of Engineers (ACOE) RGP-3. – Staff response. The draft SMP does not follow the ACOE RGP-3, including larger dock sizes being allowed under the Draft SMP.

8. 1,000 sq. ft. dock maximum is too large. – Staff response: The average dock size on Mercer Island is 828 sq. ft. The Commission has reviewed a dock analysis, which demonstrates that “No Net Loss” can be achieved with the draft dock dimensional standards. Applicants must still comply with ACOE and other agency size requirements.

9. Concern regarding the draft thresholds for when a dock has to come into conformance with regulations (40% replacement of dock pilings/50% replacement of dock decking). – Staff response: The 5/5/10 draft does not contain the above thresholds. (These thresholds were included in previous drafts.) Planning Commission discussed the option at the 3/17/10 meeting.
<table>
<thead>
<tr>
<th>Luther Burbank Park</th>
<th>Public Access</th>
<th>Critical Areas</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Concern regarding the commercialization of Luther Burbank Park or allowing private membership clubs to operate within the park. – Staff response: The Planning Commission has reviewed the Luther Burbank Master Plan, acknowledging it in the draft SMP.</td>
<td>1. Concern that Subdivisions of more than four lots require public access. – Staff response: Public access does not necessarily have to be provided on-site; WAC 173-26-221(4)(d)(iii) provides for alternatives to on-site access.</td>
<td>1. Buffers from Critical Areas are inadequate. – Staff response: In 2004, after a lengthy process and analysis of existing conditions, a Critical Areas Ordinance was adopted by the City Council. This process utilized “Best Available Science” to arrive at the critical area buffers in place today.</td>
<td>1. There should be a citizen commission or sub-commission to review the regulations. – Staff response: The Planning Commission is comprised of volunteer Mercer Island citizens and is soliciting input throughout the process.</td>
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<td></td>
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<td></td>
<td>2. Regulations are beginning to take over the exemptions provided in WAC 173-27, with regard to subdivisions. – Staff response: Subdivision is not included in the definition of “development”, per WAC 173-27-030(6), and therefore this does not apply. No changes to exemptions to Shoreline Substantial Development are proposed. The draft is consistent with WAC 173-27 for development exempt from the Shoreline Substantial Development process.</td>
</tr>
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<td></td>
<td>3. The City of Mercer Island passed resolution 1347, Ratifying the WRIA 8 Chinook Salmon Conservation Plan. – Staff response: Resolution 1347 was adopted by the City Council on September 6, 2005. No proposed changes in to the SMP conflict with the Conservation Plan.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Concern there is a conflict of</td>
</tr>
</tbody>
</table>
interest with regard to the City’s consultant team, as they may benefit from strict regulations that call for extensive design and mitigation development. – Staff response: The City’s consultant does not have a conflict of interest. Any design or mitigation work is not required to be performed by the City’s consultant. Property owners may choose their own qualified professional to complete any required work. The City’s consultant has provided analysis of existing conditions, acted as a science information resource, and has contributed to the required Cumulative Impacts Analysis, and Restoration Plan.

5. The presence of wildlife has increase over time. – Staff response: This is a personal observation. The increase of wildlife may be contributed to regulations developed to protect wildlife, especially those on the endangered list.

6. Project value threshold that would require a Shoreline Substantial Development permit is too low. – Staff response: This threshold is established by the
| | | **Washington State Office of Financial Management per WAC 173-24-040(2)(a); the City does not have the authority to modify the threshold.** |

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March 30, 2010

Travis Saunders
City of Mercer Island
9611 SE 36th Street
Mercer Island, WA 98040

Dear Travis Saunders;

Thank you for your continued and diligent work on the City’s SMP Update products. It is appreciated and respected. In order to successfully assist the City through the final step of having an approved and updated SMP, Ecology shares the following concerns with the present draft SMP.

**Setbacks and Vegetated Buffers**

Ecology has concerns that the existing language prescribing vegetated buffers could result in only 25% of the total area adjacent to OHWM being vegetated. As the City’s SMP appropriately states, “Shorelands directly impact water quality as surface and subsurface waters are filtered back into the lake.” Ecology recommends that the code language clarify that the vegetated cover should not be limited to one small area or corner of a lot; rather, it is intended to be extended across the face of the lot adjacent to OHWM. With this clarification, the buffer could provide the expected functional water quality benefits. This could be worded, something like: “the vegetated portion of the setback shall average 20 feet in depth from OHWM and across 75% of the entire lot adjacent to Lake Washington, up to a maximum of 60 feet across the shoreline. The first 5 feet, landward from OHWM, of that area will consist of native vegetation.” The 75% allows for a pathway (25%) to the water and the optional limit of 60 feet across the shoreline provides a limit for shoreline landowners with lots wider than 60 feet.

**Dock Specifications**

Ecology also has concerns with the dock requirements of the proposed SMP. Although Ecology appreciates the continued work on the SMP, remember that the locally adopted SMP must illustrate no net loss in order for Ecology to approve this program. A fundamental requirement of the SMP guidelines is the concept of Mitigation Sequencing (Avoidance, Minimization, and Mitigation). Impacts from existing docks cannot be avoided; but they can be minimized by the grating requirement. This inclusion of grated decking for “repair” and “replacement” is an important piece of the City achieving no net loss. Although it is true that the City can contribute to its achievement of no net loss with the addition of grating to existing docks that do not have grating, it does not necessarily hold true that expanding the
size of new single family docks to 1000 square feet can achieve no net loss with only the addition of
grating. Based on a formal biological opinion on jeopardy of endangered species, the ACOE requires that
new piers on Lake Washington include fully grated decking with at least 60% open area. The ACOE also
limits the overwater coverage to 480 square feet for single-family docks. Basically, Ecology accepts the
ACOE standards for residential piers and docks in Lake Washington. If the City wants more flexibility to
expand acceptable dock sizes, minimizing and mitigating the multiple impacts of larger docks needs to
also be included. For example, the additional inclusion of denser and larger vegetated buffers and the
addition of overhanging trees could help assure against no net loss of ecological function. As an
example, I have enclosed a piece from Kirkland’s cumulative impacts analysis displaying their effort to
identify potential impacts of new docks and then reference the City’s proposed regulations that address
those impacts in the updated SMP.

The one-to-one trade-off for grated areas on “new” docks to reduce “effective” “new” dock area is not a
straight-across equivalency. New piers are required by the ACOE to be fully grated, as well as a suite of
other conditions listed on the attached ACOE Table 3 of the Regional General Permit standards for Lake
Washington. These standards are intended to avoid the multiple impacts of new docks to species, water
quality and navigation interests. The City is also required to have multiple conditions in place to begin to
assure no net loss of ecological function with the addition of “new” and larger sized docks. Basically, the
outright allowance of 1000 square foot docks is inconsistent with both avoidance and minimization of
impacts and the recent standards set by neighboring jurisdictions on Lake Washington.

If you have any questions regarding the subjects in this letter or would like a presentation or meeting on
any topic in this letter, please feel free to contact me at 425-649-4309. Ecology’s role is to provide
support, direction and input on the draft SMP, with the overall objective to have an approved SMP
update that adequately reflects local conditions and protects against any overall net loss of ecological
functions.

Sincerely,

Barbara Nightingale
Regional Shoreline Planner
3190 160th Avenue SE
Bellevue, WA 98008

BN:cja

Enc

Cc: Geoff Tallent, SEA Section Manager
Example of achieving “No Net Loss” through dock specifications in the recently adopted City of Kirkland SMP

New docks have multiple impacts. These include impacts to: aquatic vegetation, juvenile salmon, sediment movement, chemical contamination and external lighting impacts. All of these impacts need to be addressed and avoided, minimized or mitigated. The following is an example, based on the City of Kirkland’s Cumulative Impacts Analysis, on how these additional impacts of piers and docks can be avoided, minimized and mitigated by regulations in the City’s SMP and how it can be demonstrated in the Cumulative Impacts Analysis Report.

The proposed regulations have specifically been crafted to avoid and minimize the following specific potential impacts as outlined below:

1. **Growth of aquatic vegetation**: Overwater cover is minimized through size and height; restrictions for new piers (SMP 83.270(4) and 83.280(5)), restricting size of replacement structures (SMP 83.270(5) and 83.280(8)) and requiring grated decking (SMP 83.270 and SMP 83.270).
2. **Juvenile salmon migration**: Impacts to juvenile salmon migration are mitigated via the same provisions listed under #1 above. Additionally new piers must be mitigated through the addition of shoreline vegetation (SMP 83.270(4)(g) and SMP 83.280(7)).
3. **Sediment movement**: Piles and floats are restricted in the nearshore area (SMP 83.270(4) and SMP 83.280(5)). The use of jetties or groins are prohibited in most environments except they are allowed only with a Conditional Use Permit (SMP 83.170).
4. **Chemical contamination**: Piers and other structures shall be constructed of materials that will not adversely affect water quality (SMP 83.270(5) and SMP 83.280(5)).
5. **External lighting impacts**: Placement and direction of external lighting is restricted to minimize impacts (SMP 83.470).
<table>
<thead>
<tr>
<th>General Approach</th>
<th>The Army Corp regulates total area of the pier as well as width, length, configuration of the main pier and any attached floats, ramps, and ells.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where Allowed</td>
<td>No structure can be installed within 100 feet of the mouth of a river, stream or creek.</td>
</tr>
<tr>
<td>General Configuration</td>
<td>Only piers and ramps are allowed within the first 30 feet from shore. All floats and ells must be 30 feet waterward of OHW. No skirting is allowed on any structure.</td>
</tr>
<tr>
<td>Overall Size</td>
<td>Total Allowed Surface Coverage (includes all floats, ramps, and ells) is as follows:</td>
</tr>
<tr>
<td></td>
<td>• Single property owner: 480 sq. ft.</td>
</tr>
<tr>
<td></td>
<td>• Two property owners (residential): 700 sq ft.</td>
</tr>
<tr>
<td></td>
<td>• Three or more residential property owners: 1000 sq. ft.</td>
</tr>
<tr>
<td>Length</td>
<td>There are no direct regulations of length except through maximum area requirements.</td>
</tr>
<tr>
<td></td>
<td>Any proposed pier that extends further waterward than adjacent piers is reviewed on a case-by-case basis. Piers determined to have an adverse effect on navigation will not be authorized.</td>
</tr>
<tr>
<td>Width</td>
<td>Piers can not exceed a width of 4 feet.</td>
</tr>
<tr>
<td>Height</td>
<td>The bottom of all structures except floats must be at least 1.5 feet above OHW.</td>
</tr>
<tr>
<td>Extensions, Floats,  Ells and Ramps</td>
<td>As mentioned previously, all floats and ells must be 30 feet waterward of OHW. No skirting is allowed on any structure.</td>
</tr>
<tr>
<td></td>
<td>Floats must be in water with depths of 10 feet or more at the landward end of the float. They may be up to 6’ wide by 20’ long and must contain a minimum of 2 feet of grating down the center.</td>
</tr>
<tr>
<td></td>
<td>Ells must be in water with depths of 9 feet or greater at the landward end of the ell and may be built in the following manners: (Currently problematic as some docks are limited to 8 foot depth under current Seattle regs.)</td>
</tr>
<tr>
<td></td>
<td>a) Up to 6’ wide by 20’ long with a 2-foot strip of grating down the center.</td>
</tr>
<tr>
<td></td>
<td>b) Up to 6’ wide by 26’ long with grating providing 60% open area over the entire ell.</td>
</tr>
<tr>
<td></td>
<td>c) One 2’ wide by 20’ long, fully grated finger ell is allowed.</td>
</tr>
<tr>
<td>Pier Grating</td>
<td>Piers must be fully grated with at least 60% open area.</td>
</tr>
</tbody>
</table>
## Table 3. Army Corps of Engineers Regional General Permit (RGP) 3 Regulations for residential piers

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>Other grating rules are outline in Extension, Floats, Ells and Ramps above.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing habitat features such as woody debris or substrate material can not be removed.</td>
</tr>
<tr>
<td></td>
<td>Plantings for 10 feet on either side of OHW are required for entire length of property if site is appropriate. If pier is shared, all co-owners must execute plantings.</td>
</tr>
<tr>
<td></td>
<td>* No chemical fertilizers, herbicides and pesticides can be used in the planting area.</td>
</tr>
<tr>
<td></td>
<td>* A 6 foot path without vegetation is allowed for access to the pier.</td>
</tr>
<tr>
<td></td>
<td>* A minimum of 2 trees and 3 willow plants is required; otherwise there appears to be a lot of flexibility in the planting plan.</td>
</tr>
<tr>
<td></td>
<td>* The plantings must be maintained for the life of pier with a 100% survival rate required in first and second year and a 100% survival rate for tree and an 80% survival rate for remaining plants in years 3-5.</td>
</tr>
<tr>
<td></td>
<td>* Monitoring reports for planting due annually for 5 years</td>
</tr>
<tr>
<td></td>
<td>Status reports on impact reduction construction must be submitted 12 months after permit is issued. They are due annually until the Corp accepts as-build drawings.</td>
</tr>
<tr>
<td></td>
<td>Construction must abide by work windows for bald eagles and listed fish species.</td>
</tr>
<tr>
<td></td>
<td>Work disturbing soil in substrate, bank or riparian area must occur in the dry whenever practical.</td>
</tr>
<tr>
<td></td>
<td>Equipment should be operated out of water whenever possible, should minimize disturbance of soils and should be maintained in clean condition. Proper sediment control must also be used.</td>
</tr>
<tr>
<td></td>
<td>Disturbance of bank vegetation should be limited. When disturbed, it must be replaced with native vegetation.</td>
</tr>
<tr>
<td></td>
<td>Structures within 100 feet of a wetland must avoid impacts to the wetland to the maximum extent possible.</td>
</tr>
</tbody>
</table>

| Existing Piers | Existing structures within 30 feet of OHW may need to be removed to receive a permit unless they facilitate water access. |

| Other | Regulations regarding spacing of pilings, treatment of materials, mooring piles and maintenance are also detailed. |
Travis Saunders

From: Nightingale, Barbara (ECY) [bnig461@ECY.WA.GOV]
Sent: Wednesday, May 12, 2010 9:51 AM
To: Travis Saunders
Cc: Tallent, Geoff (ECY)
Subject: Draft SMP Dock and Buffer Provisions

Travis,

At this point in the process, without a complete package to review, I can only restate two general areas of concern with the present draft SMP. These are:

1) The draft SMP includes SFR dock standards, more than twice as large as those standards set by the ACOE. The ACOE standards are intended to functionally achieve no-net-loss. This difference needs to be addressed with incentives or mitigation to avoid a net loss of ecological function, which the guidelines require.

2) Lack of clarity on shoreline vegetation management and buffer standards in the present draft language does not clearly state intended vegetation extent. This lack of clarity can leave the intent open to gross misinterpretation.

Ecology looks forward to getting a full package to comment more extensively upon.

Barbara Nightingale

Regional Shoreline Planner

425-649-4309

Shorelands and Environmental Assistance

Department of Ecology
April 21, 2010

Dear Mr. Saunders and Mercer Island Planning Commissioners,

My name is David Douglas, formerly a Permit Coordinator with Waterfront Construction. I now represent Integrity Shoreline Permitting and believe my position also supports the concerns of your waterfront property owners and the marine permitting and construction industry as a whole.

I have continued to monitor the progress of the Mercer Island Shoreline Master Program Update and would like to offer the following comments aimed at making the future SMP more reasonable and less burdensome for property owners. My recommendations are based on vast experience in permitting projects on Lake Washington and Mercer Island in particular.

I have previously provided the City with recommendations and valid and practical support opposing several changes to areas of the proposed SMP draft including; boatlift and personal watercraft lift definitions, 50 foot setback from street ends Urban Parks), moorage cover triangle, square footage of docks, mooring piles, handrail and side rail heights, nonconforming structure thresholds, and shoreline stabilization.

While the Planning Commission has implemented some suggested changes for which I am grateful, I have never received any feedback or reasoning for why other recommendations were not made.

Previous and current issues that should be discussed and explanation given include:

- Nonconforming structures being required to be brought into conformity if:
  - 40% of existing piles are replaced.
    - Replacing piles is actually less impacting to the environment in the long-term because they are smaller diameter and untreated
    - Total pier replacement is a common method of repair for this type of development and is supported in the WAC as being exempt from the Substantial Development Permit (SDP) process.

  Has the Commission devoted the time necessary to adequately debate the practicality of and reasoning for this regulation and its future impacts on property owners?

  Can better reasoning than that in DSG Policy Memorandum Administrative Interpretation #05-02 dated May 12, 2005 be provided? Other jurisdictions tend to align their nonconforming structure policies with the WAC and allow total replacement as long as there is no increase in nonconformity.

  Staff Response: There are no regulations for nonconforming piers in the existing SMP. Administrative Interpretation #05-02 was issued to address when non-conforming piers lose their non-conforming status, since piers are not discussed in MICC 19.01.050 – Non Conforming Structures, Sites, Lots, and Uses, which primarily discusses nonconforming structures such as houses. The 40% figure in Administrative Interpretation #05-02 was derived from the provision in MICC 19.01.050 that sets the threshold at 40% for alteration of an accessory structure’s perimeter or length. (After considering that the application of a length or perimeter standard to piers would not serve the intent of MICC 19.01.050, Administrative Interpretation #05-02 sets the threshold for piers at 40% replacement of the pilings.)
Under the current draft SMP, due to the change in the definition of “normal repair and maintenance,” Administrative Interpretation #05-02 would no longer apply. Total replacement of a nonconforming pier would be allowed, without a threshold, if the applicant can demonstrate that (1) such replacement is the common method of repair for the type of pier, (2) the replacement pier is comparable to the original structure, and (3) the replacement does not cause substantial adverse effects to shoreline resources or environment. This definition should adequately protect the ecological shoreline resources from a no net loss perspective; however, it could have the effect of allowing non-conforming piers to continue in perpetuity without being brought into compliance with other zoning requirements such as the moorage cover triangle and urban park setbacks.

WAC 173-26-191(2)(a)(iii)(A) states that provisions should be included to address nonconformities. Other jurisdictions address when nonconforming piers lose their legal status in their draft SMPs. A common method is to apply a monetary threshold comparing the cost of construction to the appraised value of the structure. MICC 19.01.050(D)(3)(b) provides an example of this method. That section allows for the alteration of certain legally non-conforming structures so long as the alterations do not cost more than 50% of the structure’s appraised value and do not increase the structure’s non-conformity.

Staff recommends clarifying its intent in the SMP with regard to when legally non-conforming uses will be required to be brought into conformance with the current zoning regulations. The Commission could choose to uphold Administrative Interpretation #05-02 and set the threshold for bringing piers into conformity at replacement of 40% of the pilings, or modify the piling replacement threshold to a larger or smaller number. The Commission could continue on its current track to allow for total replacement of nonconforming piers without loss of nonconforming status by adding a clarification that the definition of repair and maintenance in 19.07.110(A)(7) shall be used in applying MICC 19.01.050(B); however, Alternatively, the Commission could prescribe a monetary value threshold, such as 50% of the assessed value.

Another approach to addressing non-conformities is to require only certain non-conformities to be brought into compliance when a specified level of repair, maintenance, or alterations are made to piers. For example, the City could require grated decking to be installed when decking is repaired or replaced, but not require the entire pier to be brought into compliance with other zoning regulations – such as setbacks – for the specified level or type of repair or maintenance. Using this approach, the Commission could prescribe a very low threshold for bringing construction materials such as grated decking into compliance, while establishing a higher threshold for items that are more costly and arguably less ecologically beneficial to bring into compliance – such as moving the location of the pier to conform with setbacks.

- 50% of decking is replaced.
  - Replacement of all decking and in many cases all stringers and cap beams is considered normal maintenance and repair in the marine industry and is supported in the WAC as being exempt from SDP. The City is essentially rewriting the accepted practice and adopting a more stringent guideline which will cost property owners many thousands of dollars because in many cases new piling will need to be driven and the configuration changed.
  - Decking, stringer and cap beams typically deteriorate at similar rates and therefore replacement is normally completed at the same time. This is a routine occurrence industry wide.

Has the Commission devoted the time necessary to adequately debate the practicality of and reasoning for this regulation and its future impacts on property owners?

Staff Response: As stated above, the Commission’s current definition of Maintenance and Repair could allow for the type of replacement identified by Mr. Douglas.

- Mooring piles not considered a part of the moorage facility itself and therefore if in a nonconforming location they cannot be replaced.
The City of Mercer Island is the only jurisdiction where mooring piles are not viewed as a part of the moorage structure itself and therefore if in a nonconforming location can be repaired but no replaced in that location.

Has the Commission devoted the time necessary to adequately debate the practicality of and reasoning for this regulation and its future impacts on property owners?

Staff Response: As stated above, the Commission’s current definition of Maintenance and Repair could allow for the type of replacement identified by Mr. Douglas.

- Proposed changes to how the Moorage Cover Triangle will be applied.
  - Under the proposed changes a vast number of existing moorage structures will become nonconforming and the above rules will need to be applied and essentially require these structure to be brought into conformity if the threshold are exceeded.
  - Changes to how the Moorage Cover Triangle combined with thresholds on piling and decking replacement will place a heavy burden and expense on Mercer Island property owners.

Has the Commission devoted the time necessary to adequately debate the practicality of and reasoning for this regulation and its future impacts on property owners?

Staff Response: The proposed change would result in some covered moorages to become non-conforming. However, with the recommended clarification in 19.07.110(A)(7) referring to MICC 19.01.050(B), such covered moorages would be liberally allowed to be repaired and maintained and in some cases replaced without losing their legal non-conforming status. The Commission reviewed this issue at the March 17, 2010 meeting, with a decision to make no change to the proposed covered moorage triangle, as it was determined to provide better protection of views. The Commission could reverse its decision and revert back to a covered moorage triangle that allows for movement of the triangle apex, resulting in placement of covered moorages closer to adjacent properties.

It is vital that the Commission understand and weight the fact that there have been no incremental changes to local Shoreline Master Programs similar to those made to other guidelines such as the Uniform Building Code as new information is discovered. The state has essentially sat on the sidelines for nearly 40 years holding on to this information and placed the burden of sweeping changes on local government leaders and property owners. Does decades of inaction on the part of the state justify playing catch up in a single motion whereby making property owners pay a heavy price?

Staff Response: Jurisdictions are required by WAC 173-26 to update their existing SMPs, regardless of the time since the last required update. The City of Mercer Island has conducted several minor revisions to its SMP since its adoption in 1974. Revisions occurred in 1981, 1985, 1987, 1989, 1992, and 1996. Moreover, existing structures will not be immediately affected by the changes. Rather, they will only be required to be brought into conformance under conditions specified in MICC 19.01.050 or any other conditions the SMP ultimately establishes for a development’s loss of legally non-conforming status.

- A 50 foot setback being applied to all residential properties bordering Street Ends simply because they have been classified as “Urban Parks” is impractical and unreasonable. At the very minimum, the Commission could direct City Staff to research and inventory the functionality of each street end and its public access and use and decide whether it functions as a “park”.
  - One example is what I believe is known as the SE 43rd Street Landing. As a result of the 50 foot setback the property owner was unable to replace a heavily impacting structure in the nearshore area and was actually allowed to construct a second pier on the property. Ecology had no authority to override the City’s decision even though the “Urban Park” located at this street end is nothing more than a small bench overlooking a City utility department pump station. According to the adjacent property owner, the “park” is only used during Seafair.

Has the Commission devoted the time necessary to adequately debate the practicality of and reasoning for this regulation and its future impacts on property owners, and in the case cited above, the environment?
Staff Response: The Commission reviewed this issue at the March 17, 2010 meeting with a decision to make no change to the 50 feet setback, as it was concluded that the setback provides appropriate separation for park uses, which have the potential (existing or future) to be higher in intensity. The Commission could decide to reverse its decision and require a 10 feet setback, similar to that for properties abutting urban residential properties.

I have also had the opportunity to review the March 30, 2010 letter from Barbara Nightingale from the WA Department of Ecology. These comments align with those received by other local governments during their SMP Updates and for the most part they reflect Ecology’s attempt to use inconclusive science and the Corps RGP-3 to impact the process.

I provide the following comments Ecology’s letter:

- **Setbacks and Vegetated Buffers**
  - I believe the City is taking a property owner focused and appropriate approach on the issue of vegetation and it is important to remember that projects involving overwater structures must also go through reviews by WA Department of Fish and Wildlife (WDFW) and the Army Corps of Engineers (COE). During the course of their review, state and federal regulators, including the local Tribal Community make comment on all aspects of a project including the planting plan. The local SMP is one of several steps and not a stand-alone process required to overly scrutinize every aspect of a project including vegetation.
  - I believe local governments are steering clear of using the term “buffer” as a result of its closer association with streams and wetlands and use in conjunction with the Growth Management Act. Streams and wetlands are typically classified as “critical areas” where buffers are more appropriately applied. Lake Washington is not considered a critical area but a “shoreline of statewide significance”. Most local governments are using setbacks in conjunction with their SMP’s under the Shoreline Management Act. Because buffers are viewed as “no activity” zones there has been legal action regarding whether or not they constitute a taking of property in other areas.

- **Dock Specifications**
  - As a precursor to comments from Ecology on dock specifications, it is important for the Commission to understand that Ecology conducted no independent and very little joint research on how the Corp RGP-3 was being used by the Army Corps and Federal Services under the ESA Section 7 Consultation requirements. The Agency has simply tried to push the RGP-3 standards on local governments and property owners but has faced a lot of resistance in other areas. Ecology has cited Kirkland as an example to follow but the standards adopted by Kirkland, although better than originally proposed, fall well short and has left property owners frustrated at many of the changes.
  - Mercer Island should be applauded in their effort on behalf of property owners to creatively calculate the replacement of solid surfaces with grating to reduce “effective overwater coverage” as we refer to it in the industry. No other local government has taken this approach and since grating is a requirement for pier repair and replacement by WDFW and COE it is commendable.
  - Although I am not a biologist, I believe Ecology’s description of the Corps document for piers in Lake Washington and Lake Sammamish being a “formal biological opinion” may be inaccurate. I have reviewed the “Biological Evaluation” associated with the RGP-3 and it is a standard document similar to any other that would be completed for projects required to address impacts on listed species under the ESA. Furthermore, if Ecology is accurate in their position that any single family pier larger than 480sqft and having less than 60% open area on grating constitutes a “jeopardy on listed species” or even more accurately a “take” then nearly every pier reviewed and approved by the Corps itself, with concurrence form U.S. Fish and Wildlife and NOAA Fisheries- National Marine Fisheries Service, is guilty of allowing such to occur. Under the ESA and by law, these agencies simply cannot do such a thing.

Because Ecology has incorrectly listed the Corps RGP-3 standards as requirements rather than recommended and flexible construction specifications, has the Commission considered a process whereby the City processes projects as it has been and requires applicants to provide a copy of the approved Corps
Section 10 permit to the City upon receipt? The City could subsequently provide a copy to Ecology as proof that the project was approved by the very agency Ecology is saying does not allow piers to exceed a certain size and grating to be less than a certain open space.

Staff Response: Enclosed in the May 19, 2010 packet is an email from the Department of Ecology that states a departure from the RGP-3 would need to be addressed via incentives or mitigation to avoid a loss of ecological functions.

Regulations from other agencies combined with recent trends by property owners resulting in more functional docks with less overwater coverage, fully grated surfaces, less piling, elevated higher above the water, with narrower components, and native planting plans ensure that no net loss will be achieved most effectively through the repair and replacement of larger existing structures. If the City takes an overly restrictive approach in any area, either locally or as recommended by Ecology it will cause property owners to retain existing structures as long as possible, and in the case of nonconformities, lead to unauthorized work being done through self-help or renegade contractors. If this happens, what have we accomplished?

Thank you for your time and consideration. If you have any questions I may be contacted at integritypermitting@hotmail.com or by phone or text at 425-343-2342.

Sincerely,

David Douglas
Integrity Shoreline Permitting
WHITE PAPER

Over-Water Structures: Freshwater Issues

Submitted to

Washington Department of Fish and Wildlife
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Note:
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Overview of Aquatic Habitat Guidelines Project

As part of the process outlined in Washington's *Statewide Strategy to Recover Salmon: Extinction is Not an Option* the Washington Departments of Fish and Wildlife, Ecology, and Transportation were charged to develop Aquatic Habitat Guidelines employing an integrated approach to marine, freshwater, and riparian habitat protection and restoration. Guidelines will be issued, as funding allows, in a series of manuals addressing many aspects of aquatic and riparian habitat protection and restoration.

This document is one of a series of white papers developed to provide a scientific and technical basis for developing Aquatic Habitat Guidelines. The white papers address the current understanding of impacts of development and land management activities on aquatic habitat, and potential mitigation for these impacts. The following topics are addressed in the white paper series:

- Over-water structures - marine
- Over-water structures - freshwater
- Over-water structures - treated wood issues
- Water crossings
- Channel design
- Marine and estuarine shoreline modification issues
- Ecological issues in floodplain and riparian corridors
- Dredging - marine
- Dredging and gravel removal - freshwater

Individual white papers will not necessarily result in a corresponding guidance document. Instead, guidance documents, addressing management and technical assistance, may incorporate information from one or more of the white papers. Opportunities to participate in guidelines development through scoping, workshops, and reviewing draft guidance materials will be available to all interested parties.

Principal investigators were selected for specific white paper topics based on their acknowledged expertise. The scope of work for their projects requested a "comprehensive but not exhaustive" review of the peer-reviewed literature, symposia literature, and technical (gray) literature, with an emphasis on the peer-reviewed literature. Readers of this report can therefore expect a broad review of the literature, which is current through late 2000. The coverage will vary among papers depending on research conducted on the subject and reported in the scientific and technical literature. Analysis of project specific monitoring, mitigation studies, and similar efforts are beyond the scope of this program.

Each white paper includes some or all of these elements: overview of the Aquatic Habitat Guidelines program, overview of the subject white paper, assessment of the state of the knowledge, summary of existing guidance, recommendations for future guidelines, glossary of technical terms, and bibliography.
The overarching goal of the Aquatic Habitat Guidelines program is to protect and promote fully functioning fish and wildlife habitat through comprehensive and effective management of activities affecting Washington's aquatic and riparian ecosystems. These aquatic and riparian habitats include, but are not limited to rearing, spawning, refuge, feeding, and migration habitat elements for fish and wildlife.
Assessment of the State of Knowledge

This white paper evaluates the state of knowledge of the effects of over-water structures on the functioning of freshwater ecosystems and their relation to salmonids. Scientific and technical literature on the subject was compiled and examined, and input from experts on freshwater habitats and organism life histories was solicited and evaluated. Effects on an array of organisms and communities are considered.

Although reference to a particular genus is made when appropriate within this paper, all seven native salmon and trout of the genus *Oncorhynchus* (i.e., chinook, coho, chum, sockeye, and pink salmon, and steelhead and cutthroat trout) that occur in Washington are collectively referred to as salmonids.

Predators of salmonids consist primarily of the following species. In lakes of western Washington (particularly Lake Washington and Lake Sammamish), largemouth (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) are the juvenile salmonid predators that use shore-zone structures more than other species. In eastern Washington, existing hydrological characteristics of river reservoirs (particularly in the Columbia and Snake rivers) favor the northern pikeminnow (*Ptychocheilus oregonensis*; formerly the northern squawfish) as the major predator of juvenile salmonids (Petersen et al. 1993; Poe et al. 1991; Ward et al. 1995). However, smallmouth bass also have a high potential as juvenile salmonid predators in river and reservoir systems of eastern Washington, particularly in the spring when they inhabit rocky shoreline areas also inhabited by juvenile salmonids (Gray and Rondorf 1986). In this discussion of effects of in-, on-, and over-water structures (hereafter, over-water structures) on predation, the emphasis is on predation of juvenile salmonids by these species.

Methods

**Literature Sources**

An extensive search of available literature was conducted, including but not limited to the following:

- University of Washington electronic library and commercial databases:
- University of Washington catalogs
- Aquatic Sciences and Fisheries Abstracts (ASFA)
- Water Resource Abstracts (WRA)
- National Technical Information Service (NTIS)
- BIOSIS previews.

The University of Washington catalogs contain over 1.9 million titles held by more than 20 branches of the University of Washington libraries. The ASFA database covers all aspects of marine, brackish, and freshwater environments including biology, ecology; fisheries, aquaculture, oceanography, limnology, resources and commerce, pollution, biotechnology, marine technology, and engineering. The WRA database contains abstracts of journal articles,
monographs, and reports covering the development, management, and research of water resources. The NTIS Government Reports is an index produced by the U.S. Department of Commerce, which is a central source for public sale of U.S. government-sponsored research, development, and engineering reports. The BIOSIS previews databases and supplies comprehensive coverage of international life science journals, including references found in biological abstracts.

This review of literature on over-water structures incorporates analysis of existing data available on freshwater organism responses to over-water structures. More specifically, it focuses on the review of studies that address direct and indirect effects of over-water structures and associated construction activities on juvenile salmonids and their habitats. The literature sources include (but are not limited to) peer-reviewed journal articles, theses and dissertations, books, technical documents, previous over-water impact studies in the state of Washington, previous over-water structure impact literature searches, and regulatory documentation. When available, internet web sites that contain information reviewed in this paper are provided. In addition, personal communications with local scientists have been included where related research has yielded pertinent results.

For the purpose of this white paper, sources referring to the ecological effects of over-water structures (i.e., direct sources) are distinguished from literature sources not referring directly to such effects (i.e., indirect sources). Direct sources, then, comprise those references that directly address the mechanism of impacts of over-water structures, as well as those that directly address the response of an organism (particularly juvenile salmonids) to over-water structures (Appendix C). Indirect sources comprise those that address organism predation, behavior, and habitat function without reference to the presence of over-water structures.

During the development of this white paper, a literature review prepared for the City of Bellevue (i.e., Kahler et al. 2000) became available. This literature review was prepared with the collaboration of researchers of the Washington Department of Fish and Wildlife. Also during the development of this white paper, a conference was held to present current and ongoing research on chinook salmon in Lake Washington (i.e., King County 2000). This conference, coordinated by King County, presented research by state and federal agencies. There was some duplication among these three endeavors (i.e., the literature review by Kahler et al. 2000, the conference by King County 2000, and this white paper). Due to time constraints and in the interest of avoiding further duplication, Kahler et al. (2000) and King County (2000) are not fully reviewed in this white paper.

Categorizing Information

In this white paper, unless otherwise stated, only research on over-water structures known to occur in freshwater environments is considered in the literature survey, and the analysis focuses on freshwater environment studies. Appendix B provides a matrix of data availability. A literature review and analysis of the effects of over-water structures in estuarine and marine environments is included elsewhere in the series of white papers and therefore is not discussed here.
Pertinent information on ecological effects of over-water structures (and associated structures and activities) in freshwater environments was found only for the following:

- Docks, piers, boathouses, and floats
- Marinas
- Wharves and pilings
- Log booms and log rafts
- Riprap and retaining walls
- Pile driving and removal
- Construction and operational activities.

This white paper assesses the ecological effects of over-water structures based on the current state of knowledge. In order to analyze and present the available data in a logical and easily referenced format, the information sources are divided into either direct or indirect mechanisms of impact, then categorized by the type of response observed.

For the purpose of this white paper, three direct mechanisms of impact associated with over-water structures have been identified: shore-zone habitat structure changes, shading and ambient light changes, and disruption of water flow pattern and energy. One indirect mechanism of impact associated with construction activities and ongoing operation of over-water structures has been identified: physical/chemical environmental disruption (e.g., water quality degradation and noise). Interrelated effects of over-water structure use and operation (i.e., boating activities) are also included under the discussion of this indirect mechanism of impact.

Over-water structures often induce simultaneous responses on predation, behavior, and habitat function, potentially confounding the assessment of any individual response. However, such structures may induce a response in an organism without eliciting a response from its habitat and without promoting a response to its predator-prey system. For this reason and in the interest of clarity, a simple three-part categorization is used here for the range of responses. Under each of the direct mechanisms of impact, available research is grouped into the following categories of response:

- Shore-zone habitat structure changes
  - Predation
  - Behavior
  - Habitat function

- Shading and ambient light changes
  - Predation
  - Behavior
  - Habitat function

- Disruption of water flow pattern and energy
  - Habitat function.
Objective

The objective of this paper is to evaluate the state of knowledge of the effects of over-water structures on the functioning of freshwater ecosystems within the context of salmonid protection. For this purpose, the following fundamental question is the focus of the review: What are the effects of over-water structures on the ecosystem, measured both by mechanism of impact and by type of response?
Overview of Ecological and Habitat Issues

In general, modification of riparian areas and near-shore littoral zone habitat (i.e., shoreline development) degrades freshwater aquatic communities. Local habitat modification (e.g., construction of individual residential docks) leads to changes in fish assemblages, particularly “when many diverse incremental changes have accumulated within a basin over time” (Jennings et al. 1999).

Cumulative effects of incremental shoreline development on fish assemblages are typically not considered during the construction of a single over-water structure. Years of shoreline development (i.e., construction of over-water structures and associated activities) along lakes, rivers, and reservoirs around the state are now showing the accumulated effects on habitat and fish species. This passage of time has increased the awareness and conviction that cumulative effect analysis is essential to effectively manage the consequences of human activities on the environment (Council on Environmental Quality 1997). However, only recently has the issue of cumulative effects of incremental shoreline habitat modification in freshwater environments been studied (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Ward et al. 1994; Christensen et al. 1996; Jennings et al. 1999; Lange 1999).

More studies have been conducted on the effects of a range of human activities that alter structural elements of aquatic systems such as size and uniformity of substrate particles (Jennings et al. 1999), quantity and composition of shoreline habitat (Christensen et al. 1996), artificial habitat structures (Beauchamp et al. 1994; Ward et al. 1994), and composition and density of macrophytes (Bryan and Scarnecchia 1992). Among these activities, a high level of concern exists with regard to over-water structures, associated in-water structures, and their related construction activities. This is due to the great potential of these activities to affect, both directly and indirectly, ecological and habitat functions, and thereby individual species.

Jennings et al. (1999) studied the cumulative effect of incremental shoreline habitat modification on fish assemblages in northern temperate lakes. They found that “fish do not respond to shoreline structures: rather, fish respond to various habitat characteristics that are the result of the structures.” In addition, fish respond to habitat changes resulting from alterations in the riparian zone (e.g., vegetation and woody structure removal) associated with the placement of the in-water structure (Jennings et al. 1999).

Direct Mechanisms of Impact

Shore-Zone Habitat Structure Changes

Docks, Piers, Boathouses, and Floats

Docks, piers (and pier skirting), boathouses, and floats alter the shore-zone habitat structure, promoting changes in fauna and flora assemblages. These over-water structures can thereby affect the biological community and the environment by altering predator–prey relationships, fish behavior, or habitat function.
Docks and piers are typically structures of open construction that extend into the water from shore (Mulvihill et al. 1980). They come in various shapes, heights, and sizes. They occur in lakes, rivers, and reservoirs throughout Washington and are used for recreational and commercial purposes. They can be pile-supported or supported by a solid base.

A boathouse typically is a building that houses and protects boats. A houseboat is a watercraft with a broad beam, usually a shallow draft, and a large superstructure resembling a house. Houseboats can be either free-floating, anchored on moorages, or supported by pilings. In this regard, one would expect houseboats supported by pilings to have the greatest potential for habitat disruption, because they not only shade the underwater environment but also permanently disrupt the bottom sediments and modify the habitat structure, potentially creating habitat for predatory fishes.

Only two papers were found that address environmental effects of boathouses on aquatic animals and plants (i.e., Brown 1998 and Lange 1999). No literature sources were found addressing the environmental effects of houseboats.

Floats occur in a variety of sizes and shapes, including small moored floating objects (buoys), and larger floating flat objects, known as platforms. Typically, buoys are used for a variety of purposes, for instance, as aid to navigation or for attachment of vessels or instrumentation (Mulvihill et al. 1980). Floating platforms are used for recreational or commercial purposes.

**Predation**

Predator–prey relations in this section focus on the potential influence of docks, piers, and floats on predation of juvenile salmonids by bass, northern pikeminnow, and piscivorous birds, and by salmonids on their prey. The effects of over-water structures on predator–prey interactions are widely recognized but have not been extensively examined. The literature reviewed does not provide any quantitative or qualitative evidence that docks, piers, boathouses, or floats either increase or decrease predation on juvenile salmonids. No literature source was found addressing pier skirting. No studies have been found examining mortality due to predation specifically associated with over-water structures.

The literature reviewed presents the following observations and inferences:

- Smallmouth bass and largemouth bass have a strong affinity to structures, including piers, docks, and associated pilings.
- Bass have been observed foraging and spawning in the vicinity of docks, piers, and pilings.
- Smallmouth bass are opportunistic predators that consume prey items as they are encountered.
- Smallmouth bass are major juvenile salmonid predators, likely due to the overlap in rearing habitat.
In the Colombia and Snake river reservoirs, northern pikeminnow is an important predator of juvenile salmonids because of their in-shore preferences and preference for low-velocity microhabitats, which are created by in-water structures.

In western Washington, largemouth bass and smallmouth bass are common predators of juvenile salmonids. Several authors have documented the use of over-water structures by bass in western Washington waters. Stein (1970), examining the types of largemouth bass cover in Lake Washington, found that they prefer areas of heavy log and brush cover over other habitat types (including docks). However, largemouth bass are commonly found under docks in early spring and are thought to be present there until late summer (Stein 1970).

White (1975) studied the influence of piers in Lake Washington and found that fish species (including largemouth bass) are not significantly more abundant (based on catch-per-unit-effort) beneath these over-water structures than at adjacent sites lacking artificial structures. White’s (1975) findings led him to suggest that piers provide neither shelter nor habitat for predatory species that prey upon salmonids. However, his sampling method had two major flaws. First, he employed variable-mesh horizontal gill nets as sampling gear, which are more effective for sampling peamouth (*Mylocheilus caurinus*), northern squawfish, and yellow perch (*Perca flavescens*) than for sampling bass. Second, the sampling gear was placed adjacent to the pier rather than beneath it, precluding the characterization of fish composition under the structure. Consequently, the data obtained by White (1975) do not provide information of predatory fish abundance under the piers. In addition, the study sampling gear was ineffective in sampling some fish species, including bass, and therefore, the results do not accurately reflect use of over-water structures by all fish species.

Additional supporting evidence on bass utilization of docks and piers associated with over-water structures comes from unpublished data. Biologists with the Washington Department of Fish and Wildlife found that in local lakes, bass preferentially utilize natural structures, but are also found associated with docks (Kahler et al. 2000). Also, biologists with the Muckleshoot Indian Tribe found that in Lake Sammamish, smallmouth bass preferentially locate their nests near residential piers and associated in-water structures (Kahler et al. 2000). These findings are consistent with the findings of Stein (1970), who observed a largemouth bass affinity for dock, piers, and associated pilings.

Interactions of smallmouth bass and juvenile salmonids depends on factors such as timing of salmonid out-migration, salmonid species, and residence of the juvenile salmonids in lentic or lotic environments (Warner 1972; Pflug and Pauley 1984; Gray et al. 1984; Gray and Rondorf 1986; Poe et al. 1991; Shively et al. 1991; Tabor et al. 1993 and 2000; Fayram and Sibley 2000).

Although substrate type often determines the acceptability of an area for bass spawning, adjacent cover and structural complexity are also necessary for protection while the fish are concentrated in shallow water (Stein 1970; Cooper and Crowder 1979; Helfman 1981b; Pflug and Pauley 1984). Therefore, one would expect that an increase in numbers of docks, piers, boathouses, and floats could be beneficial to the bass population by increasing spawning habitat utilization. Increases in the concentration of bass in spawning sites, where there is an occurrence of juvenile
salmonids, may increase the predation on juvenile salmonids. However, researchers have indicated that structural complexity can moderate predator–prey interactions by providing more refuges for prey species as well as reducing the foraging efficiency of the predator (Cooper and Crowder 1979). This moderation may apply to naturally occurring structural habitat complexity, as well as habitat complexity due to the presence of docks, piers, boathouses, and associated pilings. In such a case, fish may adapt to the use of artificial structures in lieu of natural habitats. Prey such as juvenile salmonids, in the absence of natural hiding cover, may use artificial structures as refuge. However, snorkel observations conducted by Roger Tabor in Lake Washington indicate that although they may migrate along the shoreline, passing under docks, the juvenile chinook salmon prefer open areas rather than areas covered by docks (King County 2000). Moreover, although manmade structures can serve as refuge for prey, they may also provide refuge for predators (Cooper and Crowder 1979).

It has been suggested that the increase in the number of docks around the shoreline of Lake Washington might have caused the observed decrease in freshwater survival of juvenile sockeye salmon (Fayram 1996). Studying the spatial location and temporal duration of predation by bass on juvenile sockeye salmon, Fayram (1996) speculates that the increase in docks potentially provides increased locations for bass to ambush prey such as juvenile sockeye salmon while they are in the littoral zone. Fayram (1996) also suggests that the cumulative effect of an increase in predation due to the increase in number of docks may have been great enough to cause the decline in sockeye salmon freshwater survival.

One would expect that the temporal duration of sockeye salmon predation by bass depends on the extent of the overlap of these two species in littoral zones. This overlap may be strongly affected by temperature because, in subyearling fall chinook, temperature appears to control the duration of shoreline residence in Lower Granite Reservoir (Curet 1993). In Lake Washington, the overlap is typically restricted to late April and most of May because juvenile sockeye normally leave the system by the end of May. It is possible that warming of the lake water over time has increased the period of habitat overlap between these two species (Fresh 2000 personal communication). In addition, Vigg et al. (1991) suggests that among the factors influencing consumption rates of smallmouth bass, water temperature is the single most important factor.

The presence of docks and piers may adversely affect existing macrophyte vegetation, potentially altering predator–prey interactions, particularly those in which largemouth bass plays a role. In Lake Baldwin, Florida, largemouth bass showed a significant preference for piers only where aquatic vegetation was absent (Colle et al. 1989). In Lake Sammamish, largemouth bass have been shown to prefer moderate to dense vegetation and silt and sand substrate (Pflug 1981). The preference of largemouth bass for aquatic vegetation habitat may increase their foraging success on passing schools of salmonids, compared with the lesser success of smallmouth bass that occupy habitat with little concealment (Pflug 1981; Helfman 1981b).

Consistent with these findings, Fayram (1996) found that in Lake Washington, largemouth bass are more structurally oriented than smallmouth bass. Floats have been reported to influence the distribution of fish (Crossman 1959; Helfman 1979). Helfman (1979), studying shade-producing experimental floats in Cazenovia Lake, New York, found that several species of predator fishes are particularly attracted to the area under the floats. The author suggests that the large
aggregation of prey fishes under floats may also attract predator species, although this is inconclusive in his study. In this study, largemouth bass showed little response, positive or negative, to the presence of floats (Helfman 1979). However, Helfman (1979) observed that largemouth bass occasionally hovered near and below the floats but usually moved away as the diver approached. He speculates that this response to the diver might have biased the data collection process and hence the study results by reducing the numbers of largemouth bass observed at the floats. He also attributes this response to a largemouth affinity for “more massive structure than was provided by the experimental floats.” Helfman (1979) did not observe smallmouth bass beneath or near floats, although this species was common in the lake.

The northern pikeminnow (formerly known as the northern squawfish), and to a lesser extent the smallmouth bass, are primary predators of juvenile salmonids in eastern Washington. Existing hydrological characteristics of major river systems have favored the northern pikeminnow as a predator of juvenile salmonids. These hydrological characteristics are the result of a substantial habitat modification, mostly due to the construction of dams. The following quotation from Gray and Rondorf (1989) better illustrates this: “Man has significantly altered the aquatic habitat and fish species complex in the Columbia River, and its alteration has created substantial changes in the dynamics of predator-juvenile salmonid relationships . . .”

During this literature survey, numerous studies of the effects of dams on the ecology and biology of the Columbia basin reservoirs were found, in particular, studies of the effects of dams on salmonid predation. Those studies are beyond the scope of this white paper and therefore are not discussed here. In contrast, only a few studies of ecological effects of in-water and over-water structures in eastern Washington systems were found (Beamesderfer and Rieman 1988; Knutsen and Ward 1991; and Petersen et al. 1993). Such studies show some inconsistencies in the evidence of predatory fish aggregation associated with such structures, and study results show no direct evidence of an increased predation rate on juvenile salmonids. This inconsistency may be due to characteristics of each study site (e.g., fast, free-flowing areas or slow-flowing protected areas) and the species targeted (e.g., northern pikeminnow or smallmouth bass) in each particular study.

Although only a few direct sources have been identified, the following characteristics are all reported to be related to fish predator behavior and distribution in the context of juvenile salmonid predation:

- Degree of habitat overlap (i.e., potential for predator–prey interaction)
- Location in relation to the river mile
- Location in relation to the river stem
- Location in relation to the river flow (i.e., free-flowing or backwater)
- Degree of shore-zone development
- Characteristics of the shoreline (i.e., slope and substrate type)
- Presence of manmade in-water structures (i.e., flow obstructions)
- Species of predatory fishes.

Beamesderfer and Rieman (1988) studied juvenile salmonid predation by northern squawfish and smallmouth bass in a main stem Columbia River reservoir. Beamesderfer and Rieman (19898
conclude that northern squawfish have the greatest potential for predation of juvenile salmonids because of their preference for in-shore low-velocity microhabitat. Low-velocity microhabitat can be created by in-water structures such as jetty pilings (Petersen et al. 1993), but can also be created by dock and pier pilings located along the banks of narrow, fast-flowing sections of the Columbia River reservoirs (Carrasquero 2000 unpublished observation). Therefore, one would expect that resulting low-velocity microhabitats could potentially increase juvenile salmonid predation by providing aggregating habitat for northern pikeminnow and perhaps juvenile salmonids as well.

Additional evidence of predation by squawfish was found by Petersen et al. (1993), who, in a study of the systemwide significance of predation on juvenile salmonids in Columbia and Snake river reservoirs, found that northern squawfish feed primarily on juvenile salmonids. The authors speculate that northern squawfish as well as juvenile salmonids might congregate near flow shears (i.e., back-eddies) created by in-water structures (i.e., jetty pilings), to avoid high-velocity water (Petersen et al. 1993). This preference of northern squawfish for back-eddies has been reported elsewhere (Faler et al. 1988). Consequently, in the Columbia and Snake river reservoirs, in-river obstructions associated with over-water structures such as jetty pilings can make salmonids more vulnerable to predation.

In contrast, Ward et al. (1994) found that developed sites (i.e., sites having floating platforms and pile-supported piers) do not increase predation by northern squawfish. Studying the effect of harbor development on juvenile salmon predation by northern squawfish in the lower Willamette River, Ward et al. (1994) found more northern squawfish in areas without development (i.e., where floating platforms and pile-supported piers are not present).

In terms of understanding the contrasting results, it is noteworthy that the hydrological conditions and shoreline configurations of the sites studied by Petersen et al. (1993) greatly differ from those of Ward et al. (1994). The study sites of Petersen et al. (1993) include free-flowing and high water velocity areas in eastern Washington, with the presence of in-water obstructions and gently sloping littoral terrain. On the other hand, the western Oregon study area of Ward et al. (1994) includes protected harbor areas with low water velocity and steeply sloped bottoms caused by dredging. This difference in study site conditions may help to explain the different results found.

Smallmouth predation on subyearling fall chinook salmon may also be significant in eastern Washington. For example, smallmouth bass accounted for 7 percent of the loss of late-migrating subyearling fall chinook salmon in Lower Granite Reservoir on the Snake River (Anglea 1997). Other research in the Columbia River basin also suggests that smallmouth bass may be a substantial predator of subyearling fall chinook salmon because both species rear in littoral habitat with low water velocities and therefore have a high potential for habitat overlap (Garland and Tiffan 1999; Curet 1993; Tabor et al. 1993).

Shallow near-shore water with a low gradient is an important habitat element for subyearling fall chinook salmon rearing in free-flowing areas of the Snake River. Bennett et al. (1992) reported that areas with low gradients were characteristic of juvenile chinook salmon rearing areas in
Little Goose Reservoir. Similarly, Dauble et al. (1989) found that shallow near-shore areas were preferred by subyearling fall chinook.

Juvenile chinook salmon use of the littoral zone is not unique to eastern Washington systems. In Lake Washington, chinook fry reportedly use shallow shoreline habitat characterized by a sandy bottom and no aquatic vegetation, with an absence of large woody debris (King County 2000).

Tabor et al. (1993), studying smallmouth bass and squawfish predation in the Columbia River, found that juvenile salmonids are the dominant prey item of smallmouth bass, and that crayfish are the dominant prey of northern squawfish. Tabor et al. (1993) also found a habitat overlap (i.e., a near-shore area where current velocities are reduced) between salmonids and smallmouth bass and suggested this as the factor that, when combined with the small size and high abundance of prey, may have contributed to the high salmonid predation rate observed. Smallmouth predation on juvenile salmonids due to habitat overlap has been reported previously (Poe et al. 1991).

Interestingly, Tabor et al. (1993) speculates that “predation on juvenile salmonids may be quite different in free-flowing and adjacent areas from predation in main-stem reservoir areas.” If experimentally verified, one may expect this speculation to be consistent with the findings of Petersen et al. (1993). In fact, low incidence of predation on juvenile fall chinook salmon by smallmouth bass in all areas of the free-flowing Snake River already has been reported (Garland and Tiffan 1999).

Also supporting the conclusion of Tabor et al. (1993), Beamesderfer and Rieman (1988) found smallmouth bass more abundant in embayments. This is consistent with previous findings in the Columbia and Snake river reservoirs indicating that smallmouth bass are most abundant in protected embayments (Hjort et al. 1981; Palmer 1982, both as cited by Beamesderfer and Rieman 1988).

Hence, in river reservoirs of eastern Washington, smallmouth bass and northern pikeminnow predatory systems may operate at two different spatial scales, determined by the relative position occupied in reservoirs. These two spatial scales seem to consist of near-shore areas where current velocities are reduced, for smallmouth bass (Tabor et al. 1993), and free-flowing areas with low-velocity microhabitats produced by in-water-obstructions, for northern pikeminnow (Faler et al. 1988; Beamesderfer and Rieman 1988; and Petersen et al. 1993).

As stated earlier, the degree of habitat overlap may affect the rate of predation of smallmouth bass on juvenile salmonids. Studies of habitat use by subyearling fall chinook salmon conducted in reservoirs of the Snake River have shown a subyearling fall chinook salmon preference for littoral habitats. These results have been consistent regardless of the gear type and sampling technique employed (i.e., beach seining [Bennett et al. 1992; Curet 1993] and electrofishing [Garland and Tiffan 1999]).

In terms of avian predation on salmonids, no published data directly pertaining to the effect of over-water structures in freshwater environments were found. (See Phinney [1999] for an overview of avian predation throughout the Yakima River basin and a reference list of Columbia...
River studies of avian predation on salmonids.) Nonetheless, a few indirect sources produced some related unpublished data.

Although common in Lake Washington, double-crested cormorants (*Phalacrocorax auritus*) rarely use docks or bulkheads for perching. On the other hand, gulls, also common in Lake Washington, perch on low decks (unpublished data cited by Kahler et al. 2000). Both double-crested cormorants and gulls are known predators of juvenile salmonids.

Cederholm et al. (2000) report that in 1997, a colony of 14,000 Caspian terns (*Sterna caspia*) used Rice Island (a dredge material disposal island) in the lower Columbia River for nesting and roosting, constituting the largest known colony in North America. Their data suggest that in 1997, the terns appeared to be largely dependent on juvenile salmonids for their dietary sustenance (mostly hatchery-originated). Cederholm et al. (2000) also found that although salmon is not their primary diet item, common murre (*Uria aalge*) would use salmon resources during food-stress conditions. In this regard, piscivorous birds are believed to be opportunistic feeders that use the available prey in a system (Modde et al. 1996). No information was found on the use of over-water structures by the Caspian tern or common murre.

Habitat type and location used by fish may determine bird predation success and thereby fish survival. Hence, fish that inhabit pelagic waters (e.g., rainbow trout) are more vulnerable to birds than substrate-oriented fish (e.g., brook trout; Matkowski 1989), because bird predation strategies may be limited by physical characteristics of the habitat such as amount of cover, depth, etc. In this regard, Wood and Hand (1985) found that cover reduces success of capture by one species of bird, the merganser (*Mergus merganser*). Therefore, over-water structures and related construction activities that modify the shoreline configuration (e.g., increasing the shoreline slope and eliminating shallow-water habitat refugia) could potentially affect predation rates on salmonids. This may occur, for example, if the shore-zone habitat and shallow habitat refugia are eliminated, forcing juvenile fish to venture into deeper waters where predator diving birds may have increased success. This hypothetical situation is of particular importance to juvenile chinook salmon, which have the greatest affinity to shore-zone shallow-water habitats (King County 2000; Garland and Tiffan 1999; Fresh 1999 personal communication; Curet 1993; Bennett et al. 1992; Healey 1991; Rondorf et al. 1990; Wydoski and Whitney 1979).

The presence of over-water structures may also influence the distribution of prey items for juvenile salmonids. In Lake Washington, benthic fish food organisms for salmonids, such as insect larvae, amphipods, and mollusks, have been suggested to prefer docks and piers in the absence of aquatic vegetation (White 1975). The presence of benthic organisms, while providing an increased source of food for juvenile salmonids, may also expose the salmonids to increased predation through increased aggregation. This is yet to be demonstrated.

**Behavior**

No evidence was found to indicate whether docks, piers, boathouses, or floats disrupt the migration of salmonids or cause a delay in migration in riverine systems or in lakes, and no literature sources were found addressing pier skirting. Numerous studies present data suggesting that docks, piers, and floats attract fish, and that this is the main effect of these over-water
structures on fish behavior. Anecdotal information from sport fishermen is consistent with these data. Also, it consistently emerged that where vegetation is lacking within a system, largemouth bass populations seek other forms of structures such as dock pilings. Alterations of predator–prey interactions associated with fish behavior that has been modified by human activities are discussed above in the predation section.

Knutsen and Ward (1991) studied waterway development factors (including floating platforms, piers, and associated pilings) and in-river activities (i.e., dredging and construction) with the potential to affect migration rate and distribution of juvenile salmonids migrating through the Portland harbor section of the Willamette River. They found that subyearling chinook salmon occur closer to shore at developed sites than at undeveloped sites. Although Knutsen and Ward (1991) found no evidence that waterway development directly attracts juvenile salmonids or slows migration, they argue that development that causes loss of preferred habitat may have subtle and indirect adverse effects. However, even relatively subtle anthropogenic changes are of concern because of their implications for cumulative effects (see habitat function section below).

Knutsen and Ward (1991) speculate that the amount of time that a particular race of juvenile salmonids spends migrating through Portland harbor might determine the effects of waterway development on their behavior. As juvenile steelhead migrate faster than yearling chinook salmon through Portland harbor, they are exposed to waterway development or activities over shorter time periods (Knutsen and Ward 1991). In addition, because subyearling chinook may be present in Portland harbor during most times of year, in-river activities have more potential to affect this portion of the salmon population (Knutsen and Ward 1991).

Ward et al. (1994) also studied the effects of waterway development on juvenile migration in the lower Willamette River, finding that floating platforms (on a riprap and sand shoreline) and pile-supported piers (on a clay shoreline) have no effect on juvenile salmonid migration. Although Ward et al. (1994) conclude that waterway development presents few risks to migrating salmonids, they recommend that dredging and construction be avoided in the spring when fish are out-migrating, in order to avoid potential construction-related adverse effects.

Several studies indicate that in both eastern and western Washington, juvenile chinook salmon prefer habitats that exhibit the following characteristics (Bennett et al. 1992; Curet 1993; Garland and Tiffan 1999; King County 2000):

- Shallow near-shore habitats with sandy bottom and no aquatic vegetation
- Near-shore shallow water with a low gradient in free-flowing areas
- Littoral habitat with low water velocities.

Hence, juvenile chinook salmon generally are adversely affected wherever these characteristics are modified by shoreline development.

Data from studies conducted in other systems indicate that shoreline development induces behavioral responses in fish. Beauchamp et al. (1994) studied the effect of shore-zone structures (i.e., piling-supported piers and rock-crib piers) on littoral fishes in Lake Tahoe. The piling-
supported piers consisted of 20- to 30-centimeter-diameter steel or wood, sunk into the substrate at approximately 5-meter intervals, with a solid deck on top. Piers of this construction provide simple submerged structures lacking complexity. The rock-crib piers consisted of a timber framework, filled with boulders and cobbles, providing habitat complexity in three dimensions (Beauchamp et al. 1994).

Beauchamp et al. (1994) found that piling-supported piers have no significant effect on the densities of any littoral fishes, whereas rock-cribs piers enhance both the density and diversity of fishes in the immediate area. However, this research was conducted at a time when the pier walkways were 2 to 3 meters above water surface and thus provided little or no shade (Beauchamp et al. 1994). The lack of shaded area may have been responsible in part for the low density of fish found, as other authors have shown that fish (particularly prey fish) use shaded areas under docks (Helfman 1979, 1981a).

With regard to fish attraction to shaded areas, Helfman (1979) studied fish attraction to shade-producing experimental floats in Cazenovia Lake, New York. These floats were placed in 3-meter deep water, among dense macrophyte vegetation, although the vegetation was cleared from the area below the floats. Helfman (1979) found that snorkeled-estimated fish densities were significantly higher under the floats than at the control and in adjacent areas, and the densities under floats were positively correlated with the float surface area. In his study, adult golden shiner (Notemigonus crysoleucas) and black crappie (Promoxis nigromaculatus) were observed near the float, whereas bluegill (Lepomis macrochirus) and pumpkinseed L. gibbosus were found beneath the float. Although fish were present under the floats during daytime and nighttime, their densities were lower at night and highest at midday, and little feeding activity was seen (Helfman 1979).

In a related study also in Cazenovia Lake, Helfman (1981a) found that the number of fish aggregating beneath shade-producing objects is directly proportional to the size of the objects (i.e., larger floats attract more fishes as more shade is produced). Helfman (1981a) speculates that “the amount (or depth) of shade produced was a determinant of the attraction phenomenon,” which in general may significantly influence the advantage to fish of hovering under such structures. Helfman (1981a) deduces that tactile attraction to the physical structure of the floats is not involved, because fish were not attracted to control floats that consisted of wood frame only. He further indicates that because large numbers of fish were commonly found under docks and under overhanging trees that were supported above the water (i.e., objects located at a fixed height that provide shade without the tactile stimulus), the observed behavior cannot be attributed to tactile attraction.

Consistent with the hypothesis that fish are attracted to the shade produced by on- and over-water structures are recent research data presented during a conference titled Selected Ongoing and Recent Research on Chinook Salmon in the Greater lake Washington Watershed, November 8–9, 2000 (King County 2000). The synopsis of findings included data on the factors influencing the decline in all life stages of chinook salmon. These data indicate that migrating adult salmon hold at various locations within the Sammamish River, and that most of these locations are in the shaded area underneath bridges.
The findings discussed in the preceding two paragraphs suggest that the attraction of fish (including chinook salmon and largemouth bass) to floating or overhanging objects is linked to the shade produced by the object rather than to the tactile stimulus. Also, these data suggest that the larger the floating object, the greater the shaded area, and thus the greater the number of fish attracted to such objects, potentially altering fish distribution and aggregation.

An alternative explanation of fish attraction to on- and over-water structures is that both the structures and the shade they cast may provide fishes with physical reference points for orientation (Fresh 2000 personal communication).

In terms of bass habitat preferences in relation to docks and piers, Bryan and Scarnecchia (1992) compared the abundance of juvenile fish assemblages between naturally vegetated sites and developed sites (i.e., with residential structures, boat docks, and manmade beaches) in Spirit Lake, Iowa. Bryan and Scarnecchia (1992) found species richness and total fish abundance (including largemouth bass abundance) consistently greater in natural sites than in developed sites. In contrast, smallmouth bass were consistently found in greater abundance in developed sites.

Studies conducted in Lake Sammamish by Pflug and Pauley (1984) found that smallmouth bass nest sites (located in 1.5 to 2.5 meters of water) were typically situated next to benthic structures such as isolated boulders, logs or dock pilings. Similar results were found by Helfman (1981b) in Cazenovia Lake and Skaneateles Lake, New York, and Mirror Lake, New Hampshire.

Stein (1970) found that in Lake Washington, largemouth bass prefer areas of heavy log and brush cover to all other habitat types, including docks, but often occur under docks in early spring. In Lake Sammamish, largemouth prefer moderate to dense vegetation and silt or sand substrate, and nests are constructed at depths from 0.6 to 1.5 meters, in vegetated areas with soft sediment or gravel substrate on moderate to steep slopes (Pflug 1981). In Cazenovia Lake and Skaneateles Lake, New York, and Mirror Lake, New Hampshire, juvenile largemouth bass also use macrophytes (in depths less than 1 meter) for protection against predators (Helfman 1981b).

The preceding discussion clearly indicates a largemouth bass affinity for aquatic macrophytes, thus posing a question of the implications of removing such vegetation for the construction of over-water structures. The studies discussed below provide some insight into this question.

Colle et al. (1989) studied the distribution of largemouth bass in Lake Balding, Florida after all submerged aquatic vegetation was eradicated by grass carp. Movements of 16 largemouth bass were monitored using radio telemetry from April 11, 1986 to April 4, 1987. A distinct depth segregation was evident for the radio-tagged largemouth bass, which were divided into three groups for purposes of analysis: in-shore (water depth 0–2.0 meters), mid-depth (0–3.5 meters), and offshore (more than 3.5 meters). Colle et al. (1989) found that six largemouth bass had home ranges in the in-shore zone extending 15 to 70 meters from shore. Five largemouth bass used both the in-shore region and the mid-depth region, coinciding with the maximum depth of the blue-green algae in the lake (Lyngbya sp). Five largemouth bass used the offshore region. In-shore largemouth bass preferred habitat near a water tupelo (Nyssa aquatica) area and avoided bare sand areas. In-shore fish had home ranges averaging 4.1 hectares, whereas offshore fish had...
home ranges averaging 21 hectares. Largemouth bass that used the entire area out to the 3.5-
meter contour preferred the 11 piers in the lake, especially the mid-depth group. Largemouth
bass associated with piers moved more than other fish and were associated with multiple piers.
Adult largemouth bass using an in-shore fringe of water tupelo as an underwater structure were
relatively sedentary (Colle et al. 1989).

Based on these data, Colle et al. (1989) conclude that a component of the largemouth bass
population preferred the artificial habitat provided by piers. Colle et al. (1989) suggest that the
fact that offshore largemouth bass had a greater home range (i.e., 21 hectares) than the in-shore
largemouth bass may be explained by a difference in prey density and structure abundance. That
is, prey density was probably lower in the offshore region than in the in-shore region, thereby
forcing largemouth bass to shift from ambush to active hunting, because of the absence of
underwater structures offshore (Colle et al. 1989).

Both largemouth and smallmouth bass are structurally oriented for both foraging and spawning
(Colle et al. 1989; Helfman 1981b; Pflug 1981; Pflug and Pauley 1984; and Stein 1970). They
will use docks, piers, and associated pilings in the absence of natural structures. It is not clear
which elements of these structures attract them. Additional evidence from published and
unpublished data on the behavioral response of bass to docks, piers, and associated pilings can be
found in Kahler et al. (2000).

A possible attracting feature of docks, piers, and associated pilings is related to food-web
interactions of prey fishes. Chmura and Ross (1978) address the environmental impacts of
several in-water and over-water structures, suggesting that as fouling communities grow on
docks and piers, they add to the biological productivity of the area (also suggested by Mulvihill
et al. 1980). In various rivers and lakes of Washington, it is not uncommon to see fish (including
juvenile salmonids) feeding upon periphyton, insects, and macroinvertebrates adhered to dock
and pier pilings (Carrasquero 2000 unpublished observation). Thus, associated in-water dock
and pier structures that provide substrate for growth of fish food organisms can alter the behavior
of both prey and predator species. This is further discussed in the following sections.

*Habitat Function*

With regard to habitat function, one might argue that the impact of over-water structures is not
attributed exclusively to the structure but rather to the resulting changes induced by the structure
and associated activities. Within this context it has been proposed that “fish do not respond to
shoreline structures; rather, they respond to a suite of habitat characteristics that are the result of
the structure, changes to the riparian zone associated with its placement (vegetation and woody
structure removal), and often, intensive riparian zone management that occurs on developed
properties” (Jennings et al. 1999).

In this white paper, habitat function is defined as the attributes of the ecosystem that are created
and maintained by biological, chemical, and physical processes through the interaction of the
various ecosystem components (e.g., shore-zone, shoreline, and riparian). Individual habitat
modifications may lead to only small changes in local fish species richness, but the fish
assemblage structures respond to the incremental changes that accumulate over time within a given basin (Jennings et al. 1999).

In this regard, shoreline development (e.g., construction of docks and piers) in Lake Washington has increasingly eliminated shallow-water habitat (Kahler et al. 2000), particularly affecting juvenile chinook salmon. Once the shoreline is developed, docks and associated pilings may provide shallow-water cover for juvenile salmon, although they may also provide cover for predators (see Cooper and Crowder 1979). Thus, this type of shoreline modification may affect not only the physical habitat but also the various elements of the biological community and the habitat function.

Lange (1999) studied the effects of shoreline residential development on littoral fish abundance (i.e., fish catches) and species richness at different scales of observation (i.e., sampling site distances of 122, 244, and 488 meters) in Lake Simcoe, Ontario, Canada. He found that fish aggregated near permanent rock-crib-supported docks and avoided shoreline areas with bank stabilization structures (i.e., retaining walls built above the ordinary high water line). He also found that in shorelines where multiple features such as docks and break walls were present, fish abundance was positively correlated and species richness negatively correlated with these structures. Features such as docks and break walls combined with boathouses were generally associated with a decrease in both abundance and richness of fish species (Lange 1999).

In addition, Lange (1999) found that shoreline development was associated with sites having hard substrate (i.e., boulder, rubble, and gravel) and an absence of aquatic vegetation. Abundance and richness of fish had a significant positive correlation with both submerged vegetation and the presence of soft substrate types such sand, mud, and detritus, but were negatively correlated with hard substrate types.

Interestingly, Lange (1999) also found reduced fish abundance and species richness with increased density and diversity of shoreline residential development. He found that the specific development features associated with this pattern changed with the scale of observation, indicating that fish respond to both proximally and distantly located habitat alteration.

These results suggest that the cumulative effects of shoreline development might influence fish abundance and species richness. The results also suggest that shoreline alteration can affect fish abundance and species richness regardless of the relative distance of the development from the study site. This clearly illustrates the importance of considering the cumulative effects of even small new residential over-water structures that may be proposed in systems where numerous over-water structures already exist.

Some studies suggest that in the absence of certain predatory species such as bass, piers constructed in shore-zones may have a minimal influence on fish. For example, Beauchamp et al. (1994) studied the effect of shore-zone structures on the density of littoral-zone fishes in Lake Tahoe, California/Nevada. They found that piling-supported piers have no significant effect on the densities of any littoral fish, in contrast to rock-crib piers (i.e., timber framework filled with boulders and cobbles), which actually enhance both the density and diversity of fishes. Beauchamp et al. (1994) suggest that the difference in fish density associated with these two
types of piers might be attributed to the greater habitat complexity of rock-crib piers due to the interstitial spaces within the boulders.

Similarly, Lange (1999), studying the effect of shoreline residential development on littoral fishes, found that fish abundance and species richness were higher in rock-crib-supported docks (i.e., permanent docks) than in docks supported by pillars (i.e., seasonal docks).

One may argue that this response should be seen as an adverse effect, because it promotes anthropogenically induced fish aggregation. It is not known whether artificial structures used for habitat restoration in streams actually contribute to the enhancement of the targeted fish species, or whether such structures merely provide a focal point for fish distribution (King County 2000; Beschta et al. 1994; Everest and Sedell 1984; Kauffman et al. 1993; Reeves and Roelofs 1982). A high incidence of failure of artificial habitat structures has been reported for streams of the Pacific Northwest (Fissell and Nawa 1992). Artificial structures that alter fish distribution may increase salmonid predation rates by also aggregating predatory fish. Indeed, to be effective, artificial habitat structures used in restoration projects must be designed with attention to the needs of resident and desired species and consideration of the prevailing physical factors in a particular river or stream (Howe 1997). For example, recent snorkel observations at restoration sites in slow-flowing areas of the Sammamish River indicate that added large woody debris is providing habitat for predatory species rather than for salmon (King County 2000).

Based on qualitative observations of piscivorous fishes in Lake Joseph, Ontario, Canada, Brown (1998) suggested that the presence of predators around crib structures is a response to the abundance of forage fishes. She also studied the influences of shoreline residential development (i.e., docks and boathouses) and physical habitat on fish density in the Lake Joseph littoral fringe zone (i.e., 0–2.5 meters offshore with average depth of 0.53 meters). She found that coarse woody debris (CWD) was the most important habitat variable predicting density of total forage fishes. Sites with the higher number of shoreline structures had the lower densities of coarse woody debris. She also found that crib structures increased densities of forage fishes (<100 millimeters) in the littoral fringe on exposed shorelines or in areas where coarse woody debris had been removed.

Brown (1998) also found that forage fish density in the fringe zone and around shoreline structures increased with the addition of shoreline structures. She attributes this result to the added structural complexity that these structures provide, suggesting that this may increase protection from predators and from physical elements such as wave energy. She speculates that interstitial spaces within crib structures provided refuge from waves and predation for small fish along exposed shorelines.

As noted previously, shoreline development, with its suite of associated human activities and presence of artificial structures, degrades aquatic communities. In the review of habitat function above, individual over-water structures and overall shoreline development are discussed. Bryan and Scarnecchia (1992) studied species richness and juvenile fish abundance (young-of-the-year, YOY) in developed areas (i.e., with docks present) versus undeveloped areas (i.e., naturally vegetated), in Spirit Lake, Iowa. Bryan and Scarnecchia (1992) consistently found greater species richness and total juvenile fish abundance in natural sites than in developed sites in both...
near-shore and intermediate depth zones (0–1 meters and 1–2 meters, respectively). However, they found little difference between natural and developed sites in the offshore depth zones (2–3 meters). Throughout this study, juvenile fishes were more abundant where macrophyte abundance was greater (i.e., where vegetation was not removed for development). Smallmouth bass was the only species consistently found in equal or greater abundance in developed sites, which Bryan and Scarnecchia (1992) attribute to its lack of reliance on vegetative cover.

Hence, one might expect that if shore-zone development (in particular, construction of docks and associated in-water structures) eliminates the macrophyte vegetation, it might adversely affect fish species assemblages and young-of-the-year survival, particularly of vegetation-dependent species. In this regard, DiCostanzo (1957, as cited by Bryan and Scarnecchia 1992) speculate that insofar as juvenile fish use vegetation beds to avoid predation and to feed during their first summer of life, human activities that eliminate such habitat may reduce juvenile survival.

Collins et al. (1995) compare fish use of fringe zones adjacent to lawns with their use of undeveloped shorelines in Lake Rosseau, Ontario. They found that fish exhibit much less rearing and feeding activity in lawn-edge zones, where wave disturbance is greater, than in undeveloped habitats. Based on their results, Collins et al. (1995) identify shallow water as critical for foraging, refuge, and migration of small fishes (i.e., less than 100 centimeters total length).

Loss of riparian and wetland vegetation resulting from the construction of over-water structures and activities associated with shore-zone development has an adverse effect on water temperature. An increase in water temperature can promote temperature barriers, thus limiting the range and survival of certain fish species (Donald and Alger 1993). Indeed, results of field studies conducted in streams, rivers, and lakes suggest that the distribution and survival of certain species of trout, including bull trout (*Salvelinus confluentus*), are limited by water temperature (Fraley and Shepard 1989; Goetz 1989; Donald and Alger 1993; Rieman and McIntyre 1993; Ratliff et al. 1996; McPhail and Baxter 1996). In general, bull trout are uncommon where water temperature exceeds 15°C for more than a few days per year. In fact, a study of distribution of juvenile bull trout in the upper Cedar River and upper Yakima River drainages found that this species was absent in streams where summer water temperatures exceeded 14°C (Goetz 1997).

Only one source was found addressing benthic communities in the context of the effects of over-water structures. White (1975) studied the influence of shoreline development on fish and benthic fish food organisms in Lake Washington. He found that during the fall, population densities for insect larvae, mollusks, and amphipods were significantly higher outside the piers than under the piers. Conversely, in spring, population densities for mollusks, amphipods, and insects other than Chironomidae larvae (and presumably other grazing insects) were all significantly higher under the piers.

White (1975) suggests that the observed seasonal difference may be due to a combination of factors, including food availability, light, and life histories. The organisms whose partial or complete life cycles are related to aquatic vegetation did not avoid docks during the fall, but rather, responded to the available vegetation outside the docks (White 1975). He attributed the
spring preference (for protection, food, and shelter) of areas under docks and piers to the spring vegetation lacking the heavy growth observed during the fall. Therefore, during the spring, the docks offered a viable alternative type of structure to that provided by the vegetation during the fall (White 1975).

In White’s (1975) study, chironomids, an important food item for juvenile salmonids, showed no difference between population densities under and outside the piers. White (1975) did not discuss the potential implication of his results on the survival of juvenile salmonids, particularly juvenile chinook salmon. Interestingly, the samples he obtained from sites without docks (“natural zones”) indicated that chironomids were the most abundant organism at these sites. Clearly, his suggestion that docks offer an alternative type of structure to that provided by vegetation does not seem to apply for Chironomidae larvae.

Chmura and Ross (1978) state that “piers, docks, and wharves can have detrimental effects on both salt and freshwater marshes by blocking light and water flow . . . especially if piers are supported by closed (solid) bases.” The associated problem of use of treated wood is also mentioned by Chmura and Ross (1978).

**Marinas**

As defined by Mulvihill et al. (1980), “a harbor is a protected water area offering a place for safety to vessels. Small craft harbors are protected areas whose depth and maneuvering area limit usage to small craft. ‘Marina’ is used synonymously with small craft harbor, but generally refers to harbors for pleasure crafts.” Although marinas might be seen as over-water structures typical of marine environments, in Washington there are marinas in freshwater environments as well.

During the preparation of this white paper, Kahler et al. (2000) published *A Summary of the Effects of Bulkheads, Piers, and Other Artificial Structures on ESA-Listed Salmonids in Lakes*. This summary provides a comprehensive literature review of published and unpublished data primarily focused on Lake Washington and Lake Sammamish. Although marinas are not explicitly addressed in this review, there is a discussion of the effects of piers, bulkheads, lighting, chemical contaminants, and recreational and construction activities on fish and their habitat, which relates to the potential environmental effect.

Only two papers, both literature reviews, were found that directly address the environmental impact of marinas on freshwater environments (Chmura and Ross 1978; Mulvihill et al. 1980). The Chmura and Ross (1978) paper includes 66 literature citations and is organized by structure type, type of effect, and management considerations. The Mulvihill et al. (1980) paper includes 555 information sources, provides a summary of the literature, and is organized by coastal region case history studies. This review includes environmental impacts and biological impacts, the latter divided by construction, chronic, and cumulative effects. The Mulvihill et al. (1980) review is focused on the impact on the coastal environment and is somewhat outdated, particularly from an environmental viewpoint. Both the Chmura and Ross (1978) and Mulvihill et al. (1980) reviews address issues related to marinas in freshwater, estuarine, and marine environments.
Chmura and Ross (1978) identify both adverse and beneficial impacts caused by marinas. Among the adverse effects, the primary impacts cited are habitat loss, pollution resulting from stormwater runoff, and aesthetic (visual) pollution. Among beneficial impacts, the authors mention concentration of shoreline development (“as opposed to many scattered private docks”), and increased habitat diversity generated where substrate is provided for fouling organisms. Although habitat loss is seen as a primary adverse impact, the authors state that marinas also “provide an artificial habitat with its own unique environment,” and that associated in-water structures “can add to the biological productivity of the area and attract fish.” While documentation for this statement is not provided, an examination of the Chmura and Ross (1978) reference list suggests that marine or estuarine studies may be the source of this information. Nonetheless, the fish attraction noted by Chmura and Ross (1978) is consistent with the supporting evidence found elsewhere for docks, piers, and floats (see discussion above). However, the Chmura and Ross (1978) review provides no discussion of the potential adverse effect of such fish attraction (i.e., an increase in predation rate).

Dredging is addressed elsewhere in this series of white papers. Therefore, although dredging issues are discussed by Chmura and Ross (1978), only the general adverse effects of dredging associated with over-water structures are listed here:

- Promotion of water turbidity
- Promotion of onsite and offsite pollution
- Reduced oxygen content
- Induced burial of organisms
- Disruption and removal of bottom sediment, and alteration of benthic communities.

The Mulvihill et al. (1980) review provides an examination of the biological and physical impacts of marina placement. Harbors cause loss of benthic succession and impoverishment of substrate and water quality. Furthermore, elimination of wetland areas as productive habitat may result from cumulative effects of harbors constructed in wetland areas (Mulvihill et al.1980).

**Wharves and Pilings**

Although usually associated with docks, piers, and marinas, wharves and pilings possess their own mechanism of impact on the shore-zone habitat function and structure. Because their effects have been studied for the same categories of response as for docks and piers, some pertinent information discussed in the docks, piers, and floats section above is omitted here.

Empirical indirect evidence indicates predatory fish attraction to pilings and wharves by the following two mechanisms:

- Modification of the underwater habitat complexity, in which case predatory fish are attracted to the physical structure itself (i.e., pilings)
- Physical disruption of the water flow (i.e., back-eddies, backwater, or shear flow), resulting from flow obstruction by such structures.
These two mechanisms seem to be controlled by the shoreline configuration and its degree of natural protection, and also by the hydrological characteristics of the system. The empirical data also indicate a species-specific response of the involved predatory fish. For example, northern pikeminnow is attracted to back-eddies, backwater, or shear flow created by piling structures in free-flowing areas; whereas smallmouth bass is attracted to the piling structure. Some pertinent information in this regard is included above in the discussion of docks and piers and therefore is not discussed here.

**Predation**

Petersen et al. (1993) found that in the Colombia and Snake river reservoirs, northern squawfish feed primarily on juvenile salmonids and are associated with back-eddies created by jetty pilings. In this regard, Petersen et al. (1993) suggest that in the Columbia River, in-river obstructions below the Bonneville Dam (e.g., pilings) might make salmonids more vulnerable to predation because of the potential for aggregation in back-eddies they create. It is unknown whether this aggregation affects the out-migration rate of juvenile salmonids. Nevertheless, the implication of this behavioral response in terms of increased predation rates on juvenile salmonids may have even more profound consequences on their freshwater survival. This is because juvenile salmonids whose migratory behavior is delayed by aggregating structures may experience increased exposure to predators.

In contrast, Ward et al. (1994), studying the effect of harbor development on juvenile salmon migration and predation by northern squawfish in the lower Willamette River, found that offshore wharves supported by pilings do not have an effect on juvenile salmonid migration. The difference in location between the studies of Petersen et al. (1993) and Ward et al. (1994) may explain these contrasting results. Petersen et al. (1993) focused their study in the Columbia River in an area of free-flowing water in which jetty pilings constitute flow obstructions and create back-eddies. Conversely, the study sites of Ward et al. (1994) are located within a protected area of Portland Harbor in the Willamette River.

As with docks, piers, floats, and marinas, no studies on the effect of pilings and wharves on avian predation were found. Some unpublished data indicate that in Lake Washington, double-crested cormorants perch on individual piles (Kahler et al. 2000).

**Habitat Function**

Knutsen and Ward (1991) studied the behavior of juvenile salmonids (chinook and steelhead) migrating through the Willamette River at developed sites (i.e., with presence of wharves, pilings, floating platforms, riprap, and vertical walls) and undeveloped sites (i.e., no structure present, and mostly clay, silt, or sand bottoms, steeply sloped from dredging). They report that although there appears to be a species-specific difference between habitat occupied by migrating juveniles at undeveloped sites versus that at developed sites, variables that characterize such habitats seem to have a temporal variation.

To explain, subyearling chinook salmon were found closer to the shore in developed sites than in undeveloped sites, particularly in one site containing a wharf supported by closely spaced pilings.
(i.e., less than 10 feet apart; Knutsen and Ward 1991). This site had a completely riprapped shoreline and a shallow backwater, with a soft bottom at the downstream end of the wharf. The authors do not specify whether this backwater might have formed as a result of the existing in-water obstructions. However, the downstream location of the wharf and the bottom characteristics suggest that this backwater and associated deposition area (i.e., soft bottom) were at least partially related to the presence of the wharf. Therefore, this, and the fact that at this site the shoreline was completely riprapped, preclude possible inference of the (sole) effect of the wharf.

In general, Knutsen and Ward (1991) found that yearling chinook salmon were closer to the surface than were subyearling chinook salmon at developed sites. Subyearling chinook salmon were found closer to the shore in developed sites than in undeveloped sites. However, results from this study are inconclusive, because the authors are not able to infer whether the observed distribution is related to increased water depth at developed sites or to the presence of developments themselves (Knutsen and Ward 1991).

Nonetheless, one may argue that for future construction, at least the potential physical effect (such as creation of backwater and associated deposition areas) should be considered when placing this type of in-water structure. Increased fine sediments and detritus loading expected to occur in deposition areas such as this could adversely affect bottom-dwelling communities by embedding organisms and promoting anoxic microzones, making bottom habitats unsuitable for benthic organisms.

Although effects of treated wood piling are not addressed within the scope of this white paper, a few of the sources reviewed address this issue as an associated problem of wharves and piling structures. Within this context, two studies are of particular interest: Chmura and Ross (1978) and White (1975).

In their literature review regarding effects of marinas, Chmura and Ross (1978) found that wharves have been reported to be potentially detrimental, through blockage of light and through adverse impacts on water quality (and thereby habitat conditions) due to the treated wood pilings. Also, pilings have been reported to provide suitable substrate for periphyton and some macroalgae species growth (Chmura and Ross 1978; White 1975) and therefore have potential for habitat structure modification.

White (1975) used five experimental pilings (one control, one treated with creosote, one with ammoniacal copper arsenate, and two with pentachlorophenol) to study periphyton attachment in Lake Washington. After one month, diatoms occurred more frequently than other periphyton on all the pilings. The alga, *Cymbella* sp, was the only algal species common to all pilings. The creosote-treated piling had the greatest number of algal species growing on its surface. After one year, all but the ammoniacal copper arsenate-treated piling had extensive algal encrustment, along with many amphipods, limpets, and watermites.

This research suggests that periphyton, algae, and eventually macroinvertebrate species can colonize even treated pilings. Juvenile salmonids as well as other fish species can feed upon these macroinvertebrates species. Therefore, the presence of this source of food on piling
surfaces may be a contributing element of distribution of fish prey and thereby fish predators around piling structures.

**Log Booms and Log Rafts**

The number and body sizes of organisms using the area influenced by a floating object are directly related to the surface area of the object (Helfman 1979, 1981a). Log booms and log rafts are capable of producing a shaded area beneath their surfaces with the consequent potential for altering ecosystem functions. Therefore one would expect a relationship corresponding to that reported by Helfman (1979, 1981a) in relation to the dimensions of log booms and log rafts found in lakes and rivers of Washington. If such a relationship exists, then it is plausible that fish predator–prey interactions similar to those suggested for docks and piers may also exist in response to log booms and log rafts. Unfortunately, no published data were found directly addressing the effects of these two types of on-water structures on fish predation or behavior.

Regarding avian predation, no empirical data were found indicating a relationship between log booms or rafts and predation on fish (nor were data found showing a relationship between these structures and modification of fish behavior [e.g., migration] in freshwater environments). However, log booms have been suggested as potentially linked to avian predation on salmonids by providing perch sites for predatory birds in Lake Washington and Lake Union. In Lake Union, double-crested cormorants perch on the log booms rather than docks, bulkheads, or pilings along the lakeshore (Warner 2000 personal communication, as cited by Kahler et al. 2000).

**Habitat Function**

Three reports were found addressing the effects of log booms or log rafts in freshwater. Schuytema and Shankland (1976) studied the effects of log handling and storage on water quality and on bottom-dwelling communities at five log-rafting areas. The bottom-dwelling community included “animals” (i.e., insects, macroinvertebrates, and mollusks), “attached algae” (i.e., periphyton), and “slime growth” (i.e., bacteria of the genus *Sphaerotilus*). The study area included Steamboat and Elochoman sloughs on the north side of the Columbia River, about 4 miles downstream of Cathlamet, Washington; Coal Creek Slough on the northern edge of the Columbia River downstream of Longview, Washington; and the western edge of the Multnomah channel, which is part of the Willamette River near Scappoose, Oregon.

Schuytema and Shankland (1976) found loss of bark to be the most significant problem associated with log rafting, with effects dependent on the intensity of the activity and the flushing action of the holding water body (i.e., slough, lake, or river). Sludgeworms, which are common inhabitants of areas subjected to organic enrichment or pollution, were consistently present in areas where a high volume of bark occurred (Schuytema and Shankland 1976). In general, they found that the biologically degraded sites identified in the study had fewer kinds of organisms, higher population density, and more bark and detritus.

Schuytema and Shankland (1976) speculate that rafting activities have an adverse effect upon bottom-dwelling organisms in some reaches where log rafts have been present. The
decomposition of the log detrital material will “probably produce a habitat more conducive to the establishment of animal populations tolerant to organically enriched conditions” (Schuytema and Shankland 1976). They also found that dissolved oxygen varies with the location depending on the amount of water flow and detritus, and speculate that in areas without adequate water flow (e.g., sloughs), log rafts could adversely affect the population of bottom-dwelling organisms (Schuytema and Shankland 1976).

Schuytema and Shankland (1976) found that dredging to remove the bark was a regularly associated activity of the log rafting sites, and although not discussed in their report, it should be considered as an associated environmental problem of log rafting practices. The implication of dredging in freshwater environments is discussed in a separate white paper within this series.

Similar results have been reported for logs stored in water. Schaumburg (1973) found loss of bark from water-stored logs to be the most significant problem, as benthic depositions exert oxygen demand and may influence the biology of the benthic zone. He also found that leachates from logs held in water storage contained mostly organic substances, and that these substances exerted both chemical and biological oxygen demand. In relatively stagnant areas, the leaching rate continually decreased due to the increased levels of dissolved organic substances, whereas in flowing water the leaching rate was nearly constant for at least 80 days (Schaumburg 1973).

In terms of toxicity, Schaumburg (1973), conducting laboratory toxicity tests, found that leachate from ponderosa pine, hemlock, and older Douglas fir produced no toxicity to chinook salmon or rainbow trout fry during 96-hour bioassay studies. However, log sections without bark were found to be more toxic than comparable sections with bark intact. The 96-hour toxicity test values ranged from 20 to 93 percent (volume/volume) for leachate from young Douglas fir logs. The author speculates that the slight toxicity for young Douglas fir logs may be due to a much greater release of soluble substances into the holding water (i.e., where the fish were held during the test). No information was found addressing bioaccumulation of toxicants and their possible adverse impacts on salmonids.

Based on his findings, Schaumburg (1973) concludes that leachates from logs held in water storage do not represent a significant water quality problem. However he states that “the severity of pollution problems associated with the storage of logs depends upon the quantity of logs stored, the age, and the species of the log and flow rate of the holding water.” Unfortunately, this author did not conduct toxicity tests in the field, thereby limiting the applicability of his results to laboratory settings. For example, in storage sites, and under certain physical/chemical conditions of temperature, pH, and dissolved oxygen, log leachate in interaction with naturally occurring substances (e.g., sulfurous compounds) may have additive effects, resulting in a higher toxicity to fish.

Pacific Northwest Pollution Control Council (1971) prepared a literature review of the physical influences of log rafts and their effects on water quality. They found that bark originating from rafting and storage of logs (about 5 percent of each log’s bark layer) is a concern because of its potential to increase organic material in the water (see Pacific Northwest Pollution Control Council [1971] for the complete review of related literature and for proposed guidelines and recommendations). A further concern is the long-lasting adverse effects of bark residue in lakes.
due to the time it may take for its complete biodegradation. For example, within a lake on the Oregon coast that was used for log handling in the early 1900s, the remaining bark residue made habitat unsuitable for several decades thereafter (Pacific Northwest Pollution Control Council 1971).

The primary problems cited by Pacific Northwest Pollution Control Council (1971) associated with bark debris in water are consistent with those cited in the two studies previously discussed. The identified problems related to the accumulation of bark on the bottom are 1) a consequent reduction in dissolved oxygen in the overlying water, and corresponding creation of an anaerobic layer near the bottom, resulting in the generation of toxic sulfide compounds; and 2) burial of benthic communities.

The secondary problem cited by Pacific Northwest Pollution Control Council (1971) is associated with leachates (i.e., release of soluble organic compounds). These leachates are reported to substantially decrease the dissolved oxygen.

**Riprap and Retaining Walls**

The effects of riprap and retaining walls (i.e., bulkheads) have been broadly studied in marine environments, particularly when used as the means to armor the shoreline for protection against wave-induced erosion (from ambient waves and boat wakes). In contrast, very few sources were found directly addressing the environmental effect of these structures in freshwater environments.

In general, bulkheads are constructed to hold fill and to protect the upland by taking the brunt of wave energy (Chmura and Ross 1978). In doing so, bulkheads prevent natural seepage of groundwater into local waters and create reflection waves which disturb sediments, and encourage scouring at the base of the bulkheads (Chmura and Ross 1978).

The construction of bulkheads promotes loss of terrestrial, shallow-water, and benthic habitat. Such construction involves the use of heavy equipment that causes physical disturbance, noise, and air pollution at the site.

The physical disturbance and damage to fish and wildlife habitat caused by the construction of bulkheads depends upon 1) the type of habitat in the area before construction, 2) the shoreline location where the structure is placed, 3) the size of the structure, and 4) the construction methods. In addition, the bulkhead and associated backfilling bury established terrestrial and shallow-water flora and fauna (Mulvihill et al. 1980).

The construction of bulkheads and associated activities also cause local erosion, new sediment deposits in the vicinity of the structure, turbidity, and hence water quality degradation. New sediment deposits are often silty and thus can destroy spawning areas, smother benthic organisms, and reduce bottom habitat diversity and food supply (Mulvihill et al. 1980).
Bulkheads also promote erosion of the foreshore because of an increase in wave energy due to waves reflecting off the face of the structure. Bulkheads can also promote erosion of adjacent beaches and interfere with sand recruitment processes (Mulvihill et al. 1980).

Bulkheads constructed in wetland areas can cause extensive damage to fishes and wildlife by the following mechanisms: 1) covering narrow fringe marshes, 2) covering the waterfront edge, and 3) altering water circulation in larger shore-front marshes (Mulvihill et al. 1980).

Riprap and retaining walls are typically associated elements of over-water structures that exert a direct mechanism of impact on marine environments. These associated elements are commonly incorporated into dock and pier design as mitigation measures providing permanent erosion control of shoreline areas disturbed by the project construction. However, the empirical data found in this literature review suggest that riprap and retaining walls may produce adverse responses in aquatic organisms.

The following quotation from Jennings et al. (1999) best illustrates the ecological significance of the use of riprap and retaining walls in lakes:

*Although riprap may increase structure complexity at the scale of the individual site, when viewed at the scale of the whole lake, conversion of the entire shoreline to this one habitat type does not increase overall habitat diversity; rather, it causes a reduction. Because of this reduction of habitat diversity, conversion of unaltered shoreline to riprap should not be viewed as enhancement. However, when erosion control is necessary, riprap appears to provide beneficial fish habitat compared with retaining walls.*

Scientific information on juvenile salmonid ecology from ongoing research indicates that in both western and eastern Washington, shallow-water near-shore habitats are important sites for migration of juvenile salmonids, particularly chinook (King County 2000; Garland and Tiffan 1999; Curet 1993; Fresh 1999 personal communication; Bennett et al. 1992; Healey 1991; Rondorf et al. 1990; Dauble et al. 1989; Wydoski and Whitney 1979). These sites are important because of the abundance of prey resources and refuge from predators. Consequently, loss of rearing and foraging habitat in the shore-zone lentic and lotic freshwater environments may increase juvenile salmonid exposure to potential predators, particularly in freshwater systems such as the reservoirs of the Columbia and Snake rivers, which are used by juvenile salmonids as migratory corridors.

In the context of the effects of shoreline armoring, and comparing retaining wall versus riprap bulkheads, sites next to retaining walls tend to be deeper, primarily because the structures are usually placed below the ordinary high water mark and then backfilled. This effectively pushes the shoreline out from its original location resulting in a corresponding increase in water depth of the littoral zone. Given that, as discussed above, out-migrating juvenile salmonids (particularly chinook) use shallow-water habitats for rearing, foraging, and migration, one may argue that retaining walls may disrupt juvenile salmonid migration. In turn, the cumulative impact of this migration disruption may be an overall reduction in survival rate, as forcing juveniles into deeper water potentially affects their survival by limiting prey resource availability, thereby decreasing
their growth rate, and also by increasing their exposure to predators, thereby increasing the predation rate.

Although riprap bulkheads may cause less loss of shallow water habitats than retaining walls, because of the interstitial spaces of their more complex three-dimensional structures, they also may provide concealing habitat to salmonid predators, such as some species of sculpin (Kahler et al. 2000).

**Habitat Function**

Jennings et al. (1999), studying the relationship between habitat modification and fish assemblage, compared three types of sites in 17 Wisconsin lakes: shoreline modified by the addition of riprap; shoreline modified by the construction of a vertical retaining wall; and unarmored sites. They found that sites with riprap contained more fish species than sites in which retaining walls were constructed and, than unarmored sites. This is because riprap provides more habitat complexity (i.e., interstitial spaces for cover and food production) than retaining walls (Jennings et al. 1999). However, the authors cautioned that their results may have been an artifact of confounding variables (scale of the investigation, heterogeneity of the unarmored sites, and the increased effort required to assess species richness at unarmored sites). Beauchamp et al. (1994) also observed fish preferences for complex habitats in the context of rock-crib piers.

It should be emphasized that although shoreline armored with riprap may provide more habitat complexity than retaining walls, riprap and most manmade structures are not comparable substitutes for naturally occurring structures and aquatic vegetation. The reason may be that from the habitat viewpoint, manmade structures only simulate physical attributes at best, but lack the chemical and biological attributes of, for example, natural wood. Naturally occurring structures such as small and coarse woody debris, as well as aquatic vegetation, possess not only unique physical characteristics contributing to habitat complexity, but also chemical and biological characteristics necessary for healthy food web and predator–prey interactions (e.g., nutrients and substrate for microinvertebrates and food for prey species).

With regard to salmonids, avoidance of armored shorelines rather than aggregation has been reported (Garland and Tiffan 1999). Garland and Tiffan (1999), studying near-shore habitat use by subyearling fall chinook salmon in the Snake River, found that this species avoided bedrock cliffs and manmade boulder (riprap) areas, and was more abundant at sites where sand was the dominant substrate. Key et al. (1996) reported little use of boulders and riprap in a study conducted in the Hanford reach of the Columbia River. Bennett et al. (1992) found most subyearling chinook over sandy substrates in Little Goose Reservoir. Also, Curet (1993) reported that subyearling chinook rearing in Lower Granite and Little Goose reservoirs exhibited a strong preference for sandy areas and showed a moderate avoidance of areas containing cobble. Curet (1993) did not report capture effort over different substrate types. However, because Bennett et al. (1992) and Curet (1993) used beach seine as sampling gear, results from their studies are limited to the areas where beach seining techniques were effective.
As the preceding discussion shows, fish response to riprap varies with the species and geographical area. For example, fish assemblages like those studied by Jennings et al. (1999) in Wisconsin lakes respond to riprap and retaining walls in a different manner than subyearling chinook salmon respond to these structures in eastern Washington reservoirs.

The effect of habitat modification on macroinvertebrate abundance resulting from the addition of riprap and retaining walls has also been studied (Schmude et al. 1998). Using simulated riprap and retaining walls in three Wisconsin lakes, they found that simulated riprap supported greater macroinvertebrate abundance and species richness than did simulated retaining walls, regardless of the shoreline conditions where the simulated structures were placed (i.e., riprap, vertical retaining wall, or natural shoreline). As in other studies discussed above, Schmude et al. (1998) attribute the greater abundance of organisms found in the simulated riprap to the greater habitat complexity that this type of structure provides. They conclude that more complex, three-dimensional artificial substrate associated with riprap, with its greater substrate heterogeneity, surface complexity, and interstitial space, supports a more diverse and abundant macroinvertebrate community in lakes than does the less complex, two-dimensional artificial substrate of the retaining wall. They also speculate that the complexity of erosion control structures (i.e., bulkheads) affects the type and abundance of colonizing macroinvertebrates (i.e., riprap bulkheads support greater abundance).

From the preceding discussion, it becomes apparent that replacement of natural shorelines with simple artificial structures such as retaining walls may reduce the quality of habitat and change the community structure, through the removal of wetland and riparian vegetation and the introduction of changes to physical attributes such as shoreline slope. Removal of wetland and riparian vegetation eliminates fish and wildlife habitat, contributes to the impoverishment of water quality and quantity, and precludes future recruitment of woody debris. In this regard, Ward et al. (1994) found that in the Willamette River, the habitat type used by salmonids at an undeveloped site was unavailable at developed sites, especially at a site where the shoreline had been armored with a vertical retaining wall. They found differences in bottom slopes, water depths, and water current velocities when comparing developed and undeveloped sites.

The simplification of the shoreline (i.e., removal of structure) during the construction of retaining walls further reduces salmonid habitat. This thesis is supported by Christensen et al. (1996), who found that removal of coarse woody debris and shoreline vegetation as a result of bulkhead construction reduced refuge habitat. Christensen et al. (1996), studying 16 lakes in Northern Wisconsin, found a strong negative correlation between riparian snag density and coarse woody debris density and the shoreline cabin density at the whole lake scale. Their results demonstrate that there are substantial impacts of shoreline residential development on littoral riparian snag and coarse woody debris abundance, and that this impact is additive. Christensen et al. (1996) speculate that humans reduce coarse woody debris in lakes, apparently through direct removal as well as by altering riparian vegetation.

However, although most data found during this literature review seem to consistently show the adverse effects of bulkheads, not all of the research results are conclusive. For example, Knutsen and Ward (1991) found that in the Willamette River, physical characteristics of the near-shore zone area did not vary greatly, except when altered by structures. Shorelines associated with
structures had steeply placed riprap or vertical walls, and alteration of water depth was commonly associated with waterway developments. The authors found evidence that suggested that water depth might influence the horizontal distribution of yearling chinook salmon and juvenile steelhead. However, the results were inconclusive, and Knutsen and Ward (1991) were unable to find any significant pattern in such distribution for these fish species.

Another inconclusive study is that conducted by White (1975) in Lake Washington. He compared benthic macroinvertebrate abundance at various depths in front of different types of bulkheads, and found that reflected wave action associated with the bulkhead did not displace organisms. However, clear trends of macroinvertebrate abundance were not found, as benthic populations at similar bulkheads often varied, thus precluding any conclusive evidence (White 1975).

**Shore-Zone Habitat Structure Changes – Summary of Findings and Data Gaps**

**Summary**

Figure 1 schematically depicts the relationships among impacts resulting from changes induced by on-, in-, and over-water structures and associated construction and operational activities. As illustrated in this figure, on- and over-water structures alter the shore-zone habitat structure, resulting in changes to fauna and flora. Changes in the habitat structure may result in salmonid behavior disruption, which may then affect predation rate. Pile driving and removal and other construction and operational activities cause short- and long-term habitat impacts. Short-term impacts are associated with noise disturbance and water quality impairment during construction. Long-term impacts associated with the presence and operation of the structure may include physical damage to aquatic organisms and a reduction in primary production. Both the presence of structures and the impacts arising from the associated construction and operational activities can disrupt the food web and thereby affect the ecosystem.

The following is a summary of findings of this review pertaining to shore-zone habitat structure changes, organized by the observed type of response.

**Predation**

- Bass are major juvenile salmonid predators, likely due to the overlap in rearing habitat.

- In reservoir systems of eastern Washington, juvenile salmonid predation is specific to the behavior and distribution of each salmonid species and of its predator. The behavior and distribution of predator and prey species reportedly depend on temperature, the degree of shore-zone development, slope and substrate of the shoreline, and the presence of manmade in-water structures.
Figure 1. Impacts resulting from changes induced by on-, in-, and over-water structures and associated construction and operation activities.
In the Colombia and Snake river reservoirs, northern pikeminnow is an important predator of juvenile salmonids because of their inshore preferences and preference for low velocity microhabitats, which are created by in-water structures.

Habitat used by fish may influence bird prey selection, and in general, cover reduces success of their capture by predatory birds.

**Behavior**

- Docks, piers, and floats reportedly attract fish, this being the main effect of these over-water structures on fish behavior.

- Over-water structures may affect the survival of organisms (particularly juvenile salmonids) by providing a focal point for predatory fish aggregation, effectively altering predator-prey interactions.

- Although it is not clear which features (e.g., shade, tactile stimuli) of over-water structures attract bass, bass have been observed foraging and spawning in the vicinity of docks, piers, and pilings.

- The shade produced by houseboats and floats versus the shade produced by fixed-height structures may induce different responses in fish.

- Different fish species respond differently to the shade produced by over-water structures.

- Smallmouth bass and largemouth bass have a strong affinity to habitat structures including piers, docks, and associated pilings.

- Fish, particularly largemouth bass, rather than being attracted to the physical structure of experimental floats, seem to be attracted to the shade they produce. In contrast, smallmouth bass do not seem to be attracted to the shade produced by such structures.

- In free-flowing systems, pilings can create back-eddy microhabitats due to the physical disruption of the water flow, thereby attracting northern pikeminnow and perhaps juvenile salmonids to such habitats.

- Bulkheads adversely affect the migration and thereby the survival of juvenile salmonids by diverting them into deeper waters along armored shorelines.

- In the Snake River, subyearling fall chinook salmon avoid bedrock cliffs and manmade boulder (riprap) areas.
The fish response to riprap and retaining walls varies with the region and the species.

**Habitat Function**

- The cumulative effects of shoreline development that accompany the construction of over-water structures, may be the main determinant of adverse effects on fish assemblages at the basin level.

- Over-water structures and associated construction and operation activities adversely affect juvenile salmonids by providing habitat for predators adjacent to natural refugia for migratory juvenile salmonids, such as coarse woody debris. Construction and placement of the over-water structures also affect juvenile salmonids by reducing refugia such as coarse woody debris.

- To be effective, artificial habitat structures used in restoration projects must be designed with attention to the needs of resident and desired species and consideration of the prevailing physical factors in a particular river or stream.

- In streams, rivers, and lakes, survival and distribution of salmonids is limited at least partially by water temperature.

- The number and body size of organisms using an area influenced by a floating object are directly related to the surface area of the object.

- Bark originating from log booms and rafts is reportedly the most significant problem associated with log rafting. This is because when bark accumulates on the bottom it may promote 1) a reduction in dissolved oxygen in the overlying water and a corresponding anaerobic layer near the bottom, resulting in the generation of toxic sulfide compounds; and 2) burial of benthic communities.

- The construction of bulkheads causes loss of terrestrial, shallow water, and benthic habitat, and thereby, loss of organisms.

- Bulkheads promote erosion of the foreshore and adjacent beaches, and interfere with sand recruitment processes.

- Due to its greater complexity, riprap reportedly has a greater potential than do vertical walls for maintaining the density and diversity of fishes and macroinvertebrates. However, armoring in general is detrimental to the environment and to organisms.
Data Gaps

No empirical data were found to support several of the processes depicted in Figure 1. Where empirical data are lacking, inferred and hypothetical associations have been drawn. The matrix of data availability in Appendix B shows where data exist for each of the categories of response studied in this white paper (i.e., predation, behavior, and habitat function).

Through this literature review, the following information needs have been identified (organized by the observed type of response):

Predation

- What are the effects of in-, on-, and over-water structures on predator-prey interactions?
- What are the predator-prey behavioral responses to each type of over-water structure and to shore-zone development in general?
- Do the over-water structures affect the predation rate on salmonids or other species? Would changes in design eliminate or minimize the effect?
- Does temperature affect the sockeye salmon and bass habitat overlap in Lake Washington?
- In reservoirs of eastern Washington, does temperature control the duration of shoreline residence of subyearling fall chinook, thereby affecting their habitat overlap with bass?
- What is the effect of over-water structures and shoreline development in general on avian predation?

Behavior

- Are bass attracted to the shade or to the physical structures (or both) of piers, dock, and floats?
- Is the food-web interaction of prey fishes an attracting feature of docks, piers, and associated pilings?
- In free-flowing areas of rivers and reservoirs of eastern Washington, do low-velocity microhabitats increase juvenile salmonid predation by providing aggregating habitat for northern pikeminnow and perhaps juvenile salmonids as well?
- Do on-water structures (e.g., boathouses and log rafts) induce the same effect on the behavior of organisms as over-water structures?
Why do subyearling fall chinook salmon avoid bedrock cliffs and manmade boulder (riprap) areas in the Snake River? Does this avoidance expose them to increased predation?

**Habitat Function**

- Do fish respond to the actual shoreline structures, or to the habitat characteristics resulting from riparian zone alterations (e.g., vegetation and woody debris removal) associated with placement of the structures?
- What is the relationship between the cumulative effects of increased number of docks in Lake Washington and the decline in sockeye salmon freshwater survival?
- Can the effects of shoreline development be fully mitigated? How?
- Can habitat function in highly developed shore-zone areas be restored? How?
- In lakes and slow-flowing rivers and reservoirs, does large woody debris enhance salmon habitat or provide habitat for salmon predators?

**Shading and Ambient Light Changes**

Light is very important in the life of organisms. For juvenile salmonids, light is necessary for orientation, prey capture, schooling, predator avoidance, and migration navigation (Simenstad et al. 1999). Docks, piers, pier skirting, floats, houseboats, boathouses, barges, marinas, pilings, wharves, log booms, and log rafts all shade aquatic habitat and limit ambient light, affecting macrophyte and phytoplankton primary production. This shading could result in a decreased survival rate, or at least promote behavioral changes in various components of the biological community. Lighting associated with these structures may possibly alter fish species behavior, posing increased risk of predation and causing disruption of fish migration patterns. Empirical evidence exists (see discussion below) that indicates that changes in the underwater light environment may have an impact on juvenile salmonid physiology and behavior (Simenstad et al. 1999).

**Predation**

No data were found supporting a direct link between lighting and an increase in predation of fishes. Research results found were inconsistent, however may provide insight into the effects of lighting associated with over-water structures with regard to increased predation.

For example, under varying light intensities, within the natural range of light intensities occurring at night, it has been shown that predation rates on juvenile salmonids increase with
increasing light (Patten 1971; Ginetz and Larkin 1976; Mace 1983, as cited by Tabor et al. 1998).

In contrast, Tabor et al. (1998) in conducting freshwater laboratory experiments found decreased predation rates at higher light intensity. These researchers speculated that rather than increased inhibition of sculpin predatory behavior, the light may have actually influenced salmon behavior, by enhancing the ability of the fry to detect and avoid sculpin, which resulted in reduced predation. Tabor et al. (1998) proposed that differences in study components (such as salmonid species, environment) between their work and earlier studies of Patten (1971) and Mace (1983, as cited by Tabor et al. 1998) may explain the difference in the results they found.

Tabor et al. (1998) in the analysis of their research results, speculated that the reason increased predation did not occur may have been a result of the predator being sculpin, a non-obligated visual fish. In the darkness, sculpin may use some other sensory mechanism besides vision (i.e., their lateral line) to detect prey and therefore, the increase in light intensity may not have enhanced its foraging ability. However, these researches suggested that in the case of visual predatory fish such as cutthroat trout, rainbow trout, juvenile coho salmon, as well as some bird species, increased light intensity might result in an increased predation rate on juvenile salmonids. Consequently, studies using any of these visual species might find an increased predation rate correlated with increased light intensity. The speculation of Tabor et al. (1998) regarding their research results may not be accurate, as other research shows. For example, Petersen and Gadomski (1994) found in laboratory experiments with increasing light intensity a decreasing predation rate between northern squawfish (a visual predator) and juvenile chinook salmon.

In addition to differences in experimental condition, the reason for the lack of consistency in the aforementioned research results may be that simultaneous variables contribute to the effect of potential light-mediated predation rates on juvenile salmonids. In the field, physical/chemical and biological variables may have confounding, interrelated, and simultaneous interactions on fish responses to artificial light associated with over-water structures. To better interpret research results providing indirect evidence of the adverse effect of lighting on fish, such variables need to be studied and further understood. Unfortunately, this is usually difficult, particularly when field experiments are performed.

One example of a physical variable confounding the results of experiments on the effects of light on fish is a study conducted by Vogel and Beauchamp (1999) regarding the effects of light, prey size, and turbidity on reaction distance of lake trout (Salvelinus namaycush) and salmonids. They found that with increasing light, reaction distances increased rapidly (i.e., from less than 25 centimeters at 0.17 lux to about 100 centimeters at a light threshold of 17.8 lux). Above this threshold, increasing light contributed no further advantage for prey detection and therefore no further risk to prey. Vogel and Beauchamp (1999) also found that the “reaction distance declined as a decaying power function of turbidity.”

Artificial light associated with shoreline development can also have an effect on predation of juvenile salmonids through the alteration of their migratory behavior. It has been proposed that in the Cedar River, increased artificial light intensity levels may delay fry emigration and cause
fry to move to areas of lower water velocity where most predation appears to occur (Tabor et al. 1998). Therefore, one might expect that a delay in emigration due to the increasing incidence of nighttime lighting associated with shoreline development or over-water structures could lead to increased predation on emigrating fry. However, this has yet to be researched.

**Behavior**

Regarding fish attraction to shade and its potential effect on predation, Helfman (1979) found that in Cazenovia Lake, New York, experimental floats attracted prey fishes (small bluegill and adult golden shiner) and suggested that this aggregation may attract predatory fish species. However, this conjecture was inconclusive in this study. Helfman (1979) speculates that largemouth or smallmouth bass would gain an element of surprise by hovering in shaded regions. Conversely, prey fish would have an advantage by being able to see approaching predators before the predator sees them. This is because floats are shade-producing objects, which reduce the conspicuousness of fish in shade while enhancing their ability to view predators approaching from sunlit surroundings.

As juveniles, predator fish might also seek protection from their own predators by occupying shaded areas. Helfman (1979) speculates that attraction of predatory fish to floats might be because of predator-protection-seeking behavior imprinted as juveniles. Consistent with this, Haines and Butler (1969) show that structures that provide darkness are most often selected by yearling smallmouth bass.

Shade from over-water structures may have effects other than those reported by Helfman (1979) that promote fish aggregation under shade-casting structures. On a species-specific basis, those effects may vary with fish physiology. For example, in their review, Simenstad et al. (1999) analyzed empirical data pertaining to the juvenile salmonid light perception in the context of behavior and physiology. Their review indicates that 1) ambient and artificial light have been reported to induce behavioral responses consistently different between species and ontogenetic stage, and the responses vary with the dispersal patterns of the species; 2) upon a stimulus, the progression of changes the fish eye must undergo from one state to another is influenced by the intensity of the introduced light to which the fish has been exposed; and 3) there are threshold light intensities for different behaviors of juvenile salmonids.

Thus, one may argue that the shade cast by over-water structures that occur over juvenile salmonid migratory corridors may disrupt their migration by creating visual barriers and promoting disorientation. Over-water structures such as docks can create sharp underwater light contrasts by both casting shade and casting light (from lighting) under ambient daylight and nighttime conditions respectively (Simenstad et al. 1999). In this regard, there is empirical evidence which indicates that changes in the underwater light environment will have an impact on juvenile salmonid physiology and behavior, and these changes may pose a risk of affecting fish migration behavior and increasing mortality risk. (See Simenstad et al. 1999; a full review is beyond the scope of this white paper.)

Similarly, it has been suggested that changes in light intensity may modify the behavior of sockeye salmon fry (Tabor et al. 1998). Tabor et al. (1998), conducting simulated stream
experiments, found that increased light, especially that above natural levels, appears to slow or stop emigration of fry, which makes them more vulnerable to predation by sculpin. Tabor et al. (1998) found that as light level increased, and in the absence of sculpin, fry emigrated downstream at a slower rate. In the presence of sculpin, fewer fish emigrated but did so at a faster rate than in the absence of sculpin (Tabor et al.1998). Similarly, McDonald (1960) found that the downstream migration of sockeye and coho salmon fry was closely related to light intensity. He found the presence of artificial lights over experimental stream channels at night inhibited the downstream migration of sockeye and coho salmon fry in these channels until the lights were extinguished. Consistent with this finding, Godin (1981), based on a literature review of diel timing of salmon fry migration, indicates that natural light intensity appears to be the major environmental factor controlling the daily onset and termination of the downstream and upstream migrations of salmonid fry. His findings indicate the physiology of these organisms is involved in the process. As changes in the underwater light environment will have an impact on juvenile salmonid physiology (Simenstad et al. 1999), it follows that both the artificial light associated with over-water structures and the shade that these structures produce have a potential for disrupting salmon fry migration and thereby increasing exposure to predators.

In terms of fish attraction to lighting generally, the only data found during this literature review comes from an indirect source (Collis et al. 1995). While conducting an unrelated study on northern squawfish predation on salmonids, Collis et al. (1995) observed that juvenile salmonids were attracted (i.e., surfaced) to work lights in a Columbia River reservoir. However, such attraction may not hold in all systems and for all different ontogenetic stages (Simenstad et al. 1999). In many different second and third order creeks on the Olympic peninsula, night snorkel surveys of juvenile salmonids indicated no attraction to the light produced by flashlights when shined from under the water or from the surface (Carrasquero 1997 unpublished observations). Instead, fry and presmolt salmonids held position, at times even regardless of the proximity of the surveyor.

**Habitat Function**

In terms of the effects of on-and over-water structures on the light environment, another concern of shading and ambient light changes relates to the potential effects on habitat function. This includes reduction of the ambient light beneath a structure due to light obstruction by an over-water structure (shading), as well as changes of the ambient light (increase in intensity) due to lighting associated with the structure.

As noted previously, shading can affect habitat function by creating visual barriers to migrating fish. The physical design and elements of the over-water structure (i.e., deck height and width, piling numbers and type, pier skirting and batter boards, etc.) can influence whether the shadow cast on the near shore covers a sufficient area and has sufficient intensity to constitute an underwater visual barrier for fish (Simenstad et al. 1999). Also, to the extent that phytoplankton and aquatic macrophytes require light during photosynthesis, over-water structures that reduce or modulate the amount of light will ultimately affect macrophytes beds and reduce phytoplankton primary production, with corresponding effects on habitat function, the food web, and consequently the ecosystem.
Because epibenthic communities depend on light (of certain intensity) to persist, artifacts that may diminish light intensity beneath a structure will affect such communities and their habitat. For example, shading from pile-supported structures may modify wetland habitat, and depending on the amount of shading, algae and aquatic vegetation that occur beneath the structure may be reduced or absent (Mulvihill et al. 1980). However, piling and piers offer substrate for algae to grow in areas where bottom depth is below the photic zone or presents unstable sediment conditions (Mulvihill et al. 1980). A loss of phytoplankton primary production due to shading may be compensated by the primary production of algae that grow on pilings, particularly in areas with bottom conditions as described above.

In this regard, White (1975) studied the light intensity under and outside over-water structures to determine whether structures significantly reduced the amount of light available for primary production of phytoplankton. Not surprisingly, he found that light intensity was higher outside over-water structures compared with intensities beneath the structures, as a result of shading from the structures. However, surface phytoplankton production at the edge of a large over-water apartment complex and under narrow residential piers, exceeded those measured outside over-water structures. White (1975) explains these results as a natural inhibition of production that occurs at the surface of water due to light conditions, which are higher than those in which algae thrive. He suggests that under narrow residential piers, at approximately one meter beneath the over-water apartment complex, light intensity may be reduced to “optimal,” resulting in higher primary production. White (1975) did not study the abundance or distribution of macrophytes under or outside the docks and piers, nor did he investigate the loss of primary production due to the reduction of macrophyte vegetation. Clearly, the loss of macrophyte vegetation due to the placement of over-water structures drastically affects primary production.

In terms of the surface area covered by piers, although suggesting that narrow residential piers do not significantly reduce phytoplankton primary production, White (1975) concludes that there is an inversely proportional reduction in such production due to the reduction of light. White’s (1975) findings that there were no significant reductions of phytoplankton primary production, do not take into consideration the cumulative effects of individual piers. Analysis of alterations occurs primarily at the spatial scale of individual, recreational, and residential properties, the effects are incremental and cumulative in nature (Jennings et al. 1999).

One may argue that a shaded underwater area beneath an over-water structure is essentially a new and different habitat from that which previously existed. This shaded habitat possesses intrinsic physical characteristic that will promote changes in various interrelated parameters such as light intensity, temperature, primary production and consequently, dissolved oxygen (Simenstad et al. 1999). It is expected that the design (i.e., dimensions, materials, and location in relation to the sun path) and flow conditions at the selected site will influence how much such parameters change, due to the shade cast by the over-water structures. In turn, these changes may induce responses in the biological community with ecological consequences, which are still poorly known and much less well understood.

Shade-producing structures can introduce changes to fish assemblages and distributions, which in turn may affect the local communities, and therefore the systems they inhabit. Helfman (1979, 1981a) studied fish attraction to shade producing objects and to experimental floats in Cazenovia...
Lake, New York. The experiments were conducted using underwater human observers and cameras. He found the number of fish aggregating beneath shade-producing objects is directly proportional to the size of the objects. Helfman (1981a) suggests that the amount (or depth) of shade produced is a determinant of the observed attraction phenomenon. Helfman (1979, 1981a) concludes that shade, interacting with water clarity, sunlight, and vision, is an important factor in attracting temperate lake fishes to overhead structures. In this regard, the major determinant of the apparent attraction of shade producing objects to fish is the relative visual advantage of a shade versus a sunlit observer (Helfman 1979, 1981a; Helfman et al. 1997). For example, during the day, largemouth bass are typically found near cover, which shields them from high light intensities and may provide a concealed vantage point for the occasional ambush of prey (Helfman 1981a).

The associated problems of shading are not exclusive to docks, piers, or associated piling structures. Floats can also shade the underwater environment in a fashion directly proportional to the site and shape of the structure. However, shaded areas caused by floats are usually small, and therefore a measurable effect is not expected (Mulvihill et al. 1980). No published empirical evidence of the specific effect of floats on habitat function was found.

Shading and Ambient Light Changes – Findings Summary and Data Gaps

Summary

Figure 2 schematically depicts the relationships among impacts resulting from changes induced by on-, in-, and over-water structures and associated construction and operational activities. As illustrated in Figure 2, these structures shade the underwater environment and limit the daylight available for photosynthesis, thus restructuring communities. Construction and operational activities associated with these structures impair water quality and promote algal blooms, thus reducing light penetration and disrupting salmonid behavior. Ultimately, these impacts disrupt the food web and in turn the ecosystem.

The following is a summary of findings of this literature review pertaining to shading and ambient light changes, organized by the observed type of response.

Predation

- In different species and under different environmental conditions, predation rates in juvenile salmonids have been shown to both increase and decrease with increasing light.

- With increasing light, reaction distances increase rapidly but only within a threshold, above which increasing light contributes no further advantage for prey detection. The reaction distance declines as a decaying power function of turbidity.

- Large or smallmouth bass may gain an element of surprise by hovering in shaded regions.
Figure 2. Impacts resulting from changes induced by on-, in-, and over-water structures and associated construction activities.
Behavior

- Ambient and artificial light have been reported to induce consistently different behavioral responses between species and ontogenetic stage, and the responses vary with the dispersal patterns of the species.

- Upon a stimulus, the progression of changes the fish eye must undergo from one state to another is influenced by the intensity of the introduced light to which the fish has been exposed.

- Changes in light in the underwater environment affect juvenile salmonid physiology and behavior. This is because there are threshold light intensities at which different juvenile salmonid behaviors occur.

Habitat Function

- Shading affects habitat function by creating visual barriers to migrating fish.

- Shading from pile-supported structures modifies the water temperature and wetland habitat, and depending on the amount of shading, algae and aquatic vegetation that occur beneath the structure are reduced or eliminated.

- The shade produced by a piling-supported pier promotes a loss of phytoplankton primary production. However, this may be compensated by the primary production of algae that grow on pilings, particularly in areas where the bottom depth is below the photic zone or presents unstable sediment conditions.

- Narrow residential piers may not significantly reduce phytoplankton primary production, but there is an inversely proportional reduction in production due to the reduction of light.

- The cumulative effects of even narrow residential piers are detrimental to the environment.

- Shade interacting with water clarity, sunlight, and fish vision is reportedly an important factor in attracting temperate lake fishes to overhead structures.

Data Gaps

No empirical data were found to support several of the processes depicted in Figure 2. Where empirical data are lacking, inferred and hypothetical associations have been drawn. The matrix
of data availability in Appendix B shows where data exist under each of the categories of response studied in this white paper (i.e., predation, behavior, and habitat function).

Through this literature review, the following information needs have been identified (organized by the observed type of response).

**Predation**

- Is there a relationship between lighting and predation on juvenile salmonids?
- Do large or smallmouth bass gain an element of surprise by hovering in shaded areas under over-water structures?
- What is the relationship between reaction distance decline (due to turbidity) and fish predation rate?

**Behavior**

- Does lighting from shoreline development and associated over-water structures disrupt or delay juvenile salmonid migration? Would this disruption have an effect on predation on juvenile salmonids?
- What is the relationship between impacts on juvenile salmonid behavior resulting from light changes in the underwater environment and changes in predation rates?
- Do changes in light intensity modify the behavior of sockeye salmon fry? Would this behavior modification make them more vulnerable to predation?
- Do algal blooms originating from nutrient loading disrupt salmonid migration?

**Habitat Function**

- What are the cumulative impacts of over-water coverage on primary production in various lakes and reservoirs of eastern and western Washington?
- How does the design of structures (i.e., dimensions, materials, and location in relation to the sun path) influence organism responses? Do these responses vary among species or systems?
**Over-Water Structures: Freshwater Issues**

**Water Flow Pattern and Energy Disruption**

Docks, piers, marinas, pilings, wharves, riprap, and retaining walls all have the potential to disrupt water flow patterns and energy. This disruption can lead to alteration of the distribution and abundance of sediment, vegetation, and detritus. In turn, alteration of these elements can restructure important habitat features, thereby affecting the biological community.

**Docks, Piers, and Floats**

**Habitat Function**

Lorang et al. (1993) studied the effects of lake level regulation and over-water structures on shoreline changes in Flathead Lake, Montana. They characterize two types of systems: 1) reflective systems characterized by dynamic gravel beach faces and steep in-shore shelves armored by wave-washed cobble, and 2) dissipative systems characterized by sand-sized substratum, broad in-shore flat shelves, and the presence of multiple linear bars approximately 350 meters offshore. They also found that piers, which intercept gravel transport, accelerated beach (backshore) erosion on “the downdrift side, and heavy aggregation of migrating gravels occurred on the updrift side.” Erosion on reflective beaches was induced by continuous wave action during the much longer full-pool period (due to lake level regulation), resulting in fore-and back-shore erosion and loss of riparian vegetation (Lorang et al. 1993).

Kahler et al. (2000) speculate that in Lake Washington, which experiences a water level regime similar to that of Flathead Lake, similar processes may occur, with the corresponding effect on riparian and emergent vegetation. They further speculate that gravel interception around shore-zone structures could potentially increase the availability of suitable spawning habitat for smallmouth bass in Lake Washington (Kahler et al. 2000).

Similar processes also occur in reservoir systems of eastern Washington (e.g., the Columbia and Snake river reservoirs; Independent Scientific Group 1996). The fluctuating water levels in those regulated reservoirs prevent the establishment of riparian vegetation. This zone in which riparian vegetation does not become established, called the “varial zone,” includes all the shallow, low-velocity habitats within the river channel of all regulated river segments in the Columbia basin (Independent Scientific Group 1996). Because of such a pattern of water level regulation, one might expect the gravel accumulation process to occur around shore-zone structures, with the corresponding effect on smallmouth bass habitat.

In areas with exposed banks, boat-induced waves moving along the exposed bank at the speed of the boat can erode the slopes, suspending sediments and removing aquatic plants and benthos (Warrington 1999a). Although armoring of the shoreline may be seen as a potential solution, retaining walls, groins, or riprap are not acceptable solutions because these methods often destroy as much habitat as the problems they are designed to treat (Warrington 1999a).

In general, loss of emergent vegetation can promote erosive cycles that preclude the recovery and reestablishment of such vegetation. Erosion of shorelines that cause a decrease in emergent vegetation will also promote changes in sediment transport patterns. This further increases emergent vegetation loss and, in turn, will promote more shoreline erosion (Rolletschek and Kuhl 1997).
Water Flow Pattern and Energy Disruption – Findings Summary and Data Gaps

**Summary**

Figure 3 schematically depicts the relationships among impacts resulting from changes induced by in- and over-water structures. As illustrated in this figure, over-water structure impacts alter habitat function directly through the loss of riparian and emergent vegetation, and indirectly through shoreline erosion. The loss of riparian and emergent vegetation results in further shoreline erosion, creating an erosive cycle that further increases vegetation loss, with a resultant adverse effect on nutrient cycles. In-water structures alter the water flow pattern, create microhabitats, and disrupt fish behavior, which may affect predator–prey relationships. Both in- and over-water structures can thereby disrupt the food web and thus adversely affect the ecosystem.

The following is a summary of findings of this literature review pertaining to water flow pattern and energy disruption.

- Piers, which intercept gravel transport, may accelerate beach erosion and promote heavy aggregation of migrating gravel. This gravel aggregation, if around shore-zone structures, may increase the availability of suitable spawning habitat for smallmouth bass in such water bodies as Lake Washington.
- In areas with exposed banks, boat waves can erode the slopes, suspend sediments and remove aquatic plants and benthos.
- Loss of emergent vegetation promotes erosive cycles that preclude the recovery and reestablishment of such vegetation.
- Retaining walls and riprap are not acceptable solutions to shoreline erosion, because these methods are often as damaging to habitat as the conditions they are designed to treat.

**Data Gaps**

No empirical data were found to support several of the processes depicted in Figure 3. Where empirical data are lacking, inferred and hypothetical associations have been drawn. The matrix of data availability in Appendix B shows where data exist under each of the categories of response addressed in this white paper (i.e., predation, behavior, and habitat function).

Through this literature review, the following information needs have been identified (organized by the observed type of response).

**Predation**

- Does disruption of flow pattern and energy have any influence on predator-prey interactions?
- Do in-water structures that promote fish aggregation by creating slow-flowing-water microhabitats have an effect on the food web?
Figure 3. Impacts resulting from changes induced by in-, on-, and over-water structures.
Behavior

- What effect does disruption of water flow pattern and energy have on behavior of various aquatic organisms, particularly salmonid fishes and their predators?

- Do in-water structures that disrupt fish behavior affect predator-prey interactions?

Habitat Function

- Does gravel aggregation around shore-zone structures affect bass population density and distribution?

- Are erosive cycles that preclude the recovery and reestablishment of emergent vegetation at work in eastern and western Washington systems? How could they be prevented?

Indirect Mechanisms of Impact

Physical/Chemical Environmental Disruption: Construction and Operation Activities

Although little studied in freshwater environments, the indirect effects of the physical/chemical processes associated with the construction and operation of over-water structures are widely recognized. Chmura and Ross (1978), Mulvihill et al. (1980) and Kahler et al. (2000) all provide literature reviews of direct and indirect effects of over-water structures documented in studies of marine estuarine and freshwater environments. A more comprehensive literature review of the impact of over-water structures on the physical environment can be found in the Over-Water Structures: Marine Issues white paper.

Physical/chemical environmental disruption due to construction and operation activities of over-water structures can have both temporary and permanent effects, and are related to noise disturbance and water quality degradation (Chmura and Ross 1978; Mulvihill et al. 1980; Kahler et al. 2000). For example, building an over-water structure involves pulse phenomena during the period of construction (e.g., pile driving, movement of sediments, release of chemicals from building materials), but these stop as soon as, or shortly after, the construction is complete (Underwood 1991). The over-water structure may, however, also cause long-term, possibly permanent adverse changes in such variables as water circulation (flow) and release of sewage or oil from boats. Any of these may cause an adverse environmental response (Underwood 1991).

Pile Driving and Removal

A major cause of disruption during construction of over-water structures is related to pile driving and removal. The effects of pile driving and removal on the habitat and its biological community typically result in localized sedimentation problems, disturbance of pollution-laden
sediiments, and disruption of normal organism behavior, particularly that of fishes. This can occur through two mechanisms. First, shock waves generated by pile driving may disrupt spawning, rearing, and migratory fish behavior temporarily. Second, pile removal may promote burial of bottom-dwelling organisms and affect water quality by reincorporating pollutants into the water column, making them more readily bioavailable. The latter mechanism can have both temporary and permanent effects.

In general, construction activities (such as pile driving) that disturb the bottom sediments also increase turbidity and can affect bottom-dwelling aquatic organisms, remove submerged aquatic vegetation, drive away fish and other mobile organisms, and alter existing habitat at the structure site (Mulvihill et al. 1980). Turbidity can clog gills of fish and other organisms, and toxic material and silt suspended by construction activities can have a detrimental effect on the biota of the immediate area (Mulvihill et al. 1980). Turbidity effects are most significant for juvenile stages and sessile organisms. In addition, dislodging of organisms can cause spree (i.e., feeding frenzy behavior) by predators during construction periods (Mulvihill et al. 1980).

No freshwater studies showing field data on the effects of pile driving on fishes were found. One published marine study (in Puget Sound) on the effects of pile driving on salmonids was located. However, because underwater sound attenuation due to salinity (i.e., water density) is negligible over the distances of interest at the infrasound frequencies important for salmonid avoidance response, empirical species-specific data from studies conducted in marine and estuarine environments can be extrapolated to freshwater environments (Carlson 2000 personal communication). However, direct extrapolation of data from one species of fish to another is not practicable, because there is a high level of inter-specific variation in hearing capabilities of fishes (Popper 1997). Therefore, results obtained in marine environment studies should be applied to freshwater systems only on a species-specific basis.

For a better understanding of the effects of pile driving on fishes, the paragraphs below summarize the basic principles of underwater acoustics and the structures and function of the fish ear and lateral line, as well as known fish responses to sound. This brief presentation is followed by a review of the published literature on the effects of pile driving.

Sound is defined as a density disturbance that propagates energy through a medium (Popper and Carlson 1998). In water, the energy in a sound wave is contained in the oscillatory movement of water particles and in the pressure that a sound wave originates. Diminution of sound, which results from a decrease in its amplitude due to geometric spreading and attenuation, is a function of distance. Diminution of sound through attenuation is induced by mechanical and chemical factors (e.g., salinity); hence it is also a function of the oscillatory movement of water particles as well as water density (Popper and Carlson 1998).

Fishes detect both the particle motion and pressure components of sound fields using two sensory systems, the ear and the lateral line. Both sensory systems use similar mechanosensory hair cells as transducing structures for signal detection, and both sensory systems respond to similar types of signals (Popper and Carlson 1998). The ear responds to position and acceleration of the body. The lateral line responds to differences between motion of the body and motion of the surrounding water, including stimuli (ranging from less than 1 hertz to several...
hundred hertz) produced by other swimming fish and other organisms (Popper and Carlson 1998). The ability of fishes to detect the pressure components of sound is species-specific.

Because the body of a fish is about the same density as the surrounding water, density discontinuities are needed within the body for sound detection to occur. These discontinuities consist of the otoliths (in the inner ear) and the swim bladder. The otoliths are at least three times more dense than the rest of the body. The swim bladder undergoes volume changes in a pressure field because it is filled with a compressible medium, thus acting as a secondary sound source in close proximity to hearing structures (Popper and Carlson 1998). This volume change generates a secondary sound field that enables a fish to detect pressure signals with the ear, either through direct coupling with the inner ear or by generating water particle movement (Popper and Carlson 1998; Fay 1997; Sand 1997). However, the efficacy of the swim bladder in exciting the fish ear depends upon the swim bladder’s proximity to the ear or direct mechanical connections by fluid-filled ducts, arrangements of bones, or other means. For example, in hearing generalist species such as salmonids, the swim bladder is relatively far from the ear, and enhancement of hearing by the swim bladder appears to be insignificant (Fay 1997; Popper and Carlson 1998). Consequently, salmonids are poorly equipped to detect sound unless they are close to a source where most of the energy in the sound field is carried by pressure.

Wild and hatchery fry and smolts of Pacific salmon and steelhead exhibit an innate avoidance response to infrasound within the frequency range of 8 to 30 hertz (Carlson 1996). The level at which a fish can detect a sound depends upon the level of background noise. The sound must be at least 10 decibels more intense than background noise to be detected; otherwise it is masked by the background noise (Popper and Carlson 1998). Salmonids have a rather poor hearing capability; hence the background noise of the environment (and thereby the masking effect) is not as important in salmonids as in other fish species (Popper and Carlson 1998).

Intense sound (180 to 200 decibels referenced to 1 μPa) can damage the mechanosensory hair cells of fishes. The effect of intense sounds may be more injurious to fish species with highly sensitive hearing (i.e., hearing specialists) such as the northern pikeminnow, and less so to fishes with poor hearing capabilities (i.e., hearing generalists) such as salmonids.

Short-term exposure (for a few minutes) to intense sound may not damage inner ear or lateral line sensory receptors. Consequently, if fishes are able to leave the ensonified area (i.e., the area immediately adjacent to the sound source), their receptors may not be mechanically damaged. Conversely, if fishes remain in the area exposed to strong sounds for extended periods, their receptors may be damaged or some other component of the hearing system may be affected. Nonetheless, sound in general may result in other stress effects, such as decreased growth, increased susceptibility to disease, and impaired reproduction, even in hearing generalist fishes (Popper and Carlson 1998). The effects of intense sound that do not result in easily observed changes in fish behavior or mechanical injury to fishes, such as shearing of hair cells, have not been studied to any extent.

Given that fish eggs and embryos cannot leave the ensonified area, these developmental stages may be adversely affected by sound energy generated by pile driving activities; this has not been studied, however. In this regard, the Washington Department of Fisheries, in a memorandum
dated January 13, 1981, recommends a minimum distance needed to protect the eggs of lakeshore spawning sockeye in Lake Washington (WDF 1981). The recommendation consists of establishing a protection area of 300 feet around sockeye spawning sites. This recommendation is based on the analysis of peak energy release and duration data for sound originating from the detonation of explosives during demolition activities.

The energy release during pile driving and detonation of explosives has a short peak period of discharge at which maximum energy release occurs. For pile driving, WDF (1981) estimates that this energy would be measurable within 100 feet of the source. However, pile driving has a relatively longer peak period of discharge than detonation of explosives. Therefore, because the distance at which the energy is felt increases in proportion to the length of the peak discharge, WDF (1981) suggests that the estimate of 100 feet be tripled, and that this new value (i.e., 300 feet) be used to establish the protection area.

It is worth noting that at present sockeye is not the only lakeshore spawner that occurs in Lake Washington. In recent years, chinook salmon have been observed spawning in lakeshore areas of Mercer Island and Lake Union (Fisher 2000 personal communication; Quinn 1999 personal communication; Kinnison 1999 personal communication). Therefore, in Lake Washington, the concern regarding potential pile driving impacts on fish eggs and embryos also applies to this species.

Carlson (1997) characterizes the underwater sound generated by impact pile driving within the context of the response of salmonids to impulse sound, and concludes that the sound thus produced is unlikely to significantly affect the migratory behavior of salmonids. These studies were conducted over a two-day period at a pile dike repair where 15 piles were replaced on the Washington shore of the Columbia River upstream of Altoona, Washington. All underwater sound measurements were made within 30 feet of the piles being driven and at one of four depths (i.e., 5, 10, 15, or 20 feet). Sound measurements were obtained near the surface, at mid-depth, and at the bottom.

Based on his findings, Carlson (1996) concludes that impact pile driving does not produce adequate stimuli for sustained avoidance responses in salmonids. The reason is that in salmonids, the effective stimulus for avoidance response is the local flow (i.e., particle displacement) component of infrasound in the range of 5 to 30 hertz where water particle acceleration is less than 0.01 m/s² (meters per second per second). At this sound level, water particle motion is found only in the near-field of volume displacement sources capable of generating an intense local flow field (Carlson 1996). In short, salmonids would have to be very close to the noise source to be disturbed and express an avoidance response. The threshold distance for an avoidance response by salmonids has been experimentally determined to be approximately 10 feet.

In another study, Carlson (1996) characterizes the underwater sound generated by vibratory pile driving within the context of the characteristics of sound known to result in avoidance response by juvenile salmonids. His experiments consisted of the comparison of data collected during vibratory pile driving operations against model data obtained from a volume–displacement–
infrasound source. The study was conducted during vibratory driving of six piles along the outer perimeter of a pier at the Hatfield Marine Science Center in Oregon.

Carlson (1996) found that infrasound generated by vibratory pile driving is not continuous and has a short life span but is probably dependent upon various aspects of the pile driving activity. Such aspects include the design and mode of operation of the vibratory hammer, the characteristics of the piles being driven, and characteristics of the substrate into which the piles are driven. For all of the piles observed, most of the energy in the sound field was located at frequencies below 50 hertz, with approximately half at infrasound frequencies. Results showed that vibratory pile driving generates a sound field with considerable energy in the frequency range where salmonid avoidance has been observed (Carlson 1996).

Carlson (1996) concludes that the vibratory pile is unlikely to cause an avoidance response by juvenile salmonids beyond the immediate vicinity of the pile driving activity. In addition, this type of construction activity is, in general, unlikely to have a significant impact on migrating salmonid behavior, because “generation of water particle motion levels in excess of fish behavioral response thresholds appears unlikely at ranges over 20 to 30 feet from the pile being driven” (Carlson 1996).

Regarding the published marine study on the effects of pile driving on salmonids, Feist et al. (1996) studied the effects of impact and vibratory pile driving on the behavior of juvenile chum and pink salmon in Puget Sound. They determined that salmonids could detect the sound of impact pile driving within a radius of at least 600 meters, and that the sound was at least 20 decibels above ambient levels at 593 meters. The pile driving did not cause juvenile chum and pink salmon to change their distance from shore or to cease foraging activities. However, Feist et al. (1996) found that the distribution and sizes of fish schools, and behavior within schools, on pile driving days significantly differed from that on non-pile-driving days.

It should be noted that this study was based on visual measurements of distribution and behavior changes, mostly using human observations, and therefore has its limitations and biases. Moreover, it is based on a small sample size and highly variable data.

**Interrelated Effects of Construction and Operations – Boating**

The operation and use of over-water structures can also promote interrelated effects such as those originating from boating activities. In this regard, Warrington (1999a,b) reports on the increasing use of freshwaters in British Columbia for recreational boating. Warrington (1999a,b) divides the aquatic environment into bottom sediment, bulk water column, surface microlayer, and shoreline habitat compartments, within which the effects of recreational boating may occur. In each of these compartments, plant or animal tissue, non-living particulate matter, and water subcompartments may exist. A number of different kinds of effects may also occur and can be categorized as either physical disturbances or behavioral effects, which also include reproductive failure (Warrington 1999a).

With regard to physical disturbances, recreational boating can cause shoreline (i.e., bank) erosion, sediment resuspension, and destruction of shallow-water and marginal vegetation (see
Warrington 1999b for a discussion of chemical pollution associated with outboard motors. In several river systems it has been observed that the physical effects of boating traffic are more pronounced in narrow, shallow river channels than in deeper channels (Warrington 1999a).

In the Illinois River, the bed sediments (i.e., silts and clays) were easily resuspended. Small pleasure craft produced waves of less than a foot and caused the least amount of shoreline wave wash. Large pleasure craft produced short, steep waves of brief duration, causing bank erosion and turbidity increases. Towboats raised the water level at first, then water was drawn down, exposing the bottom, followed by successive waves rushing back in, with the resulting turbulence causing high turbidity. The turbidity trail extended several miles behind a towboat and took several hours to return to normal (Warrington 1999a).

Turbidity increases can be attributed in part to algal growth, which may result from the increased availability of nutrients (particularly phosphorus) originating from disturbed bottom sediments (Warrington 1999a). This condition occurs when propeller-induced mixing and resuspension of sediments makes phosphorus more bioavailable to phytoplankton, resulting in greater algal growth and thereby higher turbidities (Hilton and Phillips 1982; Yousef 1974 as cited by Warrington 1999a). In addition, a significant quantitative relationship has been observed between plant community structure, submerged plant abundance, and recreational boat traffic. In this regard, it is hypothesized that turbidity and its effect on light are the cause of a decreased abundance of submerged vegetation (Warrington 1999a). In addition to increasing nutrient availability, resuspension of sediments also incorporates metals and other toxic materials that may have been precipitated and thus previously removed from biological activity (Warrington 1999a).

Aquatic plants have variable susceptibility to being uprooted or eroded from the banks or from shallow water by wave action, and this is a function of both their root structure and the type of sediments in which they normally grow (see Warrington [1999a] for a list of British Columbia freshwater submerged aquatic plants ranked in order of their relative resistance to wave action). Uprooting of submerged aquatic vegetation was observed in the pathways of outboard engines where the propellers came within 30 centimeters of the substrate (Lagler et al. 1950).

Behavioral effects of boating operations are also a concern because amphibians, fishes, and other aquatic organisms can be affected. For example, noise produced by motorboats disturbs fishes and wildlife (Warrington 1999a). In this regard, it has been shown that boats traveling at slow speeds near sunfish nesting areas usually drive the males off the nest, thereby affecting their reproductive success (Mueller 1980; Lagler et al. 1950).

In general, water turbidity can have several deleterious effects on fishes (Warrington 1999a). Turbidity can cause decreased growth due to a reduction in the primary production (Buck 1959), promote mortality through gill damage, disrupt feeding behavior and migration (Noggle 1978), and decrease egg and fry survival (Campbell 1954; McNeil and Ahnell 1964, both as cited by Warrington 1999a).

A reduction in macroinvertebrate abundance due to boating operations has also been reported. Lagler et al. (1950) found that the invertebrate abundance in the path of an outboard motorboat operated over a prolonged period in shallow water was substantially reduced.
In the context of boating operations, interdependent effects of over-water structures can also be observed. For example, human activities such as wading and swimming that involve the intense use of the shallow, vegetated areas of lakes and streams can disturb feeding and nesting waterfowl (Warrington 1999a).

Construction activities have a concomitant and inevitable degree of water pollution. Petroleum products in minor quantities may seep into the water from construction equipment, and the exhaust emissions add hydrocarbons to the air (Mulvihill et al. 1980). In general, the resultant chemical processes potentially include water quality degradation due to 1) pollution originating from the structural material (i.e., treated wood); 2) temporary reduction of oxygen content associated with oxidation of resuspended organic matter during dredging operations; and 3) temporary changes in pH due to water contact with or leakage from concrete structures. Chmura and Ross (1978), Mulvihill et al. (1980), and Kahler et al. (2000) address all but the pH issue.

**Physical/Chemical Environmental Disruption: Construction and Operations – Findings**

**Summary**

Figure 4 schematically depicts the relationships among impacts resulting from changes induced by construction and operation of over-water structures and by pile removal activities. As illustrated in this figure, there may be temporary, permanent, and interrelated impacts. Temporary impacts are associated with noise disturbance and water turbidity, and consequently salmonid behavior disruption. Permanent impacts are related to bottom sediment disturbance, burial of benthic communities, nutrient load changes, and resulting alterations of habitat function. Interrelated effects such as those resulting from boating activity cause shoreline erosion and turbidity-induced light reduction, with the consequent elimination of aquatic vegetation. All of these processes could disrupt the food web and thus affect the ecosystem.

The following is a summary of findings of this literature review pertaining to disruptions induced by construction and operational activities.

- Physical/chemical environmental disruption due to construction and operation of over-water structures has both temporary and permanent effects on aquatic organisms, related to noise disturbance and water quality degradation.

- Physical processes include construction activities that disturb the bottom sediment, increase turbidity, adversely affect bottom-dwelling aquatic organisms, remove submerged aquatic vegetation, drive away fish and other mobile organisms, and alter existing habitat at the over-water structure site.

- Chemical processes include water quality degradation due to pollution, and temporary reduction of oxygen concentrations associated with oxidation of resuspended organic matter.

- Underwater impact-pile-driving noise is unlikely to significantly affect the migratory behavior of salmonids.
Figure 4. Impacts resulting from changes induced by pile driving and removal and other construction and operation activities.
With regard to noise generated by pile driving, the threshold distance for an avoidance response has been experimentally determined to be approximately 10 feet.

Infrasound generated by vibratory pile driving is not continuous, it has a short life span, and it is unlikely to have a significant impact on migrating salmonid behavior.

Pile driving energy may affect salmonid eggs and embryos if they are located within 100 feet of the source.

Operation of over-water structures can also have interrelated effects such as those caused by boating activities. These effects include physical disturbances and behavioral effects including reproductive failure.

The interrelated physical effects include shoreline erosion, sediment resuspension (and resultant turbidity), and destruction of marginal aquatic vegetation and associated macroinvertebrate communities.

Sediment resuspension creates turbidity that affects primary production, decreases bird fish-capture rate, damages fish gills, decreases fish egg and fry survival, and can disrupt fish migration.

Operational activities such as boating can have interdependent effects from the potential intense use of shallow, vegetated areas of lakes and streams by humans.

Data Gaps

No empirical data were found to support several of the processes depicted in Figure 4. Where empirical data are lacking, inferred and hypothetical associations have been drawn. The matrix of data availability in Appendix B shows where data exist under each of the categories of response addressed in this white paper (i.e., predation, behavior, and habitat function).

Through this literature review, the following information needs have been identified (organized by the observed type of response).

Predation

- Is there any relationship between physical/chemical environmental disruption and predator–prey interactions?

Behavior

- Would field studies corroborate or reject the experimentally determined threshold for fish response to impact pile driving (i.e., 10 feet)?

- Does avoidance response in fishes vary with the time of year, the system affected, or the species of fish?
What are the effects of vibratory and impact pile driving on early stages (i.e., eggs and embryos) of aquatic organisms, particularly salmon?

Does vibratory pile driving cause an avoidance response in juvenile salmonids at distances ranging beyond 20 to 30 feet from the pile driving activity? What would be the effect of this response on salmonid migration?

What are the effects of boating on juvenile and adult salmonids? Can the reported effects on warm-water species be extrapolated to salmonids?

Does turbidity disrupt migration of juvenile and adult salmonids?

What are the effects of human activities such as wading and swimming, which involve the intense use of the shallow, vegetated areas of lakes and streams on aquatic organisms?

**Habitat Function**

Does the energy from pile driving activities adversely affect salmonid eggs and embryos?

Do 300 feet exclusion zones for pile driving activities provide adequate protection for eggs and embryos of salmonid species?
Habitat Protection, Restoration, and Mitigation Techniques

State of Knowledge

Shoreline development projects and interrelated activities can lead to habitat loss, which is one of the greatest threats to fisheries resources. Thomas (1994) considers the major causes of extinction of freshwater fishes in North America to be the loss or alteration of habitat (50 percent), the introduction of exotic species (37 percent), and over-exploitation of fisheries (8 percent).

Habitat alteration may lead to loss of habitat function and thereby to habitat loss. In recent years, several federal and state agencies, including U.S. Army Corps of Engineers, National Marine Fisheries Service, and Washington Department of Fish and Wildlife, have been implementing a policy of no-net-loss of certain critical habitats such as wetlands and eelgrass beds. Similarly, these agencies are implementing policies intended to prevent the introduction or spread of exotic species and the over-exploitation of fishery resources.

As outlined in Washington’s Statewide Strategy to Recover Salmon: Extinction Is Not an Option, development projects occurring in or around water can replace damaged or lost habitat through the use of adequate and properly monitored mitigation techniques. Restoration of habitat in combination with strict controls to prevent exploitation of resources can contribute to the recovery of imperiled species. Strict controls to eliminate or minimize the access of exotic species can effectively restrict the continued spread of such organisms.

During the course of this review, literature was found addressing wetland protection, restoration, and mitigation, as well as stream bank protection and restoration. No documents were found specifically addressing lake and reservoir protection, restoration, or mitigation within the context of shore-zone development and construction of over-water structures. However, the information obtained regarding both wetlands and stream banks may be adapted for application to lakes and reservoirs, based on appropriate site-specific conditions and project-specific requirements.

For mitigation and restoration projects, the selection of adequate measures depends on project goals, objectives, and performance standards. There are clear criteria for mitigation projects: the habitat created and the functional value of the replacement habitat must be greater than values of the habitat replaced (Ecology 1998; Ecology et al. 1994). In contrast, for restoration projects, one must first ask to which historical condition a particular habitat must be restored. Unfortunately, this question does not always have a clear scientific answer and requires historical data that may not be readily available. Nonetheless, one can see that most of the general objectives of mitigation plans may apply to restoration projects.

Some of the objectives used in selecting wetland mitigation measures include the following (Ecology 1998; Ecology et al. 1994):
The mitigation should be located in the same watershed and as close as possible to the affected area, and should provide the best possible contribution of functional values to the particular watershed system.

Offsite mitigation efforts consolidated on one site are preferred to multiple offsite locations.

Mitigation should provide better functional value than that provided by the wetland being replaced.

Wetland mitigation in the form of wetland creation or enhancement must result in an overall net gain of wetland area over the wetland area being replaced.

Mitigation sites must be of appropriate size and hydrologic condition in order to satisfy local, state, and federal requirements for wetland replacement (e.g., the wetland area lost must be replaced with a greater area of wetland created, and the functional value of the replacement wetland must be greater than the value of wetland replaced.

In addition, a monitoring plan should be implemented to evaluate the success of the created and enhanced wetland mitigation areas. For this purpose, quantifiable criteria included in the performance standards should be used as the basis for monitoring the success of the mitigation sites. Adequate mitigation techniques and timely implementation of best management practices (BMPs) can help to avoid, minimize, or compensate for impacts of proposed over-water structure projects. The basic goal of mitigation is to achieve no-net-loss of habitat functions by offsetting losses at the impact site (Washington 2000). These mitigation techniques must provide habitat protection and stability while achieving a range of parallel objectives, including terrestrial and aquatic habitat enhancement, water quality improvement, and ecosystem diversification (Schollen 1995).

Despite extensive expenditures under state and federal programs, there is little evidence in the literature to show that habitat restoration has actually improved the productive capacity of freshwater systems for salmonids. A reason for this is perhaps the lack of a clear understanding of the specific biophysical conditions that exemplify quality habitat. Although it is generally assumed that the use of BMPs has improved freshwater habitats (Independent Scientific Group 1996), empirical demonstration of the influences and benefits of BMPs on habitat is limited.

Therefore, designing to avoid environmental impacts should be a goal of all over-water structure projects. The structures should incorporate design elements that provide for fish habitat while preventing damage to the environment. However, when impacts cannot be avoided, mitigation techniques must be incorporated into the design and integrated into the operation of the structure. Thus, habitat restoration measures (either onsite or offsite, and either in-kind or out-of-kind) should be used to compensate for unavoidable habitat impacts. The site selection criteria for restoration activities should emphasize habitat connectivity, species occurrence and use, and ecological significance of the selected site from a holistic perspective (i.e., the ecosystem).
A crucial element to obtain a continued success of habitat protection and mitigation techniques is the inclusion of biological/environmental monitoring and evaluation of such techniques in programs and plans (Independent Scientific Group 1996). The importance of monitoring and evaluation is to ensure feedback to the state and federal agencies so that they can modify programs as needed to achieve their desired goals. In fact, effective observation and monitoring of the performance of mitigation plans is key to their success (Schollen 1995).

Monitoring data and general information from restoration sites can be used as the basis of watershed adaptative management plans, as well as to implement corrective actions in mitigated sites and to plan future restoration projects. For example, in a state listing of restoration projects, USEPA (2000) provides monitoring information ("lessons learned") from river corridor and wetland restoration projects. Among the elements contributing to the success of various projects, availability of monitoring information from other projects and follow-up to assure implementation and corrective actions when needed were among the most commonly cited attributes USEPA (2000).

This section of the white paper focuses on findings from the literature reviewed. Regulatory practices are described under the existing guidance summary section later in this paper. A few published sources provide information on habitat protection and mitigation techniques in the context of the over-water structures addressed in this white paper. Some of the information from early publications is outdated, and although it is discussed here, it should be used with caution. Mulvihill et al. (1980) provide regional considerations and information on function, site characteristics, environmental conditions, and placement constraints of over-water structures. Kahler et al. (2000) provide a series of conclusions and recommendations on effects of bulkheads, piers, and other artificial structures and shore-zone development on Endangered Species Act protected salmonids in lakes.

An important habitat mitigation tool is the use of bioengineering techniques. The draft Integrated Streambank Protection Guidelines (WDFW 2000) provides information on habitat impacts resulting from bank protection projects and describes several appropriate fish habitat mitigation measures, some involving bioengineering techniques. The guidelines are intended for streams, although some of the concepts and design criteria have applicability in lacustrine environments.

Similarly, Streambank Revegetation and Protection: A Guide for Alaska (ADFG 1996) provides information on bioengineering techniques developed to protect and restore stream banks. This guide also has applicability in lacustrine environments. In addition, Soil Bioengineering, an Alternative for Roadside Management—A Practical Guide (USDA-FS 2000) provides valuable techniques for stabilizing areas of soil instability, some of which are applicable to shorelines. However, soil bioengineering has unique requirements and therefore is not appropriate for all sites and situations (USDA-FS 2000).

Preservation and protection of shorelines and stream banks can be attained through a variety of approaches (USEPA 1993). However, based on the findings reviewed and presented in this white paper, preference should be given to nonstructural practices such as soil bioengineering, marsh creation, establishment and enforcement of no-wake zones, and establishment of setbacks.
Soil Bioengineering

Soil bioengineering refers to the installation of living plant material as a main structural component in controlling problems of land instability where erosion and sedimentation are occurring (USDA-FS 2000; USDA-SCS 1992). Native plants are used in order to ensure that the plant material will be well adapted to site conditions. Although a few selected species can be installed for immediate soil protection, it is expected that the natural invasion of a diverse plant community will stabilize the site through development of vegetative cover and a reinforcing root matrix (USDA-SCS 1992). Thus, adapted types of woody vegetation (i.e., shrubs and trees) are initially installed to offer immediate soil protection and reinforcement.

Soil bioengineering methods include an array of applied technologies that are effective not only for prevention but also for mitigation. These applied technologies combine mechanical, biological, and ecological principles to construct protective systems for the prevention of slope failure and erosion (USEPA 1993).

Soil bioengineering systems normally use rooted plants or cut, unrooted plant parts in the form of branches. As the systems establish themselves, resistance to sliding or shear displacement increases on shorelines, stream banks, and upland slopes. Examples of specific soil bioengineering practices include the following (USDA-FS 2000; USDA-SCS 1992):

- Native plant cutting and seed collection
- Salvaging and transplanting native plants
- Planting containerized and bare-root plants
- Distributing seed, fertilizer, and certified noxious weed-free straw or hay
- Live staking
- Installing erosion control blankets
- Installing live fascines
- Brush-layering
- Brush mattressing
- Branch-packing
- Live gully repair
- Installing vegetated geotextile
- Log terracing
- Joint planting
- Constructing live crib walls.

Information provided by USDA-FS (2000) and USDA-SCS (1992) on each of these techniques includes a description of required plant material, mechanism of action, advantages and disadvantages, tools needed, procedure for implementation, and applicability of the technique, as well as schematic cross-sections showing important design elements. While all of these techniques can be used for protection, restoration, and mitigation, they should be used on a project-specific and site-specific basis.
Marsh Creation

Another important technique that can be used to address shoreline erosion problems involves marsh creation and restoration. Plant marshes perform two functions in controlling shore erosion: dissipation of energy and stabilization of shoreline sediments. Energy dissipation is achieved through the exposed stems of plants (e.g., emergent vegetation), which form flexible masses that dissipate energy. Shoreline stability is achieved through dense stands of marsh vegetation, which create depositional areas that cause sediment accretion along the shoreline (USEPA 1993). Although most marsh creation techniques have been described for coastal areas (Knutson 1987, 1988; Lewis 1982), they also have great potential for application in freshwater environments (i.e., lakes, reservoirs, and sloughs).

Establishing and Enforcing No-Wake Zones

No-wake zones are useful tools for the prevention of shoreline and stream bank erosion and should be given preference over posted speed limits in shallow waters. The rationale is that, in theory, the boat speed that produces the maximum wake varies with the depth of the water (USEPA 1993). In shallow water, motorboats traveling even within speed limits produce wakes whose heights are equal to or near the maximum size that can be produced by the boats (USEPA 1993).

Establishing Setbacks

Another tool for the prevention of shoreline and stream bank erosion is the establishment of setbacks. Although a setback most often restricts the siting and construction of new structures along the shoreline, it can include requirements for the relocation of existing structures within the designated setback. In addition, setbacks can include restrictions on uses of waterfront and shore-zone areas that are not related to the construction of new structures (USEPA 1993). Finally, because setbacks effectively restrict the actual number of structures that can be placed on a given shoreline, they help to minimize the cumulative environmental effects of the structures.

Docks, Piers, and Floats

Because of increasing concern over the cumulative effect of over-water structures and, in response to the recent Endangered Species Act listing of several fish species, the Washington Department of Fish and Wildlife (WDFW) and the National Marine Fisheries Service (NMFS) are currently developing a series of documents establishing criteria for the construction of these structures. These documents provide recommendations and potential mitigation measures for implementation across the state. Many of these recommendations are not yet published and are available only through WDFW area habitat biologists and NMFS staff. Although not all the recommendations are yet supported by published scientific research (i.e., empirical data), these recommendations are intended to lessen or mitigate potential cumulative effects, as well as to protect fishes. Some of the documents containing criteria and mitigation measures currently
recommended by WDFW (undated[a,b,c,d]) and the NMFS (2000) for eastern Washington are presented below.

- **WDFW Salmonid Predation Reduction Measures and Dock Specifications for North Central Washington Water Inhabited by Federally Listed Fish Species** (WDFW undated[a]). This document includes some typical WDFW salmonid predation reduction requirements for dock-associated structures, specifically for piers, floats, ramps, piling, and anchors. These requirements include regulation of the following elements: 1) pier size and shape; 2) ambient light grid requirements; 3) piling size, number, and surface characteristics; 4) minimum distance waterward of the ordinary high water mark; 5) characteristics of anchors when used in lieu of pilings.

- **Some Typical WDFW Salmonid Predation Reduction Measures and/or HPA Dock Requirements on North Central Washington Waters Inhabited by Listed Fish Species Protected Under the Federal Endangered Species Act.** (WDFW undated[b]). This document includes criteria addressing the structure dimensions, avoidance of both light penetration reduction and creation of shaded areas, avoidance of predatory fish habitat creation, damage avoidance of near-shore shallow water habitats, and minimization of pile usage. The document includes the following eight criteria: 1) dock and float size and shape; 2) ambient light grid requirement; 3) minimum open water zone and distance from shoreline for floats; 4) ramp grating for light penetration and minimum ramp length; 5) dock and float anchoring; 6) piling surface characteristics; 7) reflective surface finish on flotation devices; and 8) minimum vertical distance between the ramp and float and the stream or lake bed.

- **Recommendations for Siting Marinas and Other Overwater Structures in the Lower Columbia River** (WDFW undated[c]). This document is intended to provide recommendations and mitigation measures necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. The document includes three levels of mitigation: avoidance of impacts, minimization of impacts, and compensation for impacts. Under avoidance of impacts, the following criteria are included: 1) dock and float size and shape; 2) minimum distance waterward of the ordinary high water mark; 3) maximum number of piling landward of Columbia River datum; 4) float characteristics and location; 5) treated piling restriction; 6) over-water structure siting in relation to water depth; 7) characteristics of breakwaters; and 8) preservation of a buffer along the shoreline. Under minimization of impacts, the following criteria are included: 1) size, number, siting location, and ambient light grid requirement of over-water structures; 2) bioengineering approach to shoreline protection; 3) location for boat mooring; and 4) dredging requirements. Under the compensation for impact section, the following criteria are included: 1) restoration of
filled, armored, or otherwise modified shorelines; and 2) restoration of salmonid habitat covered by over-water structures.

- *Conditions for Siting of Marinas and Boat Docks in Water Containing Anadromous Fish* (WDFW undated[d]). This document includes conditions and measures to minimize or avoid adverse effects of a proposed action on listed species and minimize or avoid adverse modification of critical habitat in freshwater. The document is intended for eastern Washington and has an appendix that includes approved in-water work windows for that region.

With regard to the recommended use of bright white PVC and paint and reflective metals for the construction of docks and associated structures referred to in the second bullet point above, empirical data obtained from the literature survey for this paper show that prey and predator fishes are attracted to white-painted floats to the same degree that they are attracted to non-white or reflective materials (Helfman 1979). Anecdotal evidence from sport fisherman and recreational scuba divers supports such empirical data. Therefore, this recommendation bears further research.

The NMFS is preparing an incidental *take statement* document, which contains “reasonable and prudent measures” necessary to minimize the take of Endangered Species Act listed and proposed species (NMFS 2000). The document addresses the upper Columbia River steelhead and spring chinook populations. The basis of this incidental take statement is that over-water structures provide an incremental enhancement to predator habitat that is directly related to the surface area of the over-water structure (NMFS 2000).

Criteria and mitigation measures specific to the construction of over-water structures in western Washington are also being developed by the NMFS. In addition, guidelines for the biological assessment of such structures have recently become available for use by project proponents. The NMFS (2000) criteria outlined below were adapted from *Guidance for ESA Section 7 Consultation—Effect Determinations for New and Replacement Piers and Bulkheads in Lake Washington* (NMFS 2000).

The safest months for construction, considering all life stages of the chinook, are November and December. In non-delta areas, August, September, and October should be construction windows with appropriate sedimentation controls. Projects that may qualify as “not likely to adversely affect” are those that fall under the following criteria:

- Replacement pier on existing footprint with materials that do not further degrade baseline conditions
- Replacement pier area and number and diameter of pilings significantly reduced
- New minimum-sized pier with narrow, elevated walkway and minimal number and diameter of pilings, providing for a shallow near-shore
migration and feeding zone, and including aquatic and riparian vegetation rehabilitation

- Shoreline rehabilitation directed toward providing complex in-water habitat (e.g., emergent plants; some woody debris with branches) and riparian vegetation with mixture of native trees, shrubs, vegetation overhanging the water, and ground covers.

Within the context of habitat protection and mitigation, both direct and indirect modifications of structural complexity of the aquatic environment have been used to protect and improve habitat. Direct or indirect manipulation of aquatic vegetation alters a wide variety of variables simultaneously (Cooper and Crowder 1979). For example, manipulation of brush shelter, rock rubble, and other artificial stream and lake improvement technologies can directly alter substrate areas, light penetration, and prey refuges. These same manipulations can also indirectly alter nutrient cycles, water chemistry, and food resources (Cooper and Crowder 1979).

The effects of docks, piers, and wharves can be minimized if these structures are constructed high enough above marshes to allow light to reach the water surface (Chmura and Ross 1978). In this regard, light-penetrating elevated walkways can be used for preventing stream bank damage where access to a sensitive or critical area is required (ADFG 1996). These structures prevent erosion and protect underlying vegetation, allowing vegetation recovery while providing access. Floating docks can be connected to elevated walkways to provide boating access (ADFG 1996). In addition, it is recommended that docks and piers extend out far enough to reach depths in which dredging will not be required (Chmura and Ross 1978). In a literature review of the effect of marinas, Chmura and Ross (1978) found that floating docks and pile-supported piers have the least effect on water circulation and therefore are preferred to solid structures. It should be pointed out, however, that Chmura and Ross’ (1978) recommendation on floating docks does not take into consideration the shade avoidance criteria set forth by the revised WAC 220-110-60, which requires maximum height to minimize shading of the area under the structure.

Chmura and Ross (1978) also recommend avoiding painting underwater surfaces. The basis for this recommendation is that over-water structures such as docks and piers “provide additional substrate for the growth of fouling communities.” Painting of the wood surfaces discourages such growth. Other researchers (Mulvihill et al. 1980) recommend that if structures are painted or otherwise covered, all coatings must be dry before placing floats in the water to avoid contamination.

Marinas

Mulvihill et al. (1980) provides a review of biological impacts of minor shoreline structures, but mostly in marine environments (see Mulvihill et al. 1980 for study review and recommendations beyond the scope of this white paper). Site selection and corresponding site-specific engineering design are the first steps in environmental impact avoidance. For example, a site with maximum natural protection will minimize alterations and the concomitant adverse impacts of construction of marinas (Mulvihill et al. 1980).
In general, attention to selection of sites with the “maximum natural physical benefits” can help to avoid alterations and continual maintenance associated with dredging (Mulvihill et al. 1980). To minimize impacts, it is recommended that marinas be located “…at the end of, or between drift sectors, or on self-contained pocket beaches…” (Bauer 1973 as cited by Mulvihill et al. 1980).

Warrington (2000) provides comprehensive recommendations for best management practices (BMPs) to be employed during the construction and operation of marinas. The recommended BMPs are grouped by activities, including choice of location; construction; management of liquid waste, fuel, and solvents; sewage disposal; boat cleaning; boat coating; generation and disposal of solid waste; and protection of upland areas. However, these BMPs, which are proposed for construction activities in British Columbia, Canada, may not all apply in the state of Washington because of differences in laws and regulations, or they may not provide a sufficient level of environmental protection.

Quoted below are selected recommendations proposed by Warrington (2000) that apply to marinas in freshwater environments. These recommendations are in essence BMPs that should be incorporated as permit conditions for individual projects, in order to ensure that these BMPs are implemented (Fresh 2000 personal communication):

**Choice of Location**

- Avoiding construction of mooring basins in blind channels or sloughs where there is insufficient tidal current or natural flow to ensure adequate and regular flushing
- Providing two entrances to provide for maximum flushing action
- Orienting the basin entrance to provide for maximum tidal flushing and prevailing current water exchange
- Orienting marina floats with currents or prevailing winds to prevent trapping surface debris and oily residue
- Designing marinas to retain as much existing natural aquatic and marginal vegetation as possible

**Construction**

- Constructing dredged basins with more than one water depth; the depth must decrease with distance from the entrance; to avoid internal deeper pockets which act as un-flushed holding basins
- Timing construction and dredging to periods when use of the site by fish is minimal
Over-Water Structures: Freshwater Issues

- Using floating or pile breakwaters rather than rubble mounds to minimize site impacts
- Using bubble curtains or padding to disrupt the shock wave when blasting
- Cutting boat or float plane ramps out of the upland rather than building them on intertidal foreshore
- Constructing gradual slopes which can be stabilized by natural vegetation rather than rip rap or walls

Liquid Waste, Fuel, and Solvent Management

- Providing fueling equipment with automatic shut-off nozzles to reduce spillage during fueling operations
- Providing impervious pavement, berms, curbs or other means of spill containment, spill control equipment and connection to spill collection sumps for fuel and storage tank areas
- Avoiding the use of underground storage tanks which lead to very expensive clean up costs when they eventually corrode and leak and cause extensive ground and water pollution
- Storing fuels and other highly inflammable fluids in a separate area to meet local fire department regulations
- Providing fluid storage containers with level indicators to prevent overfilling and spillage
- Keeping an accurate and up-to-date inventory of everything in storage for use by spill cleanup crews and fire fighters so that potentially hazardous combinations can be anticipated
- Avoiding discharge of on-site oil/water separator waste water to sewers or to ground unless it is demonstrated to contain less than 15 mg/L of oil
- Preventing discharge of any waste liquids down floor, sink or storm drains; signing all drains
- Establishing site-specific spill contingency plans, including reporting, and training employees in use of the required equipment
Sewage Disposal

- Providing fixed point pump-out facilities consisting of one or more centrally located sewage pump-out stations, generally situated at the end of a pier and often on a fueling pier for convenience; pumps or a vacuum system with flexible hose attachment draw wastewater from a docked plane’s or boat’s pump-out fitting and move it to an onshore holding tank, a public sewer system, a private treatment facility, or another approved disposal facility; for boats with small, removable toilets, a similarly connected dump station should be provided.

- Providing portable pump-out facilities which function the same as the fixed-point system with the advantage of mobility for servicing different docks; wastes are drawn from a docked boat’s pump-out fitting via vacuum or pump setup and hose attachment into a storage tank; the full tank is discharged into the marina’s disposal facilities; these are thought by many to be the most economical and logistically feasible means of ensuring proper disposal of boat sewage.

- Providing continuous wastewater collection at the slip where live-aboard vessels are situated, this would involve fixed force main piping, pumping, and sewage disposal means on the part of the marina; language should be included in slip leasing agreements mandating the use of pump-out facilities and specifying penalties for failure to comply.

- Discharging sanitary wastes, black water and grey-water, to the municipal sewer, having it trucked/shipped out or pumped to a septic system or shore.

Boat Cleaning

- Removing boats from the water to perform cleaning where feasible.

- Cleaning boats in the water by hand.

- Using detergents and cleaning compounds that are phosphate-free and biodegradable.

- Avoiding use of detergents containing ammonia, sodium hypochlorite, chlorinated solvents, petroleum distillates, or lye.

- Collecting hull wash water and removing solids before discharge to sewers or ambient waters.

- Cleaning dock floors, lift platforms and yard surfaces before high pressure washing hulls.
Avoiding pressure washing on tidal grids, docks, planked and grated surfaces or other areas where the wash water can not be contained

Pumping collected wastewater which contains low concentrations of pollutants directly into the sanitary sewer

Treating small volumes of wastewater volume with high pollutant concentration directly by a mechanical filter system with the filtrate going to the sewer system and the sludge to an approved disposal facility

Monitoring the quality of the water discharged to sewers or ambient waters

Avoiding pressure washing on tidal grids or when beached unless there is a collection system and sump to collect all wash water; cleaning out the sump before tidal flooding; sump contents may be special waste

Covering or installing filters on floor drains to prevent entry of spent grit into sumps and sewers

Avoiding discharge of dry-dock flood water, cooling water, condenser water, boiler blow-down water and steam cleaning water to ambient waters if oil and grease exceeds 10 mg/L, turbidity exceeds 5 NTU over background or pH is outside the range 6.0 to 8.0

**Boat Coating (Painting and Anti-Fouling)**

Avoiding spraying coatings while a vessel is on a tide grid or beached

Using soft anti-fouling paint where cleaning is infrequent and hard paint where cleaning is needed frequently

Applying anti-fouling coatings well away from sensitive fish habitat, shellfish beds, fish farms, shallow estuarine areas and surface storm drains

Using tarps while vessel is on a tide grid, beached or on planked or grated docks and removing the tarps before the grid floods, it rains or washing occurs

Using airless or high volume low pressure spray guns and monitoring wind drift

Using brushes or rollers when vessel is afloat except when tops are fully shrouded
Permitting use of tributyl tin paints only by licensed operators

Avoiding use of tributyl tin paints on non-aluminum hulls under 25 m long

Avoiding painting under high wind conditions when drift is evident

**Solid Waste Generation and Disposal**

- Ensuring that solid waste from boat operation and maintenance at marinas is properly disposed of or recycled regularly

- Prohibiting in-the-water hull scraping or any process for removing paint from the boat hull that occurs underwater

- Providing proper waste disposal facilities including recycling facilities where possible

- Providing filters on all drains to keep debris from entering stormwater or sewers

- Providing sufficient area above the high water line, for boat repair and maintenance: such work should not be allowed outside of designated areas

**Protection of Upland Areas**

- Providing a paved upland area for cleaning and painting

- Providing proper waste disposal facilities including recycling facilities where possible

- Collecting all surface runoff from paved upland areas in a storm water collection system

- Passing all the collected storm water through a sediment and oil separation treatment prior to discharge

- Collecting all paint and cleaning residues and storing in a covered container prior to off-site disposal

- Collecting all oil and filters for recycling or off-site disposal

- Using submerged outfalls which extend beyond tidal or seasonal low water levels
Riprap and Retaining Walls

As with any structure, the design and material choice for the construction of bulkheads can be altered to minimize their impact. Nonetheless, regardless of the design, these structures will modify the environment and thereby adversely affect aquatic organisms, in a cumulative fashion.

The NMFS (2000) has recently released a document with guidelines for the determination of effect of piers and bulkheads that may be constructed or replaced in Lake Washington. In the context of bulkheads, the NMFS has proposed as "not likely to adversely affect" those projects that fall under the following criteria:

- Replacement bulkhead on existing footprint with materials that do not further degrade baseline conditions.
- Replacement bulkhead footprint set back from the ordinary high water mark, with shoreline rehabilitation including overhanging vegetation.
- Replacing bulkheads with bioengineered bank protection and significant shoreline vegetation rehabilitation including overhanging native plants.

In general, when planning armoring structures (i.e., bulkheads), the total effect of the structure on the environment should be considered (Mulvihill et al. 1980). In their review, Mulvihill et al. (1980) present biological considerations for the construction of bulkheads. Although most of these considerations were obtained from studies conducted in marine and estuarine environments, the general principles of habitat conservation should apply to projects in the freshwater environment. Some of the recommendations include using designs that minimize damage to fish and shellfish habitat, avoiding the disturbance of shoreline vegetation, enhancing existing vegetation to provide shoreline stabilization, setting bulkheads landward of the mean high waterline, and restricting amounts of suspended sediments during construction (Mulvihill et al. 1980).

Bonham (1983) field-tested whether emergent vegetation could attenuate wave energy in large canals and rivers in Britain (see Bonham 1983 for details of the bioengineering design). The emergent vegetation (four species tested) was capable of dissipating approximately two-thirds of boat wake energy and inhibiting wave break. Based on his results, Bonham (1983) proposed the use of emergent vegetation for shoreline wave-energy attenuation and scour prevention.

Once anthropogenic processes are initiated, and physical responses such as erosion-induced habitat alteration are observed, corrective measures may have profound repercussions on the ecosystem and therefore should be used with caution. For example, Rolletschek and Kuhl (1997) investigated the impacts of reed-protecting structures on shorelines in the lower Havel River and Great Müggel Lake, Berlin. The purpose was to address an existing cycle of reed destruction due to erosion. Faggots and palisades successfully protected reeds by acting as wave breakers and reducing erosion in the reedy areas of the shoreline. However, depending on the type of reed-protecting structure used (i.e., gester faggots, reisig faggots, or palisades), increased
sedimentation, increased nutrient concentration, and enrichment in fine sulfide-containing detritus occurred, with a corresponding decrease in water quality.

**Pile Driving and Removal**

No literature on mitigation techniques for pile driving and removal in freshwater was found. However, one recent study conducted in a marine environment addresses the use of bubble curtains to minimize the impact of noise produced during underwater construction (Würsig et al. 2000).

Würsig et al. (2000) conducted experiments near Hong Kong on the use of bubble curtains to minimize the impacts on Indo-Pacific hump-backed dolphins from noise produced during underwater construction. Percussive pile-driving techniques were used from a barge, and a bubble curtain was used as a mitigation measure to protect wildlife, in particular the hump-backed dolphins. These researchers found that when barges were not in the sound-propagation path, the bubble curtain provided a reduction of 3 to 5 decibels in the overall broadband sound level. Conversely, when the barge was in the sound propagation path measured by the receiver systems, bubble screening was much less effective. This was probably due to the vibrations of the barge with every percussive blow, which transmitted the piling noise over the curtain. Bubble screening of entire sound-emitting structures could reduce sound even more.

Some dolphins stayed in the vicinity during construction activities, but many appeared to temporarily abandon the construction area (possibly due to other factors). However, dolphins were observed during construction or pile driving periods traveling at speeds over twice those observed during non-pile-driving periods. It is not certain whether increased speeds were a result of increased stress related to construction (Würsig et al. 2000).

**Construction and Operational Activities**

With regard to construction-specific activities aimed at protection and mitigation during the construction of over-water structures, only a few published reports were located. One of those reports is the literature review prepared by Mulvihill et al. (1980), which provides general construction recommendations. Two of the relevant recommendations are presented below.

- The placement of the structure relative to the sun, as well as the height and width of the deck of over-water structures, are important factors to consider. The structure should be placed high enough above the water to prevent shading. A narrow pier extending from north to south will not produce as much shade as a wide pier running from east to west (Mulvihill et al. 1980).

- The size, number, and placement of pilings should be evaluated in relation to the various biological zones over which the pier will extend.
Warrington (1999a) compiled and reported data concerning best management practices for construction, specific to surface stabilization. Quoted below are selected recommendations presented in the report that apply to activities associated with the construction of over-water structures. As stated previously, these recommendations are in essence BMPs that should be incorporated as permit conditions for individual projects, in order to ensure that these BMPs are implemented (Fresh 2000 personal communication):

**Scheduling**

- Coordinating the timing of land disturbing activities and installation of erosion and sedimentation control measures to minimize water quality impacts
- Scheduling (in-water) construction to avoid the period when either fall or spring spawning fish or their eggs and larvae are present
- Designing and planning the development of roads, utilities, and building sites with as little excavation and disturbance as possible
- Planning construction activities during the dry season to minimize erosion
- Staging development so that parts are being re-vegetated and parts have not been stripped yet to minimize the proportion which is actively bared and easily eroded

**Surface Protection**

- Carrying out watering, mulching, sprigging, or applying geotextile materials to a construction area to prevent soil loss as dust
- Mulching, a protective blanket of straw or other plant residue, gravel or synthetic material applied to the soil surface, to minimize raindrop impact energy and runoff; foster vegetative establishment, reduce evaporation, insulate the soil and suppress weed growth
- Seeding (permanent) to establish a perennial vegetative cover to minimize runoff, erosion and sediment yield on disturbed areas; disturbed soils typically require amendment with lime, fertilizer and roughening; seeding should be done together with mulching; mixtures are typically most effective and species vary with preferences, site conditions, climate and season
- Sodding to give permanent stabilization of exposed areas by laying a continuous cover of grass sod
- Seeding (temporary), planting rapid-growing annual grasses, small grains or legumes, to provide initial, temporary stabilization for erosion control on disturbed soils that will not be brought to final grade for more than approximately one month; seeding is facilitated by fertilizing and surface
roughening; broadcast seeds must be covered by raking or chain dragging, while hydro-seed mixtures are spread in a mulch matrix

- Treating disturbed soil with polyacrylamide (PAM) to increase infiltration and reduce suspension of soil particles
- Top-soiling, preserving and subsequently re-using the upper, biologically active layer of soil, to enhance final site stabilization with vegetation

**Runoff Control**

- Grading surfaces to redirect sheet flow
- Using diversion dikes or berms force sheet flow around a protected area
- Covering temporary stockpiles and backfill materials to prevent erosion and sedimentation
- Using silt fences to contain runoff from easily eroded slopes

**Sediment Traps**

- Constructing sediment traps, small, temporary ponding basins formed by an embankment or excavation to capture sediment from runoff; traps are most commonly used at the outlets of diversions, channels, slope drains or other runoff conveyances that discharge sediment-laden water; it is important to consider provisions to protect the embankment from failure from runoff events that exceed the design capacity; plan for non-erosive emergency bypass areas; make traps readily accessible for periodic maintenance; high length-to-width ratios minimize the potential for short-circuiting; the pond outlet should be a stone section designed as the low point
- Constructing sod drop inlet protection which consists of a permanent grass sod sediment filter area around a storm drain drop inlet for use once the contributing area soils are stabilized; this is well-suited for lawns adjacent to large buildings
- Constructing vegetated filter strips (VFSs) as a low-gradient vegetated area that filters solids from overland sheet flow; they can be natural or planted, should have relatively flat slopes, and should be vegetated with dense-culmed, herbaceous, erosion-resistant plant species; the main factors influencing removal efficiency are the vegetation type and condition, soil infiltration rate and flow depth and travel time, which are affected by size of contributing area, and slope and length of strip; channelized flows decrease their effectiveness; they are often used as buffers bordering on construction areas; level spreaders are often used to distribute runoff evenly across the strip
The operation and use of over-water structures also cause interrelated effects associated with boating activities. Warrington (1999a) compiled and reported data concerning the impact of recreational boating in freshwater environments (see also Warrington 1999b for water pollution associated with boating activities). Quoted below are a summary of selected recommendations presented in the report:

- To minimize bottom erosion, sediment suspension, vegetation loss and effects on wildlife, normal use of motorized boats should be restricted to water depths where the propeller or jet drive is at least 2 and preferably 3 meters above the sediment or vegetation surface, except at carefully selected boat launch sites. Also, in narrow channels (up to 3 boat lengths wide) boat speeds should be restricted to ‘no wake.’

- Heavy planting of floating and emergent native vegetation will help to protect the shoreline from wave-caused erosion.

- A minimal number of specified access channels between shallow and deeper water should be marked and used exclusively. These should be as short and direct as possible and should have wake limits imposed.

- Boats should not be permitted to operate in an area where they would be considered confined (boat cross-sectional area exceeds 5% of the cross-sectional area of the waterway). This is necessary to prevent bank erosion, sediment resuspension and destruction of marginal and shallow water vegetation.

- To preserve viable waterfowl and fish populations, all boating, fishing and other human activities need to be excluded from breeding and overwintering habitats during the critical seasons.

**Habitat Protection, Restoration, and Mitigation Techniques—Data Gaps**

A number of data gaps were identified during the review of literature pertaining to habitat protection and mitigation techniques for the construction of over-water structures. Further research to answer the following questions would serve to fill these data gaps.

- Which mitigation techniques are most effective in minimizing the loss of habitat or ecological function?

- Are the project goals, objectives, and performance standards used for wetland mitigation applicable to lakes and reservoirs?

- For restoration projects, how should project goals, objectives, and performance standards define targeted ‘historical conditions’?
What is the best means of preventing erosive cycles that preclude the recovery and reestablishment of emergent vegetation?

Does the use of bright white PVC and paint or reflective metals for the construction of in-water structures tend to prevent or decrease predator fish use of the structures?

Which design features of docks and piers are most effective in preventing or minimizing the environmental effects of these structures? Which features are most effective in minimizing their cumulative effects?
Summary of Existing Guidance

Regulatory Framework Governing Over-Water Structures in Freshwater

The regulatory framework governing construction and maintenance of over-water structures consists of federal, state, and local laws and administrative rules and guidelines. Following is a description of each of the applicable laws, codes, regulations, and other documents that make up the current regulatory framework.

Federal Laws and Regulations

*National Environmental Policy Act (NEPA)* (42 United States Code [USC] 4321 et seq.)

Federal agencies making funding decisions or issuing permits for over-water structures are required to comply with the National Environmental Policy Act. If the impacts of the over-water structure are determined to be environmentally significant, an environmental impact statement (EIS) is required. If the NEPA lead agency determines that the over-water structure will not significantly impact the environment, that agency issues a *finding of no significant impact* (FONSI).

*Clean Water Act Section 404* (33 USC 1344 et seq.; USC 1251 et seq.)

Construction of over-water structures that would result in discharge or excavation of dredged or fill material in United States waters, including wetlands, requires a Clean Water Act section 404 permit issued by the U.S. Army Corps of Engineers and/or the U.S. Environmental Protection Agency. The U.S. Fish and Wildlife Service, National Marine Fisheries Service, and Washington Department of Fish and Wildlife also play significant roles in the implementation of the section 404 permitting process (as authorized by the Fish and Wildlife Coordination Act).

*River and Harbors Act Section 10* (USC 403 et seq.)

Any work affecting navigable waters of the United States that extends to the ordinary high water mark in freshwater areas (including the construction of piers, docks, and floats) requires a section 10 permit issued by the U.S. Army Corps of Engineers. Navigable waters as defined in the River and Harbors Act include all presently, historically, and reasonably potential navigable waters, and all waters subject to the ebb and flow of the tide, up to mean higher high water in tidal waters and up to ordinary high water in freshwater areas.

*Endangered Species Act* (16 USC 1531 et seq.)

Because of the recent listing of several anadromous fish species for protection under the Endangered Species Act, and because many of the freshwaters of the state of Washington provide habitat for those protected species, construction of over-water structures and shoreline
development in general must comply with the requirements of the statute. The Endangered Species Act provides broad protection for fish, wildlife, and plant species that are listed as threatened or endangered. Provisions are made for listing species and designating critical habitat for listed species, as well as for recovery plans. The statute outlines procedures for federal agencies to follow when taking actions that may jeopardize listed species, and contains exceptions and exemptions. The shoreline development activities that have federal nexus (i.e., federal funds or federal permits) are subject to review under the statute. Among these activities, construction, replacement, or repair of piers, docks, mooring buoys, boat canopies, boathouses, pilings, and bulkheads require a U.S. Army Corps of Engineers permit and thereby are subject to review under the Endangered Species Act.

**State Laws and Regulations**

**State Environmental Policy Act (SEPA) (Revised Code of Washington [RCW] 43.21C)**

An over-water project proposal that requires a state or local agency permit is first required to undergo a SEPA review. In accordance with SEPA rules, one agency is identified as the lead agency for this review. This agency may determine that a project proposal is categorically exempt, or is clearly in compliance with the provisions of SEPA, in which case the SEPA review process is satisfied. If further clarification is needed, the lead agency can ask an applicant to fill out an environmental checklist, answering a standard series of questions to determine whether the project would have a significant adverse impact on the environment. If it is determined not to pose this threat, then the proposal is granted a *determination of nonsignificance* (DNS) and is considered to be in compliance with SEPA. If the proposed project is considered to pose significant adverse impacts to the environment, then an environmental impact statement (EIS) must be drafted, publicly reviewed, and finalized.

**Shoreline Management Act (SMA) (RCW 90.58)**

Construction of any type (including over-water structures) in waters of the state or in the adjacent regulated shoreline area, if it is valued at $2,500 or more ($10,000 if the project is a pier), requires a shoreline management substantial development permit issued by the city or county and reviewed by the Washington Department of Ecology. Shorelines in freshwater areas include all lake and reservoirs greater than 20 acres and their associated wetlands, and all streams and river segments with a mean annual flow greater than 20 cubic feet per second and their associated wetlands. The shoreline designation extends horizontally 200 feet from the ordinary high water mark.

Other activities in the water or shoreline area may require conditional use permits or variances also issued by the Department of Ecology. All permit activities are subject to appeal by citizens, applicants, and government agencies. Appeals are heard by the Shoreline Hearings Board.

The Shoreline Management Act requires local governments to write *shoreline master programs* that regulate streams, lakes over 20 acres, and marine waterfronts. There are 247 city and county master programs currently in effect that were written based on state guidelines. These guidelines are being revised (WAC 173-16). Cities and counties regulate projects in or adjacent to state
waters with their comprehensive plans, shoreline master programs, and other development regulations. The local laws and regulations that affect development activities (more specifically on- and over-water structures) in waters of the state vary from one jurisdiction to another, but include critical area development regulations (adopted under the state Growth Management Act) and environmental designations under shoreline master programs (adopted under the state Shoreline Management Act).

**Clean Water Act Section 401** *(33 USC 1251 et seq.)*

and **Coastal Zone Management Act** *(16 USC 601 et seq.)*

These federal laws are administered by the Washington Department of Ecology. Application for a federal permit under section 404 of the Clean Water Act to discharge dredge or fill material into state waters or wetlands, or to excavate in water or wetlands, triggers review under these laws. Section 401 certification and coastal zone consistency certification are issued by the Washington Department of Ecology.

**National Pollutant Discharge Elimination System (NPDES)**

The federal NPDES program is administered in Washington by the Department of Ecology. If a project disturbs more than 5 acres at one time, an construction permit must be issued by the Department of Ecology to ensure that state and federal water pollution provisions are upheld.

**Hydraulic Project Approval Code** *(RCW 75.20 and Washington Administrative Code [WAC] 220-110)*

Construction or operation of an over-water structure that would use, divert, obstruct, or change the natural flow or bed of any freshwater or saltwater of the state requires a hydraulic project approval issued by the Washington Department of Fish and Wildlife.

The Washington Administrative Code (WAC 220-110-060) regulates the construction of freshwater docks, piers, and floats and the driving and removal of pilings. As a result of the recent listing of fish species under the federal Endangered Species Act, state regulations are currently being revised to include all in-, on-, and over-water structures, and to grant a greater level of protection to endangered species and the environment, based on the best scientific data available. Similarly, WAC 220-110-224, which regulates freshwater boat hoists, ramps, and launches, is being revised to address the issue of cumulative effects of the siting of these structures, and to provide more specific regulatory language regarding the uses of these structures within the context of habitat and species protection.

In addition, under the state hydraulic code, WAC 220-110-223 regulates the construction of bulkheads, and WAC 220-110-050 addresses bank protection.

A memorandum of agreement between the Washington Department of Fish and Wildlife, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service was signed on April 4, 2000 to develop an Endangered Species Act compliance agreement for hydraulic project approvals, which are issued by the Department of Fish and Wildlife under RCW 75.20. This
memorandum of agreement provides language that addresses freshwater projects, including in-, on-, and over-water structures (section 5.C(3)(f)), oversight and monitoring (section 7), and adaptive management (section 10).

**Forest Practices Act** *(RCW 76.09)*

Any timber harvest or roadwork in a riparian management zone or riparian area associated with construction of an over-water structure requires a forest practices permit issued by the Washington Department of Natural Resources. This permit may require that forest landowners undertake corrective and remedial actions to reduce the impact of any forest practice that may be associated with a proposed project. The goal is to afford protection to forest soils, fisheries, wildlife, water quantity and quality, air quality, recreation, and scenic beauty.

**Aquatic Lands Act** *(RCW 79.90)*

Use of state-owned aquatic lands, including tidelands, shorelands, and beds of navigable waters, requires an aquatic use authorization (aquatic lease) issued by the Washington Department of Natural Resources.

**Water Pollution Control Act** *(RCW 90.48)*

A temporary exceedance of state water quality standards established by WAC 173-201A for in-water work (e.g., change in pH or turbidity) requires a Washington water quality standards modification issued by the Washington Department of Ecology.

**Aquatic Resource Mitigation Act** *(RCW 90.74)*

This law establishes a state policy to authorize innovative mitigation measures, by requiring state regulatory agencies to consider mitigation proposals for infrastructure projects that are timed, designed, and located in a manner to provide equal or better biological functions and values compared to traditional onsite, in-kind mitigation proposals. When making a regulatory decision, the agencies must consider whether the mitigation plan provides equal or better biological functions, compared to the existing conditions, for the target resources or species. The factors that agencies must consider in making this decision are identified in the state hydraulic code, the state Water Pollution Act, and the Aquatic Resource Mitigation Act.

**Salmon Recovery Act** *(RCW 75.46/ESHB 2496)*

In 1998 the Washington State Legislature passed the Salmon Recovery Act, in response to the state’s need for a coordinated approach to respond to the listing of salmon and steelhead runs as threatened or endangered under the federal Endangered Species Act.

**Wetland Mitigation Banking** *(RCW 90.84)*

In 1998 the Washington State Legislature passed legislation establishing wetland mitigation banking as one element of compensatory mitigation. The law directs consistency with federal
guidance on mitigation banking, and defines a wetland mitigation site as a site where wetlands are restored, created, or enhanced, or in exceptional circumstances preserved expressly for the purpose of providing compensatory mitigation in advance of authorized impacts on similar resources.

Mitigation policy guidance (RCW 75.46) states that the guidance shall create procedures that provide for alternative mitigation measures that have a low risk to the environment, yet have a high net environmental, social, and economic benefit compared to status quo options.

Local Laws and Regulations

Counties and local jurisdictions in Washington regulate the construction of over-water structures through shoreline management codes, such as the King County Shoreline Management Code (http://www.metrokc.gov/mkcc/Code/) or the City of Bellevue Land Use Code (http://www.ci.bellevue.wa.us/cobasp/lucindex.asp). These codes are drafted in the spirit of and enacted in conformance with the Washington Administrative Code.

Available Guidance Materials for Construction and Operation of Over-Water Structures in Freshwater

In response to the recent Endangered Species Act listing of species, the Washington Department of Fish and Wildlife (WDFW), the Washington Department of Ecology (Ecology), the Washington Department of Transportation (WSDOT), the National Marine Fisheries Service (NMFS), and the U.S. Fish and Wildlife Service (USFWS) have begun to update existing guidance and develop new guidance for activities with the potential to adversely affect the environment. This guidance is intended to provide a holistic approach to aquatic resources, and is expected to have the flexibility needed to address watershed activities and salmon recovery efforts while operating within the existing regulatory framework.

The following list of available guidance for construction and operation of over-water structures is not comprehensive. Rather it is limited to the most recent guidelines or those currently under revision.

- *Alternative Mitigation Policy Guidance*, February 10, 2000. This guidance was cooperatively developed by Ecology, WDFW, and WSDOT under the auspices of the Salmon Recovery Act (RCW 75.46), in order to improve the ecological benefits of compensatory mitigation for project impacts on wetlands, water quality, and fish and wildlife.

- *A Citizen’s Guide to the 4(d) Rule for Threatened Salmon and Steelhead on the West Coast*, June 2000. This guide introduces and explains the rule and provides a user-friendly description of why the rule is needed, what it contains, how it will affect citizens, and how to obtain more information: ([http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/citguide.htm#Take%20Guidance](http://www.nwr.noaa.gov/1salmon/salmesa/4ddocs/citguide.htm#Take%20Guidance)).

- *Best Management Practices to Protect Water Quality from Non-Point Source Pollution*, March, 2000. This document was prepared by Warrington (2000). It is an open-ended document produced as a web site so that it can be readily updated and expanded. The document provides recommendations that have been compiled from readily available published documents and internet sites and from some gray literature that may not be as readily available. Citations, references, and web links are provided. The document is organized by sectors. Under the service industries sector, guidelines for best management practices for the construction of wharves, docks, piers, and floats are provided ([http://www.nalms.org/bclss/bmphome.html](http://www.nalms.org/bclss/bmphome.html)).
Recommendations for Guidance Document

Shore-zone development in general modifies and degrades the environment, thereby adversely affecting wildlife and fish species. The observed responses discussed in this paper (i.e., predation, behavior, and habitat structures) confirm this fact. The resultant modification and degradation of the environment occur through the following mechanisms: shore-zone habitat structure changes, shading and ambient light changes, disruption of water flow pattern and energy, and physical-chemical environmental disruptions. However, some site-specific and species-specific responses still require further research. This research is needed to obtain information required to close existing data gaps, thereby gaining a better understanding of the mechanisms of disruption associated with all over-water structures. The following recommendations are intended for the development of future policy and guidance documents that address the environmental impacts of over-water structures and associated construction and operation activities.

General Policies

- A greater statewide level of coordination among local jurisdictions, state agencies, and federal agencies is needed in the preparation of guidelines for the maintenance, construction, and operation of over-water structures.

- Statewide guidelines are needed to protect ecosystem functions and direct habitat impact mitigation, resource management, and project planning. However, because of the hydrological characteristics of the systems and differences in fish habitat utilization, two separate sets of guidelines should be developed for eastern and western Washington.

- All new rules, regulations, and guidelines for over-water structures should be supported with scientific data.

- Future research should be focused on areas where gaps and ambiguities have been identified, and resources should be allocated for this purpose.

- Existing shoreline conditions (e.g., riparian and shallow-water) should be documented by videotaping to facilitate detection of unpermitted development activities. More intensive supervision and enforcement of shoreline use and inspection of proposed projects during construction should be implemented.

- In highly developed systems, such as Lake Washington in western Washington and Lake Chelan in eastern Washington, no net increase in over-water coverage should be allowed. In such systems, offsite mitigation alternatives (e.g., in areas with the lowest development density)
should be favored over onsite mitigation whenever the expected benefit is more cost-effective and yields greater ecological benefit.

- Preference should be given to offsite mitigation efforts consolidated on one site versus multiple offsite locations.

- All mitigation should provide better functional value than that provided by the habitat being replaced.

- If new over-water structures are to be allowed, the mitigation measures required to compensate for the construction of such structures should include site- and project-specific research to verify “not likely to adversely affect” situations prior to project implementation.

- For new and retrofitting projects, strict monitoring and evaluation programs should be required and included in the project plans. Third-party groups should conduct the monitoring and evaluation programs to preclude bias in the process.

- During the evaluation of proposed projects, a policy allowing no new over-water structures should first be considered. Because of their smaller surface area and correspondingly smaller shade effect, buoys should be selected rather than piers and docks for recreational mooring.

- There should be a greater level of regulation for activities such as boating that have interrelated effects. Funds from taxation imposed on such activities should be directed to shoreline restoration and enhancement programs.

**Shore-Zone Development**

- To provide maximum protection to juvenile chinook salmon in eastern and western Washington, further development in existing undeveloped shore-zone areas should be restricted, particularly in those areas having the characteristics preferred by this species (i.e., low-gradient habitats with sandy bottom and no aquatic vegetation).

- The goals and objectives of shore-zone restoration projects should include habitat characteristics, functionality, and values consistent with the preferred habitat for chinook salmon.

- New research should be initiated to investigate the preferred habitat characteristics for other salmonid species and their prey.
Minimum setbacks should be established to help prevent shoreline and stream bank erosion and to help minimize the cumulative effects of shore-zone development. These required setbacks could include requirements for the relocation of existing structures that may already exist within designated setbacks.

Additional research should be conducted to study the effectiveness of salmon habitat restoration projects in lakes and slow-flowing rivers and reservoirs.

**Structure Size**

- To minimize the cumulative effects of over-water structures, in particular the loss of habitat and the potential creation of refuge for predators, all structures should be as narrow as possible to achieve the project purpose. In addition, the multifamily use of individual docks should be encouraged, and only one dock per multi-lot development should be allowed.

- The number and body size of organisms using an area influenced by a floating object are directly related to the surface area of the object. Therefore, if a new over-water structure is to be allowed, the minimum possible size should be used to minimize the attraction of salmonid predators such as bass.

**On-Water Structures**

- Guidelines specifically addressing the storage and operation of on-water structures (i.e., log booms and rafts, trash-booms and trash-racks, work barges, and houseboats) should be prepared. Until structure-specific data become available, the responses observed from over-water structures should be extrapolated, particularly regarding changes in ambient light and in habitat function.

**Pilings**

- Smallmouth bass and largemouth bass have a strong affinity to pilings. Therefore, for all new projects, and for retrofitting projects when feasible from an engineering perspective, a downgrade in size and number of pilings should be required in order to minimize potential predation on juvenile salmonids.
Pier and dock pilings, which intercept gravel transport, may accelerate beach erosion. Therefore, the use of buoy and anchor systems should be preferred over pilings to prevent beach erosion.

In order to minimize the potential for predation on juvenile salmonids in free-flowing areas of systems where northern pikeminnow occur, the placement of in-water structures that create back-eddies and low-velocity microhabitat should not be allowed.

Pile-driving activities should be regulated, not because of potential noise impact, which seems to be negligible for salmonids, but for the potential to disturb bottom sediments.

The 300-foot protection zone restricting pile-driving activities in the vicinity of known sockeye spawning areas also should be required for chinook salmon in known beach spawning areas of Lake Washington.

**Bulkheads and Riprap**

- New bulkheads should not be permitted under any circumstance; instead, bioengineering solutions should be required.
- For retrofitting projects, bulkheads should be completely eliminated when possible or relocated shoreward of ordinary high water, and shorelines should be restored with emergent and riparian plant species.
- Riprap should not be allowed as an erosion control measure. Instead, site-specific bioengineering techniques should be required when alteration of the natural shoreline conditions is unavoidable, or for retrofitting projects.

**Shoreline Vegetation**

- If the over-water structure is permitted, onsite, in-kind, offsite, or out-of-kind mitigation (or any combination of these) should be required to achieve no-net-loss of habitat. This mitigation should include the establishment of native vegetation on any disturbed and adjacent shoreline areas, to minimize the adverse effects associated with cumulative loss of shoreline vegetation.
- A buffer should be preserved between new upland developments associated with over-water structures and the shoreline, to protect foraging and rearing habitat for fish and wildlife.
Shoreline development associated with the construction of an over-water structure should not include the alteration of natural stable shorelines or the creation of manicured land that extends to the river or lake edge. In already altered shoreline areas, bioengineering techniques should be used to protect altered shorelines.

**Ambient Light and Shading**

- Given that shading can affect habitat function by creating visual barriers to migrating fish, new and retrofitted over-water structures should be required to incorporate design elements to minimize the shaded area under the structure.

- New dock design elements currently required in eastern Washington (e.g., ambient light grids, white PVC sleeves for pilings, bright reflective aluminum, and bright white materials for flotation) should be investigated to determine their efficacy in reducing salmonid predation and in allowing adequate light penetration for macrophyte production. If found to be effective, these elements also should be required for projects in western Washington.

- Accessory dock structures such as pier skirting and batter boards that increase shading impacts on aquatic vegetation should not be permitted in the design or construction of new docks.

**Water Quality**

- Because the reaction distance declines as a decaying power function of turbidity, maintenance of background turbidity levels should be required during construction, to avoid potential adverse effects on salmonid predation. This can be achieved, for example, by the use of silt curtains or cofferdams.

- Because leachate from treated wood is toxic to aquatic organisms, the use of treated wood should not be allowed in construction of over-water structures.
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APPENDIX A

Literature Consulted and
Other Sources of Information
Literature Consulted
and Other Sources of Information


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<th>RESPONSE</th>
<th>In-, On-, and Over-Water Structures</th>
<th>Associated Activities</th>
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<td>Predation</td>
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<td>X</td>
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<td>Behavior</td>
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<tr>
<td></td>
<td>Behavior</td>
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April 12, 2001

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<td>Trash-booms &amp; Trash-racks</td>
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<td>Boat hoists, Boat launches, &amp; Boat ramps</td>
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<td>Beadhouses</td>
<td>Floating Breakwaters</td>
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*Numbers in brackets are keyed to entries in the list of references.*
Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems of the Lake Washington Basin

Annual Report, 2003 and 2004

March 2006
By Roger A. Tabor, Howard A. Gearns, Charles M. McCoy III and Sergio Camacho
U.S. Fish and Wildlife Service
Western Washington Fish & Wildlife Office
Lacey, Washington

Funded by Seattle Public Utilities (City of Seattle) and the City of Mercer Island
NEARSHORE HABITAT USE BY JUVENILE CHINOOK SALMON
IN LENTIC SYSTEMS, 2003 AND 2004 REPORT

by

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SUMMARY

In 2003 and 2004, we continued our assessment of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) habitat use in the nearshore areas of Lake Washington and Lake Sammamish. Additional work was conducted in Lake Quinault to study habitat features that are rare in the Lake Washington basin and serve as a more natural “reference system” to Lake Washington. Juvenile Chinook salmon are found in Lake Washington and Lake Sammamish between January and July, primarily in the littoral zone. Little is known of their habitat use in lakes, as ocean-type Chinook salmon rarely occur in lakes throughout their natural distribution. Research efforts in 2003 and 2004 focused on juvenile Chinook salmon distribution, residence time and movements, shoreline structure use (woody debris, overhanging vegetation, and emergent vegetation), depth distribution, use of nonnatal tributaries, feeding at the mouths of tributaries, abundance at restoration sites, and behavior of migrating smolts. Data on Chinook salmon habitat use were collected primarily through snorkel surveys.

We repeatedly surveyed nine index sites in 2003 in south Lake Washington to examine the temporal and spatial distribution of juvenile Chinook salmon. We surveyed four sites on the east shoreline, four on the west shoreline, and one on Mercer Island. Similar to 2002 results, the two sites closest to the Cedar River had substantially higher densities of Chinook salmon from the beginning of February to the end of May than the other seven sites. Overall, the abundance of Chinook salmon displayed a strong, negative relationship with the shoreline distance from the mouth of the Cedar River to each site. Juvenile Chinook salmon were present on Mercer Island on each survey date.

To better understand the residence time and movement patterns of juvenile Chinook salmon, we conducted a marking study at Gene Coulon Park. Approximately 100 Chinook salmon (mean, 45 mm fork length) were collected from each of two sites and each group was marked with a different color of dye and were later released where they were captured. At 1, 7, 15 and 21 days after release, we snorkeled the entire shoreline of Gene Coulon Park at night to look for marked fish. Results indicated many Chinook salmon remain in a small area. We never found any Chinook salmon that had moved more than 150 m. The median distance moved within the study area remained the same from day 1 to day 21 but the number of marked fish observed declined substantially. Therefore, it is possible that some fish moved outside of our survey area.

We continued to monitor restoration sites, both pre- and post-project, to help determine if lake-shoreline habitat can be improved for juvenile Chinook salmon rearing. A restoration project at Seward Park was completed in December 2001. The restoration site as well as other Seward Park shoreline sites were surveyed in 2002-2004 and compared to 2001 data. Numbers of juvenile Chinook salmon were generally low for each year. Overall, we found no evidence of increased Chinook salmon use of the Seward Park restoration site.

We also continued to collect baseline information at Beer Sheva Park and Martha Washington Park. In addition, we also began collecting baseline data at Rainier Beach Lake Park and Marina and the old Shuffleton Power Plant Outflow site. The boat ramp area at Beer Sheva Park had high densities of Chinook salmon, and there appear to be
sufficient numbers of juvenile Chinook salmon at Beer Sheva Park to rear at the mouth of Mapes Creek if it were restored. Overall, restoration sites close to the mouth of the Cedar River likely have a higher chance of success than further north sites because juvenile Chinook salmon are substantially more abundant near the mouth of the Cedar River than at more northerly sites.

Both day and night surveys were conducted to better quantify the water depth of the area where juvenile Chinook salmon are located. Daytime surveys consisted of surface observations of juvenile Chinook salmon feeding at the surface. Surveys were conducted once every two weeks from February to June. Nighttime surveys were conducted once a month from March to May and consisted of a series of perpendicular snorkel/scuba diving transects between 0- and 3- m depth. During the day from February 19 to April 14, Chinook salmon were only observed in water between 0- and 0.5-m deep. From late April to June, surface feeding activity by Chinook salmon was observed in progressively deeper water and by June most activity was observed in an area where the water was between 2- and 3-m deep. Results of nighttime surveys clearly showed that juvenile Chinook salmon progressively shift to deeper waters as they grow.

In 2002, we surveyed 17 tributaries and found juvenile Chinook salmon are often present at the tributary mouths. We surveyed six tributaries in 2003 and 2004 to determine if Chinook salmon forage on prey items that come into the lake via the tributary and how storm events affect the diet and abundance of juvenile Chinook salmon. Under baseflow conditions, differences in the diet between the lake shore and the tributary mouth were not pronounced; however, Chinook salmon at tributary mouths do appear to utilize prey from the tributary to some extent. Chironomid pupae and adults were the most important prey at both the tributary mouths and lakeshore sites. However, benthic and terrestrial insects were more prevalent in the diet at tributary mouths than at lakeshore sites. The diet breadth was usually higher at the tributary mouths than along the lakeshore. Tributary mouths appeared to be especially valuable habitat for Chinook salmon during high streamflow conditions. The diet breadth was much broader at high streamflow than during base streamflow conditions. A large percentage of the diet during high streamflow conditions consisted of benthic prey such as chironomid larvae and oligochaetes. These prey items were a minor component of the diet at tributary mouths during base streamflow conditions and at lakeshore sites. At May Creek, we were also able to demonstrate that the abundance of Chinook salmon can increase during a high flow event.

Of the 17 tributaries examined in 2002, Johns Creek was by far the most used by Chinook salmon. We continued surveys of Johns Creek in 2003 and 2004, to determine the spatial and temporal distribution of Chinook salmon within the tributary. We surveyed the lower 260 m of the creek once every two to three weeks. Results from Johns Creek indicated that Chinook salmon extensively use this nonnatal tributary from year to year. They use slow-water habitats and moved into deeper habitats as they increased in size. Density of Chinook salmon in the convergence pool was considerably lower than in pools and glides upstream. The convergence pool is larger and deeper than the other habitats and has very low water velocities. Also, other fish species, including predators, were often present in the convergence pool and rare or absent in the other habitats.
An overhanging vegetation/small woody debris (OHV/SWD) experiment was conducted in Gene Coulon Park in 2003. We compared the abundance of Chinook salmon at two shoreline sections with OHV and SWD to two sections with only SWD and to two sections where no structure was added. The site was surveyed during two time periods; March 24 through April 9 and May 2 through 16. During daytime in the early time period, we found a significantly higher abundance of Chinook salmon at the OHV/SWD sites than the other two shoreline types. Large numbers of Chinook salmon were located directly under the OHV. At night, no significant difference was detected. Also, there was no significant difference during the late time period (May 2 through 16), either day or night. Results indicated that overhead cover is an important habitat element early in the season; however, an additional experiment is needed to determine if OHV alone is used as intensively as OHV is in combination with SWD.

Because large woody debris (LWD) and emergent vegetation are rare in Lake Washington, we examined their use by juvenile Chinook salmon in Lake Quinault. Nearshore snorkel transects were surveyed in 2004 during a 2-week period in April and a 2-week period in June. The nearshore area was divided into one of five habitat types: open beach, bedrock, emergent vegetation, LWD, or tributary mouth. During the April daytime surveys, tributary mouths generally had higher numbers of Chinook salmon than the other habitat types and bedrock sites often had a lower number. Beach, emergent vegetation, and LWD sites were not significantly different from each other. Within LWD sites, juvenile Chinook salmon were often resting directly under a large piece of LWD. There was no difference in their nighttime abundance between habitat types. In June, few Chinook salmon were observed during the day except at tributary mouths. Apparently, Chinook salmon were further offshore during the day. At night, they were abundant in the nearshore area but there was no difference in their abundance between habitat types.

Earlier Lake Washington work in June 2001 indicated that Chinook salmon can be observed moving along the lake shoreline. In 2003 and 2004, we undertook a more in-depth sampling approach to determine when they can be observed. Additionally, we wanted to collect information on their behavior in relation to piers. In 2003 and 2004, weekly observations (May-July) were conducted at one site, a public pier near McClellan Street. Observations at other piers were only conducted when large numbers of Chinook salmon had been seen at McClellan Pier. The timing of the migration appeared to coincide with the June moon apogee, which has been also suggested to be related to the passage of Chinook salmon smolts at the Ballard Locks. When migrating Chinook salmon approach a pier they appear to move to slightly deeper water and either pass directly under the structure or swim around the pier. The presence of Eurasian milfoil (Myriophyllum spicatum) appeared to cause juvenile Chinook salmon to be further offshore in deeper water. The top of the milfoil appeared to act as the bottom of the water column to Chinook salmon. At some piers with extensive milfoil growth, Chinook salmon were located on the outside edge of the pier and the pier had little effect on their behavior.

A summary table is presented below which lists various habitat variables and displays conclusions about each variable for three time periods (Table 1). The table was
developed from results of this report as well as two earlier reports (Tabor and Piaskowski 2002, Tabor et al. 2004b).

**Table 1.--** Summary table of juvenile Chinook salmon habitat use during three time periods in Lake Washington. Summary designations are based on 2001 (Tabor and Piaskowski 2001), 2002 results (Tabor et al. 2004b) and 2003-2004 results presented in this report. (++ indicates a strong preference + indicates a slight to moderate preference; = indicates no selection (positive or negative); - indicates a slight to moderate negative selection; -- indicates a strong negative selection; ?? indicates that no data is available; and (?) indicates that only preliminary data is available. Sand/gr. indicates sand and gravel.

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INTRODUCTION

Juvenile ocean-type Chinook salmon (*Oncorhynchus tshawytscha*) primarily occur in large rivers and coastal streams (Meehan and Bjornn 1991) and are not known to commonly inhabit lake environments. Consequently, little research has been conducted on their habitat use in lakes (Graynoth 1999). In western Washington, juvenile Chinook salmon inhabit three major lakes, Lake Washington, Lake Sammamish and Lake Quinault. These lakes are used as either a migratory corridor from their natal stream to the marine environment (mostly in June) or as an extended rearing location before outmigrating (January-July) to the marine environment. Prior to 1998, little research had been conducted on juvenile Chinook salmon in the lentic environments of the Lake Washington system. Initial work in 1998 to 2000 focused on macrohabitat use and indicated that juvenile Chinook salmon in Lake Washington are primarily restricted to the littoral zone until mid-May when they are large enough to move offshore (Fresh 2000). Subsequent research in 2001 focused on mesohabitat and microhabitat use (Tabor and Piaskowski 2002). Results indicated juvenile Chinook salmon were concentrated in very shallow water, approximately 0.4-m depth, and prefer low gradient shorelines with small particle substrates such as sand and gravel. Armored banks, which make up 71% of the Lake Washington shoreline (Toft 2001), reduce the quality and quantity of the nearshore habitat for juvenile Chinook salmon. In 2002, research efforts focused on juvenile Chinook salmon distribution, shoreline structure use, use of non-natal tributaries, and abundance at restoration sites (Tabor et al. 2004b).

In 2003 and 2004, we continued to examine the habitat use of juvenile Chinook salmon in the nearshore areas of Lake Washington and Lake Sammamish. Additionally, we began an investigation of habitat use in Quinault Lake, a relatively pristine environment. This report outlines research efforts which focused on juvenile Chinook salmon distribution, use of small woody debris (SWD) and overhanging vegetation (OHV), use of non-natal tributaries, and abundance at restoration sites.

STUDY SITE

We examined habitat use of juvenile Chinook salmon in Lake Washington, Lake Sammamish, and Lake Quinault. Lake Washington is a large monomictic lake with a total surface area of 9,495 hectares and a mean depth of 33 m. The lake typically thermally stratifies from June through October. Surface water temperatures range from 4-6°C in winter to over 20°C in summer. During winter (December to February) the lake level is kept low at an elevation of 6.1 m. Starting in late February the lake level is slowly raised from 6.1 m in January to 6.6 m by May 1, and 6.7 m by June 1. The Ballard Locks, located at the downstream end of the Ship Canal, control the lake level. Over 78% of the lake shoreline is comprised of residential land use. Shorelines are commonly armored with riprap or bulkheads with adjacent landscaped yards. Man-made overwater structures (i.e., docks, piers, houses) are common along the shoreline. Natural shoreline structures, such as SWD and large woody debris (LWD) and emergent vegetation, are rare.
The major tributary to Lake Washington is the Cedar River, which enters the lake at its southern end (Figure 1). The river originates at an approximate 1,220-m elevation, and over its 80-km course falls 1,180 m. The lower 55 km are accessible to anadromous salmonids. Prior to 2003, only the lower 35 km were accessible to anadromous salmonids. Landsburg Dam, a water diversion structure, prevented Chinook salmon from migrating further upstream. A fish ladder was completed in 2003, which allows access past Landsburg Dam to an additional 20 km of the Cedar River. The escapement goal for adult Cedar River Chinook salmon is 1,250; however, this goal has not been met in recent years.

Historically, the Duwamish River watershed, which included the Cedar River, provided both riverine and estuarine habitat for indigenous Chinook salmon. Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered (Weitkamp and Ruggerone 2000). Most importantly, the Cedar River was diverted into Lake Washington from the Duwamish River watershed, and the outlet of the lake was rerouted through the Lake Washington Ship Canal (Figure 1). These activities changed fish migration routes and environmental conditions encountered by migrants. The existence of a Chinook salmon population in the Lake Washington drainage prior to 1912 is not well documented.

Lake Sammamish is within the Lake Washington basin and is located just east of Lake Washington. Lake Sammamish has a surface area of 1,980 hectares and a mean depth of 17.7 m. Most of the shoreline is comprised of residential land use. Issaquah Creek is the major tributary to the lake and enters the lake at the south end (Figure 1). A Washington Department of Fish and Wildlife salmon hatchery (Issaquah State Hatchery), which propagates Chinook salmon, is located at river kilometer 4.8.

The largest run of wild Chinook salmon in the Lake Washington basin occurs in the Cedar River. Large numbers of adult fish also spawn in Bear Creek, a tributary to the Sammamish River, which connects lakes Washington and Sammamish (Figure 1). Small numbers of Chinook salmon spawn in several tributaries to Lake Washington and Lake Sammamish. Most hatchery production occurs at Issaquah State Hatchery. Chinook salmon also spawn below the hatchery in Issaquah Creek and other adults are allowed to migrate upstream of the hatchery if the hatchery production goal of returning adults is met. Additional hatchery production occurs at the University of Washington (UW) Hatchery in Portage Bay. Production goals are 2 million for Issaquah State Hatchery and 180,000 for UW Hatchery.

Adult Chinook salmon enter the Lake Washington system from Puget Sound through the Chittenden Locks in July through September. Peak upstream migration past the locks usually occurs in August. Adult Chinook salmon begin entering the spawning streams in September and continue until November. Spawning occurs from October to December with peak spawning activity usually in November.
FIGURE 1.—Map of the Lake Washington basin showing the major streams and lakes. Cedar Falls is a natural barrier to anadromous salmonids. A fish ladder facility at Landsburg Dam is operated to allow passage for all salmonids except sockeye salmon. LWSC = Lake Washington Ship Canal. The location of the basin within Washington State is shown.
Fry emerge from their redds from January to March. Juvenile Chinook salmon appear to have two rearing strategies: rear in the river and then emigrate in May or June as pre-smolts, or emigrate as fry in January, February, or March and rear in the south end of Lake Washington or Lake Sammamish for three to five months. Juvenile Chinook salmon are released from the Issaquah State Hatchery in May or early June and large numbers enter Lake Sammamish a few hours after release (B. Footen, Muckleshoot Indian Tribe, personal communication). Juveniles migrate past the Chittenden Locks from May to August with peak migration occurring in June. Juveniles migrate to the ocean in their first year, and thus Lake Washington Chinook salmon are considered “ocean-type” fish.

Besides Chinook salmon, anadromous salmonids in the Lake Washington basin includes sockeye salmon (O. nerka), coho salmon (O. kisutch), and steelhead (O. mykiss). Sockeye salmon are by far the most abundant anadromous salmonid in the basin. Adult returns in excess of 350,000 fish have occurred in some years. In comparison to other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species. Besides anadromous salmonids, there are 22 extant native species of fishes in the Lake Washington basin. An additional 27-28 species have been introduced, 20 of which are extant.

In addition to the lentic systems of the Lake Washington basin, we also examined the habitat use of Chinook salmon in Lake Quinault, a natural 1,510 ha lake located in north Grays Harbor County, Washington and part of the Quinault Indian Reservation. The lake is approximately 6.3 km miles long and its outlet is at river kilometer 53.7 on the Quinault River. The mean depth is 40.5 m and the maximum depth of the lake is approximately 73 m deep. Similar to Lake Washington, Lake Quinault has steep-sloping sides and an extensive, flat profundal zone. Some recreational and residential development has occurred on the shores of Lake Quinault but the level of development is minimal in comparison to Lake Washington and Lake Sammamish. Very little of the shoreline of Lake Quinault is armored and few docks are present. Besides the Quinault River and its tributaries, Chinook salmon have also been observed spawning in Canoe Creek, Zeigler Creek, Gatton Creek, Falls Creek, and Willaby Creek. Preliminary information suggests that Chinook salmon fry enter Lake Quinault later in the year than in Lake Washington, probably due to the colder water temperatures of the Quinault River and other natal tributaries and thus the incubation time is longer. The average escapement for the past ten years of adult Chinook salmon above Lake Quinault is approximately 1,500 fish. Juvenile Chinook salmon in Lake Quinault may also come from the Quinault Indian Nation hatchery located on Lake Quinault. Approximately 300,000 to 400,000 fish are released annually. Because they are released in late summer, they would not be present when we conducted our surveys in April and June. Besides Chinook salmon, Lake Quinault is also an important nursery area for coho salmon and sockeye salmon. Unlike Lake Washington, few introduced fish species are present in Lake Quinault. The only introduced species we observed was common carp (Cyprinus carpio).
CHAPTER 1. INDEX SITES

Introduction

In 2003, we continued our surveys of index sites in south Lake Washington to determine the temporal and spatial distribution of juvenile Chinook salmon. Index sites were initially surveyed in 2002. Results indicated that, from January to June, juvenile Chinook salmon were concentrated in the two sites closest to the mouth of the Cedar River. Because of cooler water temperatures in 2002, movement to more northerly sites may have been delayed. We repeated surveys of most of the index sites in 2003 to examine the level of variability between years and to determine if cooler temperatures in 2002 reduced movements to more northerly locations.

Index site surveys were continued in 2004 on a limited basis to provide additional information for the City of Mercer Island. The city is planning to remove some aging sewer pipes along the shore of northwest Mercer Island; however, little is known about the abundance of Chinook salmon at this location.

Methods

2003 surveys.-- Twelve index sites were surveyed in 2002; however, in 2003 we reduced the number of sites to nine so a two-person crew could easily get all the sites surveyed in one night. Of the nine sites, four were on the west shoreline, four were on the east shoreline and one was on Mercer Island (Figure 2). Sites typically had sand and small gravel substrate and a gradual slope; nearshore habitat that juvenile Chinook salmon typically prefer. Many of the sites were public swimming beaches. Habitat conditions of each index site were measured in 2002 (Table 2). Index sites were surveyed once every two weeks from February 4 to July 7. At each site, we surveyed a 50- to 125-m transect depending on the amount of high quality habitat available (sandy beach with gradual slope). Two transects were surveyed at each site, 0.4- and 0.7- m depth contour. Surveys were all done at night. Snorkelers swam parallel to shore with an underwater flashlight, identifying and counting fish. Transects widths were standardized to 2.5 m (0.4- m depth) and 2 m (0.7- m depth). Snorkelers visually estimated the transect width and calibrated their estimation at the beginning of each survey night by viewing a pre-measured staff underwater.

Fish densities (Chinook salmon/m$^2$) were calculated by dividing the number of Chinook salmon observed by the area surveyed for each site and transect. A regression was developed between Chinook salmon density and distance of each site from the mouth of the Cedar River.
FIGURE 2.—Location of index sites in south Lake Washington used to study the temporal and spatial distribution of juvenile Chinook salmon. In 2003 (January to July), we surveyed four sites each on the west and east shorelines and East Mercer site on Mercer Island. In 2004 (February to June), the north Mercer and northwest Mercer sites were surveyed as well as the East Mercer, Kennydale Beach, and Gene Coulon Beach sites. The Cedar River, the major spawning tributary for Chinook salmon in south Lake Washington, is also shown.
TABLE 2. —Distance from the mouth of the Cedar River and habitat characteristics of index sites surveyed in southern Lake Washington, February to July, 2003. The distance from Cedar River is an approximate length of the shoreline from the mouth of the Cedar River to each site. The number of piers is the number of overwater structures or piers along the transect; each pier was perpendicular to shore and was approximately 2-3 m wide.

<table>
<thead>
<tr>
<th>Shoreline Site</th>
<th>Distance from Cedar River (km)</th>
<th>Transect length (m)</th>
<th>Substrate</th>
<th>Distance to 1 m depth (m)</th>
<th>Bulkhead length (m)</th>
<th>Number of piers</th>
</tr>
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<tr>
<td><strong>West</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>113th Street</td>
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<td>121</td>
<td>60</td>
<td>38</td>
<td>2</td>
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<td>94</td>
<td>6</td>
<td>0</td>
<td>22.9</td>
</tr>
<tr>
<td>Mt. Baker</td>
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<td>122</td>
<td>38</td>
<td>41</td>
<td>21</td>
<td>11.3</td>
</tr>
<tr>
<td><strong>East</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gene Coulon Beach</td>
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<td>East Mercer</td>
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<td>56</td>
<td>27</td>
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2004 surveys.-- In 2004, we surveyed two new sites on the northwest part of Mercer Island (North Mercer site and Northwest Mercer site) as well as three original index sites (East Mercer, Kennydale Beach, Gene Coulon Beach; Figure 2). Surveys of the original sites enabled us to make comparisons between the two new Mercer Island sites and other areas of south Lake Washington. Both of the northwest Mercer Island sites had a steeper slope than the original index sites. The North Mercer site was along the shoreline of two residential homes. The transect was 92 m long (70-m bulkhead length) and the substrate was mostly sand and gravel. The Northwest Mercer site was located from Calkins Landing to Slater Park (two public beaches) and included four private residential homes that were between the two beaches. The transect was 140 m long (118-m bulkhead length) and the substrate was mostly sand and gravel. All five sites were surveyed once every 2 weeks from February to June. Sampling at each site was done through nighttime snorkeling and survey protocols were the same as in 2002 and 2003.

Results

2003 surveys.-- In general, results of index sites in 2003 were similar to 2002 (Tabor et al. 2004b). The mean abundance of juvenile Chinook salmon from February 4 to May 27 was negatively related to the shoreline distance from the mouth of the Cedar River (Figure 3). The data was best fit with a logarithmic function (abundance \( y = -0.137\ln (\text{distance}(x)) + 0.36 \)). During this time period, the two sites closest to the Cedar River (113th Street and Gene Coulon) had substantially higher densities than the other sites on
most dates (Figure 4). Unlike 2002, large numbers of juvenile Chinook salmon were observed in February. Large numbers were observed as early as February 4 and were present at all sites except Mt. Baker and Chism, the two furthest north sites. A high streamflow event in the Cedar River from January 31 to February 6, coupled with a high adult return in 2002 had apparently resulted in large numbers of fry moving downstream in early February, which were also observed at the fry trap (Seiler et al. 2005a).

In June, there was no relationship between Chinook salmon abundance and distance to the mouth of the Cedar River (Figure 3; log regression, $r^2 = 0.0012$). Generally, Chinook salmon abundance in June was higher on the west shoreline sites (Figure 3; mean, east = 0.14 fish/m$^2$, west = 0.33 fish/m$^2$) but they were not statistically different (Mann-Whitney $U$ test = 2.0, $P = 0.83$).

From February to April, densities of Chinook salmon were usually considerably higher in the 0.4-m transect than the 0.7-m transect. For example, at the two southern sites (Gene Coulon and 113$^{th}$ St.) the density in the 0.4-m transect was 3.2 to 77 times higher than in the 0.7-m transect (Figure 5). In May and June, Chinook salmon were commonly found along both the 0.4- and 0.7-m depth contours.

2004 surveys.-- Few Chinook salmon were observed at the sewer replacement sites on Mercer Island (north and northwest sites) until May 24 (Figure 6). Substantially more Chinook salmon were observed at the east Mercer Island site than at either of the sewer replacement sites. Between February 7 and May 10, juvenile Chinook salmon were observed at the east Mercer Island site (mean density, 0.045 fish/m$^2$) on each survey night; whereas they were only present on 2 of 8 nights at the northwest site (mean density, 0.0042 fish/m$^2$) and on 1 of 5 nights at the north site (mean density, 0.0008 fish/m$^2$). On June 10, several Chinook salmon were observed at each Mercer Island site and the density at each site was substantially higher than at the two east shoreline sites (Figure 6). Many of these fish may have been Issaquah hatchery fish, which had been released in late May.

Abundance of Chinook salmon at Gene Coulon and Kennydale in 2004 was generally lower than either 2002 or 2003 (Figure 7). Peak abundance in Gene Coulon was 1.14 fish/m$^2$ in 2002 and 0.80 fish/m$^2$ in 2003; whereas it was only 0.27 fish/m$^2$ in 2004. In contrast, 2004 abundance of Chinook salmon at the east Mercer Island site was generally the same as or higher than 2002 or 2003.
FIGURE 3.—Relationship (logarithmic function) between the mean juvenile Chinook salmon density and the shoreline distance to the mouth of the Cedar River in south Lake Washington, 2003. The February – May density represents the mean of nine surveys dates from February 4 to May 27. The June density represents the mean of June 9 and June 23. Sites include four west shoreline sites (open circles), four east shoreline sites (solid diamonds) and one site on Mercer Island (cross mark). The distance to the Cedar River for the Mercer Island site includes the distance from Coleman Point to South Point (see Figure 2).
**Figure 4.**—Juvenile Chinook salmon density (number/m²) at four east shoreline sites and four west shoreline sites in south Lake Washington, 2003. Data represents the mean of nighttime snorkel transects along two depth contours: 0.4 and 0.7 m.
FIGURE 5.—Juvenile Chinook salmon density (number/m$^2$) along two depth contours; 0.4 m (solid line) and 0.7 m (dashed line) at two sites in south Lake Washington, 2003
FIGURE 6.—Juvenile Chinook salmon density (number/m$^2$) at three Mercer Island sites and two east shoreline sites, Lake Washington, February to June, 2004. Data represents the mean of two nighttime snorkel transects (0.4- and 0.7-m depth contours).
**FIGURE 7**—Juvenile Chinook salmon density (number/m²) at two shoreline sites in south Lake Washington, February to June, 2002 to 2004. Data represents the mean of two nighttime snorkel transects (0.4- and 0.7-m depth contours).

**Discussion**

Similar to results of 2002, juvenile Chinook salmon were concentrated in the south end of Lake Washington from February to May. Washington Department of Fish and Wildlife conducted a beach seining project in Lake Washington in 1998 and 1999 and observed the same trend that we observed (Fresh 2000). Shortly after emergence, juvenile Chinook salmon in Lake Coleridge, New Zealand were found 240 m away from the mouth of their natal streams. After a couple of months they were found about 740 m away from the natal stream but absent at 7 km away (Graynoth 1999). Therefore, it appears that the lake shore area near the natal stream is an important nursery area for juvenile Chinook salmon. In Lake Washington, the major part of this nursery area appears to be roughly from Pritchard Beach on the west shoreline and the mouth of May Creek on the east shore and the south part of Mercer Island. The distance from the mouth of the Cedar River to the edge of the nursery area is around 6 km. North of this area, the number of Chinook salmon would be expected to be relatively low until mid-May or June. Because Chinook salmon are closely associated with nearshore habitats from February to May, restoring and protecting shallow water areas in the south end would be
particularly valuable. Shoreline improvements in more northern locations would be beneficial, but the overall effect to the Chinook salmon population would be small in comparison to restoration efforts in the south end.

In Lake Quinault, juvenile Chinook salmon in April were relatively small but appeared to have dispersed around the entire lake. Lake Quinault is much smaller than Lake Washington and there are natal systems on the east and south shorelines and every shoreline area is probably within 7 km of a natal stream. However, even at our sites that were the furthest from a natal stream, juvenile Chinook salmon were relatively abundant. Chinook salmon in Lake Quinault may disperse around the lake faster than in Lake Washington because of habitat conditions. Most of the shoreline of Lake Quinault appeared to have good quality habitat (small substrates and gentle slope) for juvenile Chinook salmon. In Lake Washington, much of the shoreline is armored with riprap or bulkheads, which may be a partial barrier to juvenile Chinook salmon if they are moving along the shore. Juvenile Chinook salmon may also disperse faster in Lake Quinault than in Lake Washington if prey availability is lower. In Lake Washington, prey abundance appears to be high (Koehler 2002) and thus Chinook salmon may be less inclined to move.

Our results of surveys of index sites appear to be in general agreement with the Cedar River WDFW fry trap results with one notable exception (Seiler et al. 2004; Seiler et al. 2005a; Seiler et al. 2005b). In early February 2003, a large pulse of Chinook salmon was observed in the lake and at the fry trap. Similar to fry trap results, we observed fewer juvenile Chinook salmon in 2002 than 2003 and they moved into the lake later in 2002. However, a large pulse of Chinook salmon was observed in late February 2002 at the fry trap but we did not detect it in the lake. Instead, we did not observe large numbers of Chinook salmon at the southernmost index sites until late April. Similarly, we did not observe a pulse of Chinook salmon in early February in 2004. In 2002 and 2004, juvenile Chinook salmon fry may have remained near the mouth of the river or perhaps they dispersed rapidly around the south end of the lake. Little is known about the movement patterns of Chinook salmon fry as they enter the lake.
CHAPTER 2. RESIDENCE TIME AND MOVEMENTS

Introduction and Methods

Little is known about the residence time and movement patterns of juvenile Chinook salmon in south Lake Washington. In 2003, we undertook a study to test the feasibility of conducting a mark-recapture study and collecting initial data on Chinook salmon movements. Preliminary testing of the marking technique was conducted on juvenile coho salmon at the USFWS Quilcene National Fish Hatchery in February 2004. We tested different methods of marking including syringes and needless injectors (Microjet and Panjet). Also the dye was placed in different locations of the fishes’ body including the caudal fin, dorsal fin, and other locations. Overall, syringes appeared to provide the best mark. They took longer to apply than injectors but the mark was more visible. Placing the mark in the caudal peduncle area appeared to be the best location.

Collection of Chinook salmon in south Lake Washington was done with a beach seine on March 25 at two Gene Coulon Park sites: the swim beach and the north experimental site (Figure 8). We marked approximately 100 fish at each site. The caudal peduncle of each Chinook salmon was marked with a photonic dye that was injected with a syringe. The swim beach fish were dyed yellow and the north Gene Coulon fish were dyed red.

After release, locations of marked fish were determined through nighttime snorkeling. To maximize the number of fish observed over a large distance, we conducted nighttime snorkeling transects along one depth contour at 0.4 m. Except for a few inaccessible locations, we snorkeled the entire Gene Coulon Park, a shoreline length of approximately 1,700 m. The shoreline was divided in 100-m transects that were established in 2001 as part of our random transect survey to determine substrate use by Chinook salmon (Tabor and Piaskowski 2002). Residence-time snorkel surveys were conducted 1, 7, 15, and 21 days after marking. The location where each marked fish was found was flagged and the shoreline distance to the release site was determined. The number of unmarked Chinook salmon was also counted within each 100-m transect.

Results

A total of 210 juvenile Chinook salmon were marked and released on March 24. One hundred and eight were marked yellow (mean, 46.0 mm FL; range, 40-60 mm FL) and 102 were marked red (mean, 43.9 mm FL; range, 38-57 mm FL). A total of 113 marked Chinook salmon observations (65 yellow and 48 red) were made for the four snorkel surveys. Twenty-nine percent of the all marked fish released were observed one day after release. For both groups, the number of marked Chinook salmon we observed progressively declined from the first survey (1 day after release) to the fourth survey (day 21 after release) (Figure 9). For the four survey dates, 60 of the 113 (53%) total marked fish observations were made on March 25, one day after release.
FIGURE 8.—Map of south Lake Washington displaying the shoreline of Gene Coulon Park surveyed (bolded line) to determine movements of juvenile Chinook salmon, March to April 2003. The release site (open circles) of each group of dye-marked fish is also shown.
Marked Chinook salmon that were observed after release did not move appreciably from the release site. All marked Chinook salmon we observed had moved less than 150 m from the release site (Figures 10, 11, and 12). Movement from the release site occurred both towards (south to southeast) and away (north to northeast) from the mouth of the Cedar River. However, slightly more fish appeared to move away from the Cedar River than towards the river (Figure 13). On all dates, the distance moved by fish that moved towards the Cedar River appeared to be similar to those that moved away from the river (Figure 13) except on day 1, when red-marked fish that moved away from the river had moved substantially further than those that had moved towards the river.

Unmarked Chinook salmon were observed along the entire shoreline surveyed. The total number of Chinook salmon we observed ranged from 3,424 on March 25 to 1,779 on April 9. Similar to earlier sampling in 2001, their abundance appeared to be related strongly to shoreline armoring (rip rap or bulkhead). In the seven transects that were mostly armored, the number of juvenile Chinook salmon was three times lower than in transects that had little or no armoring (Mann-Whitney $U$ test = 9.0; $P = 0.005$). Additionally, large numbers of Chinook salmon were present on the boat ramps, as was observed in previous years.
Figure 10—Map of south Lake Washington displaying the overall shoreline area (dashed lines) where marked Chinook salmon were found for each release group. The perpendicular lines to shore indicate the boundaries of the shoreline area where marked Chinook salmon were found. The bolded line is the shoreline area of Gene Coulon Park surveyed. The release site (open circles) of each group of dye-marked fish is also shown. Marked Juvenile Chinook salmon were released on March 24, 2003, and snorkel surveys were conducted 1, 7, 15, and 21 days after release.
FIGURE 11. —Median distance (m, ± range) moved from release site of two groups of marked Chinook salmon, Gene Coulon Park, south Lake Washington, 2003. Fish were released on March 24. One hundred and eight yellow-marked fish were released at the south part of the park and 102 red-marked fish were released at the north part of park.

FIGURE 12. —Frequency of the distance moved (20-m increments) from the release site by marked Chinook salmon for each survey date, Gene Coulon Park, south Lake Washington, 2003. Fish were released on March 24. Data were combined from two release groups.
Discussion

Results of the residence time investigation indicated many Chinook salmon remain in a small, localized area; however, it is possible other Chinook salmon moved outside our study area. Some of the marked Chinook salmon had moved over 80 m after 1 day and therefore, may have left the study area by the next survey, which was 6 days later. Because the median distance moved remained the same from day 1 to day 21 and the number of recaptures was greatly reduced, it would seem reasonable that some of the marked Chinook salmon remained close to the release site and another substantial portion of the marked fish moved a relatively long distance by moving outside the survey area. Results of index site surveys in February 2003 also indicate that some Chinook salmon are capable of moving a long distance in a relatively short period of time. For example, we observed Chinook salmon on Mercer Island as early as February 3 in 2004 and they were first captured in the Cedar River fry trap on January 18 and large numbers of fry were not observed at the trap until January 29 (Seiler at al. 2005b). Therefore, Chinook salmon fry appear capable of moving approximately 8.5 km (Cedar River trap to Mercer Island) in two weeks or less.

In general, the movement patterns of Chinook salmon in Lake Washington may be similar to patterns observed in other salmonids and other fishes. Fausch and Young (1995) reviewed several studies of fish movements in streams and concluded that often a large percentage of the fish population is resident but a substantial percentage move a considerable distance. The authors suggested that often these long distance movements are not known unless some type of radio telemetry project is undertaken. In Lake Washington, detecting long distance movements of juvenile Chinook salmon in February through April would be difficult because the fish are too small for radio tags.

Use of marked fish and snorkel surveys appeared to be an effective method to determine residence time, but to accurately determine the overall movement and residence time of juvenile Chinook salmon, a larger, more involved study is needed. Marking more fish would increase the probability of observing marked fish at locations.
that are a fair distance from the release site. Probably 1,000 to 2,000 fish would need to be marked to effectively estimate movement patterns. Enlarging the survey area would help determine if some fish are moving long distances. Besides increasing the number marked and enlarging the survey area, additional work needs to be done on the marking technique. We did observe a few marked Chinook salmon that appeared to have some type of injury in the caudal peduncle due to the marking process. Further testing of the location of the mark, type of mark, and marking instrument needs to be conducted.
CHAPTER 3. RESTORATION SITES

Introduction and Methods

We continued to monitor restoration sites in 2003 and 2004. A total of five locations were surveyed: Seward Park (Figure 14), Martha Washington Park, Beer Sheva Park, Rainier Beach Lake Park and Marina, and the old Shuffleton Power Plant Outflow (Figure 15). Except for one site in Seward Park, surveys were conducted to collect pre-project baseline information. The only restoration project that has been undertaken thus far was a substrate replacement project in Seward Park.

**Seward Park.** In December 2001, the City of Seattle and the Army Corps of Engineers (ACOE) deposited 2,000 tons of gravel along a 300-m shoreline section in the northeast part of the park. This shoreline section was divided into two equal sections. The north section (site 3b) received fine substrate and the south section (site 3a) received coarse substrate. The general size composition of the substrate was 0.5 to 5.0 cm for the north section and 2.5 to 15 cm for the south section. The new substrate extended out approximately 5 m from shore.

Pre-project snorkel surveys were conducted in 2001 and post-project surveys were initially conducted in 2002. Results from 2002 indicated that few Chinook salmon were present in Seward Park sites and no increase in the use of the restored site was observed. Surveys were conducted in 2003 and 2004 to continue monitoring of the restoration site and determine if the use of the restoration site may have been somewhat reduced in 2002 because of cool water temperatures, which may have limited Chinook salmon movements to northerly locations such as Seward Park. Also, Chinook salmon may have avoided the restoration site because of low prey abundance associated with the new, clean substrates.

Similarly to 2001 and 2002, snorkel surveys in 2003 were conducted at the restoration site as well as five additional sites in Seward Park (Figure 14). The additional sites served as controls and enabled us to make between-year comparisons of the restoration site. Also, the other five sites are potential restorations sites and the survey data could serve as baseline information. The restoration site and the five control sites were the same sites used in 2000 by Paron and Nelson (2001) to assess the potential for bank rehabilitation projects in Seward Park.

In 2003, we continued nighttime snorkeling surveys of the six sites in Seward Park. A total of nine night snorkeling surveys were completed on an approximate biweekly schedule from 19 February through 30 June. Survey protocols in 2003 were the same as restoration project monitoring survey methods used in 2001 and 2002 (Tabor and Piaskowski 2002; Tabor et al. 2004b). Surveys were conducted at a depth contour of 0.4 m water depth.

In addition to the six sites surveyed in 2000 to 2003, two supplemental sites (S-1 and S2) were also surveyed in 2003. We expected the abundance of Chinook salmon at site S-1 would be the highest of any site in Seward Park from February to May because the site had high quality habitat (gradual sloping beach with sand substrate) and was the
closest to the Cedar River of any site in Seward Park. Thus, this site should indicate the maximum number of Chinook salmon that would be possible at any restoration site in Seward Park. Site S-1 was surveyed five times from April 7 to June 10. The other transect (S-2) was located in the southeast corner of the park and was identified by park managers as a potential site for a substrate replacement project. Site S-2 was surveyed seven times from March 26 to June 30. Snorkeling procedures of the supplemental transects were the same as the other transects.

Surveys of Seward Park sites were also conducted in 2004; however, only four sites were surveyed (sites 1, 3, 5, and S-1) and they were only surveyed once a month from February to June.

![Figure 14: Location of snorkel transects in Seward Park, Lake Washington, March to July, 2002. Sites 3a and 3b are the completed restoration site, a substrate modification project finished in December 2001. Sites 1 through 6 are the original sites used in 2000 to 2003. Sites S-1 and S-2 are supplemental sites surveyed in 2003. In 2004, only sites 1, 3a, 3b, 5, and S-1 were surveyed.](image)
Beer Sheva Park.—At Beer Sheva Park, the City of Seattle has proposed to daylight the mouth and lower 100 m of Mapes Creek, which currently is in a culvert and enters the lake a few meters below the lake surface. We continued our monitoring of Beer Sheva Park in 2003 to provide an estimate of the temporal abundance of juvenile Chinook salmon in the vicinity of Mapes Creek. Only the boat ramp area was surveyed in 2003. Results from 2001 and 2002 indicated that most of the Chinook salmon were present on the boat ramps and few were present in other park locations where fine soft sediments (silt/mud) predominate. The boat ramp site was 65 m long, which included four boat ramps totaling 42 m and a 23-m shoreline section at the south end of the boat ramps. The average distance from the shore to one-meter depth was 6.9 m. Eight night snorkeling surveys were conducted from February to June. Beer Sheva Park was not surveyed in 2004.

Martha Washington Park.—Martha Washington Park was surveyed in 2002 and 2003 to provide the City of Seattle with baseline information on Chinook salmon abundance. We surveyed one 80-m long shoreline transect from March to May. Substrate was composed predominately of boulders and cobble with some gravel. Riprap was present along the entire shoreline except for two small coves that were each about 6 m long. Within the small coves, small gravel was the predominant substrate type. All surveys were conducted at night. Snorkelers swam close to the shore along the 0.4-m depth contour. Because of the steep slope, we were able to survey from 0.0- to approximately 0.9-m depth. In October 2003, the Seattle Parks and Recreation undertook a restoration project at Martha Washington Park; 61 m of shoreline in the south part of the park was restored by removing riprap and adding gravel and LWD. No post-project monitoring of this site was conducted in 2004.

Rainier Beach Lake Park and Marina.—The Seattle Parks and Recreation owned a small, old marina at the south end of Rainier Beach. The marina was removed in 2004 and modifications to the shoreline to improve habitat conditions for juvenile Chinook salmon began in summer 2005. We began snorkel surveys of the marina in 2003 to provide the city with baseline information on Chinook salmon abundance. Baseline surveys were also conducted in 2004. The Rainer Beach site was separated into two transects: a 100-m transect within the marina and an adjacent undeveloped shoreline transect (150 m long) south of the marina. The shoreline of the marina transect consisted mostly of riprap and bulkhead. The substrate of the undeveloped shoreline transect was mostly small gravel; however, the southernmost 20 m was riprap (because no Chinook salmon were observed in the riprap and it did not represent an undeveloped shoreline, it was not included in the final calculations of abundance). The shoreline was vegetated with various trees and shrubs; however, there was little vegetation that provided overhead cover. A depth contour of 0.4 m was used for both transects. In 2003, night snorkeling surveys were conducted on four dates from March to May. In 2004, surveys were conducted once a month from February to June.

Shuffleton Power Plant Outflow.—The City of Renton has proposed to build a trail between Gene Coulon Park and the Cedar River Trail Park. Part of the project includes restoring a shoreline section that is currently a steel wall that is part of the old Shuffleton Power Plant outflow channel. Because the power plant has been demolished, the outflow channel is no longer needed. Proposed restoration work includes removing the steel wall
and replacing it with a more natural shoreline that could improve fish habitat conditions. Snorkel surveys of the proposed restoration site were conducted in 2003 to provide the City of Renton with baseline information on Chinook salmon abundance. This restoration site area was divided into two transects: one transect along a steel wall for approximately 200 m and another transect along an adjacent sandy beach cove (approximately 70 m long). The cove is located south of the west end of the steel wall. Night snorkeling was conducted proximal to the wall. The sandy beach transect depth contour was 0.4 m. The site was only snorkeled on 2 nights in 2003: April 8 and May 6.

**Figure 15.** Map of south Lake Washington displaying restoration monitoring sites (Martha Washington Park, Beer Sheva Park, Rainier Beach Lake Park and Marina, and Shuffleton Power Plant Outflow), and the experimental overhanging vegetation (OHV) and small woody debris (SWD) site (Chapter 7).
Results

Seward Park, 2003.—In 2003, all six Seward Park sites were surveyed nine times between February 19 and June 30. Combined, 171 juvenile Chinook salmon were observed; over 45% (n = 79) were found at the west sites (sites 5 and 6). With the exception of May 22, the west sites had the highest number of juveniles per 100 m on all survey dates (Figure 16). Of the 79 Chinook salmon observed in the west sites, 59 were present at site 5. A comparison between 2001, 2002 and 2003 for the months of April, May, and June indicated the overall abundance of Chinook salmon was similar in 2001 and 2003 (except June) but the abundance in 2002 was substantially lower (Figure 17).

A total of 38 juvenile Chinook salmon (9 at site 3a and 29 at 3b) were observed at the restoration site in 2003. Chinook salmon were observed at site 3b (small substrate) on each survey in 2003 except June 30; although, on three dates only one Chinook salmon was observed. At site 3a (large substrate), Chinook salmon were only observed on four of nine survey dates and most Chinook salmon (78%) were observed on the last three surveys which were after mid-May. Although Chinook salmon abundance was low throughout 2003, there was a significantly more Chinook salmon at site 3b (small substrate) than at site 3a (large substrate) (Wilcoxon sign rank test; Z = 2.4; P = 0.019).

Figure 16. — Number of juvenile Chinook salmon (number/100 m) observed at night along three shoreline areas of Seward Park, south Lake Washington, 2003.
Figure 17. —Monthly abundance (mean number per 100 m of shoreline) of juvenile Chinook salmon observed during night snorkel surveys of six shoreline sites in Seward Park, south Lake Washington, 2001-2003. ND = no data.

At site 3b (small substrate), there appeared to be a slight increase in Chinook salmon abundance in 2003 from the pre-project abundance; however, at site 3a (large substrate) the abundance appeared to be reduced (Figure 18). The ratio of Chinook salmon at site 3 to the other sites combined was 0.46:1 in 2001; therefore the expected mean abundance of Chinook salmon at site 3 in 2003 would be 1.5 Chinook salmon/100 m of shoreline (mean abundance of the other sites 1,2,4,5,6 was 3.4 Chinook salmon/100 m of shoreline). The observed abundance in 2003 was 0.8 in site 3a (large substrate) and 2.1 Chinook salmon/100 m of shoreline in site 3b (small substrate). No increase in abundance at either site 3a (expected 0.4; observed 0.2 Chinook/100m of shoreline) or site 3b (expected 0.4; observed 0.3 Chinook/100m of shoreline) was observed in 2002.

During the first three surveys of supplemental site S-1 in 2003 (April 7 through May 6), a total of 76 Chinook salmon were observed and their abundance was higher on each date than any other site in Seward Park. On two of these three surveys, more Chinook salmon were observed at site S-1 than the other sites combined. Only six Chinook salmon were observed at site S-1 during the last two surveys in 2003 (May 22 and June 10) and their abundance was similar to other sites in Seward Park.

The high abundance of Chinook salmon at site S-1 is likely due to better habitat conditions, specifically the sand substrate and gradual slope and the site is closer to the Cedar River than other Seward Park sites. The abundance at S-1 was also substantially higher than the Seward Park beach index site (Figure 2)(mean abundance April 7-May 12, 2003, site S-1, 19.5 fish/100 m, index site, 7.1 fish/100 m), which has similar habitat conditions but is approximately 3.7 km further away from the Cedar River than site S-1.

A total of 23 Chinook salmon were observed at site S-2 during seven surveys in 2003 (March 26 to June 30). In general, abundance of Chinook salmon was similar to that of site 1 which was close by and had similar habitat conditions.
FIGURE 18. —Mean abundance (number observed per 100 m of shoreline) of juvenile Chinook salmon at the restoration site (open bars, site 3) and other sites (shaded bars, sites 1,2,4,5,6 combined) in Seward Park, south Lake Washington, April–June 2001-2003. Site 3 is located on the northeast side of Seward Park. Site 3a is the southern section of site 3 that received large gravel and cobble while site 3b is the northern section that received small gravel.

Seward Park, 2004. —From February to April, no Chinook salmon were observed at any of the five sites (1,3a, 3b, 5, S-1) surveyed in Seward Park in 2004. In contrast, large numbers of Chinook salmon were observed at most of these sites in May and June (Figure 19). More Chinook salmon were observed at site 1 than the other three sites combined. On both May 11 and June 4, 37 Chinook salmon were observed. Prior to 2004, the highest number of Chinook salmon observed in May or June at site 1 was 9 fish and at all sites the highest number was 13 fish. At the restoration site (sites 3a and 3b), no Chinook salmon were observed throughout the study period.

Beer Sheva Park, 2003.—Eight night snorkeling surveys were conducted at Beer Sheva Park (boat ramp transect only) from February 19 to June 30. Chinook salmon were observed on each survey date (Figure 20). Similar to 2002, the highest abundance occurred in May. The mean abundance (March-June) of Chinook salmon was substantially higher in 2003 (51 fish/100 m) than 2002 (33 fish/100 m) but differences were not significant (Wilcoxon sign rank test; $Z = 1.2; P = 0.25$).
Figure 19. — Number of juvenile Chinook salmon (number/100 m) observed at night at four sites (shoreline transects) of Seward Park, south Lake Washington, 2004. Site 3 is the restoration site and includes two transects; site 3a (large substrate) and 3b (small substrate).

Figure 20. — Abundance (number observed per 100 m of shoreline) of juvenile Chinook salmon observed along the Beer Sheva Park boat ramp transect, south Lake Washington, 2002 and 2003.
Martha Washington Park, 2003. —In 2003, a total of 40 juvenile Chinook salmon were observed along the 80-m-long transect during four night snorkeling surveys. In contrast, only two Chinook salmon were observed during three surveys of the same transect in 2002. This transect was surveyed from March to early May in both years.

Rainier Beach Lake Park and Marina, 2003. —Four night snorkeling surveys were conducted at the Rainier Beach site from March to May 2003. On all survey dates, the abundance of juvenile Chinook salmon at the undeveloped transect exceeded that of the developed marina transect (Figure 21). On average, their abundance was four times higher on the undeveloped transect than on the marina transect. The mean number observed was 85 Chinook salmon (65 fish/100 m shoreline) on the undeveloped transect and 20 Chinook salmon (20 fish/100 m shoreline) on the marina transect.

Rainier Beach Lake Park and Marina, 2004. —Five night snorkeling surveys were conducted at the Rainier Beach site from February to June 2004. Substantially fewer Chinook salmon were observed at the Rainier Beach Lake Park and Marina site in 2004 (Figure 22). In 2003, a total of 420 Chinook salmon were observed; whereas in 2004, only 57 were observed. In 2003, the number of early migrants from the Cedar River was 195,000 (Seiler et al. 2005a), whereas in 2004 it was 67,000 (Seiler et al. 2005b). In both years, the highest number of Chinook salmon at the Rainier Beach Lake Park and Marina site was observed in March; in 2003, 146 Chinook salmon were observed along the undeveloped shoreline and in 2004, 32 were observed. Similar to 2003, most Chinook salmon in 2004 were along the undeveloped shoreline transect.

Shuffleton Power Plant Outflow, 2003. —Two night snorkeling surveys were conducted at the Shuffleton Power Plant Outflow in 2003. On both surveys, the abundance of juvenile Chinook salmon was substantially higher at the sandy beach transect than along the steel wall (Figure 23). Because of the gradual slope of the sandy beach area, we only surveyed a part of the nearshore habitat while we were able to survey the entire nearshore area of the steel wall because of its 90° slope and depth. Therefore, the difference in abundance between the two transects is probably greater than shown in Figure 23.
Figure 21. — Juvenile Chinook salmon abundance (number/100 m of shoreline) at two adjacent shoreline transects (undeveloped and marina shoreline) at the Rainier Beach Lake Park and Marina, March-May 2003, south Lake Washington.

Figure 22. — Juvenile Chinook salmon abundance (number/100 m of shoreline) at two adjacent shoreline transects (undeveloped and marina shoreline) at the Rainier Beach Lake Park and Marina, February to June 2004, south Lake Washington. ND = No data
Figure 23. —Juvenile Chinook salmon abundance (number/100 m shoreline) at the Shuffleton Power Plant Outflow (steel wall) and an adjacent sandy beach area, south Lake Washington (2003).

Discussion

We surveyed a variety of potential restoration sites in 2003. Because juvenile Chinook salmon are concentrated in the south end of the lake, restoration projects in that area would most likely be more beneficial than those in other areas of the lake. The Shuffleton Power Plant Outflow is much closer to the mouth of the Cedar River than the other sites and thus would probably be a better site for a restoration project. The habitat at this site is highly degraded; there is little shallow water habitat or riparian vegetation due to the steel wall. Both Beer Sheva Park and Rainier Beach Lake Park are relatively close to the mouth of the Cedar River and good numbers of Chinook salmon appear to be present and thus these sites would be good restoration sites. Chinook salmon were abundant at the Beer Sheva Park boat ramps in 2002 and 2003 and therefore, there should be several juvenile Chinook salmon in the area to use the mouth of Mapes Creek if it is daylighted. The undeveloped section of Rainier Beach Lake Park appeared to have good quality habitat due to its small gravel substrate and gentle slope. This site could be improved, however, with some additional shoreline vegetation (e.g., willows *Salix* spp.) to provide overhead cover as well as small woody debris for structural complexity. Certainly, the marina shoreline could be improved with the removal of the armoring and replacing it with small substrates and some riparian vegetation on a gentle sloping bank.

Seward Park has been surveyed for the past five years (2000 by USACOE and 2001-2004 by USFWS) and during that period the nearshore abundance of juvenile Chinook salmon has been relatively low at all six sites. Even at the best location in Seward Park (supplemental site S-1 in the southwest corner of other park), the abundance of Chinook salmon in 2003 was 1.4 to 6 times lower than the undeveloped restoration transect at the Rainier Beach Lake Park. Restoration projects in Seward Park will have a positive effect on Chinook salmon habitat but the effect will most likely be small.
CHAPTER 4. DEPTH SELECTION

Introduction

Detailed information on the water depth of the lake where juvenile Chinook salmon are located has not been available. Preliminary work conducted in 2001 consisted of one nighttime scuba survey and a few visual daytime observations in May and June (Tabor and Piaskowski 2002). In 2004, we examined the water column depths used by juvenile Chinook salmon during day and night. At night, we could survey Chinook salmon by snorkeling/scuba diving because the surveyor can get close enough to the fish to accurately measure the fishes’ depth. During the day, juvenile Chinook salmon are difficult to survey because they avoid snorkelers/scuba divers, especially after March. Other techniques that could be used during the day, such as vertical gill nets, pop-up nets, or hydroacoustics are either very harmful to the fish, are labor intensive, or are ineffective during some part of the sampling period (February to June). One technique that appeared to be consistent throughout the sampling period (February to June) and was unobtrusive to Chinook salmon was visual surface observations. When the water is calm in the early morning, Chinook salmon can be observed feeding at the surface. Chinook salmon appear to feed extensively on surface prey such as chironomid pupae and adults (Koehler 2000). Also, Chinook salmon are concentrated in the south end of Lake Washington and are the most abundant fish species present in many areas. Therefore, we felt it was a reasonable assumption that the vast majority of surface feeding would be Chinook salmon. Also, we assumed that the number of feeding events at the surface was related to Chinook salmon abundance. The water column depth (surface to bottom) where Chinook salmon were located was estimated by determining the location of feeding fish.

Methods

Visual surface observations were conducted in south Lake Washington at the swim beach in Gene Coulon Park (Figure 2). Observations were only conducted at dawn. The evening before observations were conducted buoy lines were laid out to delineate depth contours (0.5-, 1-, 2-, 3-, 4-, and 5-m depth). The lines were laid out parallel to shore and each line was 20 m long. The next morning, if the water was calm, visual observations were conducted. The observer counted the number of times a Chinook salmon surfaced between the depth contours. Observations were made from shore for 15 minutes. Surveys were conducted approximately once every 2 weeks; however, some surveys had to be moved to the next week because of weather conditions. We used results of index snorkel surveys at the swim beach to determine the abundance of Chinook salmon in relation to other fish species. Because the depth categories had different areas, we used Chesson’s selectivity index to make comparisons (Chesson 1978).

At night, Chinook salmon are inactive, appear to be resting near the bottom, and can be easily approached. Therefore, we used snorkeling/scuba diving transects to measure their depth distribution at night. A series of transects were conducted at night that were each perpendicular to shore. The depth from 0 to 1 m was surveyed by a snorkeler and the depth from 1 to 3 m was surveyed by a scuba diver. Each time a Chinook salmon was located, a weighted flag was placed at that location. After the
snorkeling and scuba diving were completed, each weighted flag was retrieved and the water column depth was measured. Nighttime surveys were conducted once a month from March to May in the north part of Gene Coulon Park. At this location the distance from shore to 3-m depth was approximately 14 m. Water depths where Chinook salmon were located were compared between months with an ANOVA and Fisher’s LSD test. Beach seining was also conducted shortly after each survey to collect information on the sizes of Chinook salmon.

**Results**

From February 19 to April 14, all surface activity at dawn was observed in the shallowest section (0 and 0.5 m deep; Figure 24). Feeding activity was observed in deeper and deeper sections from April 27 to June 2. By the last date, June 2, feeding activity was observed primarily between 2 and 3 m, and some between 3 and 4 m, but little between 4 and 5 m. Results of Chesson’s selectivity index (α) indicated the same trend (Figure 25).

We assumed that the vast majority of surface feeding was Chinook salmon. From February 24 to April 13, approximately 70% of the salmonids observed at Gene Coulon swim beach during night snorkeling (index site surveys) were Chinook salmon. The rest were almost all sockeye salmon fry, which were considerably smaller than Chinook salmon. Sockeye salmon appeared to feed somewhat at the surface but their feeding activity was barely noticeable and was not counted. From April 26 to June 7, 65% of the salmonids were sockeye salmon and 35% were Chinook salmon. Therefore some of the feeding activity may have been due to sockeye salmon, which were considerably smaller and closer to shore than Chinook salmon. Based on the size of the fish we observed feeding at the surface, we felt most of the feeding activity was from Chinook salmon. In some cases, fish were observed jumping completely out of the water and all of these fish appeared to be Chinook salmon. Threespine stickleback (*Gasterosteus aculeatus*) and prickly sculpin (*Cottus asper*) were also common throughout the study period but it is doubtful if they were feeding at the surface to any significant degree.

Nighttime water column depths were measured for a total of 117 juvenile Chinook salmon (March 10, n = 31; April 7, n = 40; May 12, n = 46). Snorkel surveys indicated the same general pattern as dawn visual observations. In February, the mean nighttime depth was only 0.2 m (range, 0.12 to 0.48 m). In April and May, Chinook salmon progressively used deeper waters; however, none were ever observed between 1 and 3 m deep. Water column depths were significantly different between each monthly sample (Figure 26; ANOVA and Fisher’s LSD; \( P < 0.001 \)).
FIGURE 24. —Percent of surface activity observed within six depth categories (m) at Gene Coulon Park, Lake Washington, 2004. Observations were made from shore at dawn.

FIGURE 25. —Selectivity values (Chesson’s α) of surface activity within six depth categories (m), Gene Coulon Park, Lake Washington, 2004. Observations were made from shore at dawn. The dashed line indicates the level of selectivity if all depth categories were used at random.
Observations of both day and night depth distribution clearly showed that juvenile Chinook salmon progressively shift to deeper waters as they grow. Juvenile Chinook salmon in riverine environments have also been shown to inhabit deeper waters as they increase in size (Lister and Genoe 1970; Allen 2000; R. Peters, USFWS, unpublished data). The same general pattern has been shown in several other fish species including salmonids as well as non-salmonids. McIvor and Odum (1988) and Ruiz et al. (1993) demonstrated that predation risk for juvenile fish decreases in shallow water. Power (1987) suggested small juvenile fish inhabit very shallow water because they are especially vulnerable to piscivorous fishes and less vulnerable to wading birds because juvenile fish are very small. As juvenile fish grow they shift to deeper waters because they are less vulnerable to fish and more vulnerable to wading birds. In Lake Washington, small juvenile Chinook salmon may be in shallow water to avoid cutthroat trout (O. clarki) and prickly sculpin which are important predators in the littoral zone (Nowak et al. 2004; Tabor et al. 2004a). When they increase in size they may become more attractive to wading birds such as great blue herons (Ardea herodias) but less vulnerable to piscivorous fishes.

The last survey (June 2) indicated some juvenile Chinook salmon had moved into water that was 4-5 m deep but no feeding activity was observed in deeper waters. Recent results of ultrasonic tracking at Gene Coulon swim beach (May 24 to June 5, 2004) indicated some Chinook salmon may be in water > 7 m deep (M. Celedonia, USFWS, unpublished data). However, only fish greater than 100 mm FL were tagged. Fresh (2000) also found that Chinook salmon are further offshore in the upper pelagic area after mid-May. Thus our results may reflect the water column depth for the portion of the population that still inhabits the nearshore area and could be a gross underestimate for the
entire population. Chinook salmon that are further offshore may be difficult to observe because they may be spread out over a large area. Also, their surface activity may be reduced because the abundance of surface prey may be lower at offshore areas and Chinook salmon often switch to feeding on Daphnia (Koehler 2002) as the season progresses. After mid-May, the use of visual observations to determine the location of Chinook salmon may be problematic.
CHAPTER 5. FEEDING AT TRIBUTARY MOUTHS

Introduction

Little is known about the importance of nonnatal tributaries for juvenile Chinook salmon. The lower sections of many small tributaries to Lake Washington are in culverts and enter the lake several meters below the lake surface and thus, are of little value to juvenile Chinook salmon which inhabit shallow nearshore areas of the lake. Restoring these streams to their natural location may provide additional habitat. In 2002, we surveyed 17 tributaries of Lake Washington and Lake Sammamish (Tabor et al. 2004b). Results indicated that Chinook salmon can often be quite abundant at the mouths of tributaries. Additionally, K. Fresh (NOAA Fisheries, unpublished data) found that the abundance of Chinook salmon may be much higher at the mouth of tributaries following a storm event. In 2003 and 2004, we surveyed six tributaries to determine if Chinook salmon forage on prey items that come into the lake via the tributary and determine how storm events affect the diet and abundance of juvenile Chinook salmon.

Methods

The six tributary mouths that we examined included: Tibbetts Creek and Laughing Jacobs Creek in Lake Sammamish (Figure 27) and Taylor Creek, Kennydale Creek, Kennydale Beach tributary, and May Creek in Lake Washington (Figure 28). Our goal was to sample each tributary mouth once during base flow and once during a high flow event. Each time a tributary mouth was sampled, streamflow (Table 3) was measured according to TFW stream ambient monitoring protocol (Pleus 1999). Stomach samples of Chinook salmon were collected primarily during late March or April. Each time a tributary mouth was sampled, we also collected stomach samples of Chinook salmon from a lake reference site to compare their diets. All six tributaries were sampled in 2003 during base streamflow conditions. Because there were few storm events in 2003, we were only able to survey one of the tributaries, Kennydale Creek, during high streamflow conditions. At Kennydale Creek, we also surveyed once a mouth (base flow conditions) in 2003 from February to June to determine if there is any type of temporal effect. In 2004, we sampled May Creek and Taylor Creek during a high flow event as well as during base flow conditions. An additional sample was also taken in 2004 at Kennydale Creek during base flow conditions.
FIGURE 27.—Location of two south Lake Sammamish tributaries studied to examine the diet of juvenile Chinook salmon at tributary mouths, March to June, 2003. Issaquah Creek, a major spawning tributary and hatchery release site for Chinook salmon, is also shown.
Figure 28.—Location of four south Lake Washington tributaries (Taylor Creek, May Creek, Kennydale Creek, and Kennydale Beach tributary) studied to examine the diet of juvenile Chinook salmon at tributary mouths. Also shown are two nonnatal tributaries (Johns Creek and Culvert Creek) that were also studied to determine their use by juvenile Chinook salmon (Chapter 6). The Cedar River, a major spawning tributary for Chinook salmon, is also shown.
TABLE 3. — Streamflow conditions (cfs) at six tributaries used to determine the abundance and diet of Chinook salmon at the tributary mouths in south Lake Washington and south Lake Sammamish. Streamflow was measured shortly after fish were sampled. Fish were sampled once during base flow conditions and again under high flow conditions if possible.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Streamflow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
</tr>
<tr>
<td>Lake Washing</td>
<td></td>
</tr>
<tr>
<td>Kennydale Cr.</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>2004</td>
</tr>
<tr>
<td>Kennydale Beach trib.</td>
<td>2003</td>
</tr>
<tr>
<td>May Cr.</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>2004</td>
</tr>
<tr>
<td>Taylor Cr.</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>2004</td>
</tr>
<tr>
<td>Lake Sammamish</td>
<td></td>
</tr>
<tr>
<td>Laughing Jacobs Cr.</td>
<td>2003</td>
</tr>
<tr>
<td>Tibbetts Cr.</td>
<td>2003</td>
</tr>
</tbody>
</table>

Chinook salmon were collected primarily with beach seines (Figure 29). At the small tributaries, Kennydale Beach tributary and Kennydale Creek (Figure 29), one beach seine set was conducted, whereas at the other larger tributaries, 3 to 4 sets were usually done to cover the entire delta area. In 2003, we used two seines depending on the size of the fish. When Chinook salmon were less than 60 mm FL, we used a small seine that was 5.7 m long and 1.2 m deep with a 2-mm stretch mesh and had no bag in the middle. The larger net, used when Chinook salmon were > 60 mm FL, was 9.1 m long and 1.6 m deep and a 1.5-m deep by 1.8-m long bag in the middle. The entire net had 6-mm stretch mesh. In 2004, only one seine was used because it was effective in sampling various sizes of Chinook salmon. The net was 9.1 m long and 1.8 m deep with a 1.8- m deep by 1.8- m long bag in the middle. The mesh size in the wings was 6-mm stretch mesh while the bag was 2-mm stretch mesh. In the event that few Chinook salmon could be collected at a particular site, we collected additional Chinook salmon for diet analysis with small dip nets while snorkeling at night.

Captured fish were identified and counted and 10 Chinook salmon were randomly-selected for diet analysis. The 10 Chinook salmon were anaesthetized with MS-222, the fork length was measured, and their stomach contents were removed through gastric lavage. Stomach contents were put in plastic bags, placed on ice, and later froze.

In the laboratory, stomach samples were thawed, examined under a dissecting scope, and divided into major prey taxa. Aquatic insects and crustaceans were identified to family, while other prey items were identified to major taxonomic groups. Prey groups were counted and then the wet weight was measured. Each group was blotted by placing the sample on tissue paper for approximately 10 seconds and weighed to the nearest 0.0001 g.
FIGURE 29.—Photos of sites used to collect juvenile Chinook salmon to examine the diet at tributary mouths and lakeshore sites. The upper photo is of the mouth of Kennydale Creek and the lower photo is of the beach seine being deployed at the lakeshore reference site for Kennydale Creek. At the mouth of Kennydale Creek, a small delta was present, which was used to seine juvenile Chinook salmon.
To describe the diet of juvenile Chinook salmon, we followed the procedures of Cortés (1997) and Liao et al. (2001). For each prey group in each sample, we determined the percent weight (%W), percent number (%N), and percent occurrence (%O). A percent index of relative importance (%IRI) was then developed for each prey group:

\[ IRI = \%O_i \cdot (%W_i + %N_i) \]

and,

\[ \%IRI = 100 \cdot \frac{IRI_i}{\sum_{i=1}^{n} IRI_i} \]

To help compare the diet between samples, we also calculated Schoener’s diet overlap index (Schoener 1971):

\[ C_{xy} = 1 - 0.5 \left( \sum \left| p_{xi} - p_{yi} \right| \right) \]

where \( C_{xy} \) is the index value, \( p_{xi} \) is the proportion of food type \( i \) used by Chinook salmon at site \( x \) and \( p_{yi} \) is the proportion of food type \( i \) used by Chinook salmon at site \( y \). Researchers commonly use an overlap index level of 0.6 or less to indicate a significant difference in diet (Zaret and Rand 1971; Johnson 1981). Comparisons were made between tributary mouths and lakeshore reference sites, as well as between high and base streamflow conditions at each tributary mouth.

A diet breadth index \((B; Levins 1968)\) was also calculated to determine if Chinook salmon utilize a wider variety of prey types at the tributary mouths in comparison to the lake shore:

\[ B = \frac{1}{\sum p_i^2} \]

where \( p_i \) is the proportion of the diet represented by food type \( i \). Diet breadth index values range from 1 (no diet breadth: only one prey type in the diet) to infinity. Values less than 2 indicate little diet breadth.

Results

Catch. —In 2003, beach seine catch rates of juvenile Chinook salmon at tributary mouths and lakeshore sites were extremely variable between sites and between day and night. During the day, we were able to catch Chinook salmon at some tributary mouths but not at lakeshore reference sites. At some lakeshore sites, we could visually observe Chinook salmon but they could easily avoid the beach seine. At tributary mouths, they could be collected more easily, likely because the water was turbid or they retreated to the tributary mouth where they could be easily encircled with the seine. Because of the difficulty of collecting Chinook salmon at most lakeshore sites during the day, we collected Chinook salmon in 2004 at one site in Gene Coulon Park where they were known to be abundant.

Nighttime sampling was conducted at a few tributary mouths. Although night sampling was logistically more difficult, it appeared to be less variable than daytime.
sampling. At night, Chinook salmon were collected at each sampling location; however not enough sampling was conducted to make any meaningful comparison between tributary mouth and lakeshore sites.

During high flow conditions, the number of Chinook salmon caught at the mouth of May Creek in 2004 was substantially higher than during base flow conditions. Additionally, nine cutthroat trout (range, 147-190 mm FL) were caught during the high flow event while none were caught during the base flow condition. In contrast to May Creek, more Chinook salmon were caught under base flow conditions than during high flow conditions at the mouth of Taylor Creek (Figure 30). Different types of seine nets were used at Kennydale Creek in 2003 and thus catch rates could not be compared between streamflow conditions.

Diet.—In 2003, monthly samples (February to June) were collected at Kennydale Creek and a lakeshore reference site in Gene Coulon Park. Chironomid pupae and adults were the most important prey item for each sample date at both sites (Table 4). Other than chironomid pupae and adults, little else was present in the lakeshore diet for February to May, making up at least 89% of the diet by weight. The same was observed in the April and May diet at the mouth of Kennydale Creek. The March diet sample included a large seed pod that probably offered little nutritional value. If the seed pod is excluded from the analysis, chironomid pupae and adults made of 87% of the diet by weight. The March sample at the mouth of Kennydale Creek was taken during a high flow event yet there was no significant difference in the diet between the lakeshore sample on the same date and between the base flow sample taken in April (Table 5). In February, a large number of springtails (Collembola; 43% of the diet by number and 19% by weight) were present in diet at the tributary mouth but were absent in the lakeshore diet. Springtails are primarily inhabitants of soil and moist vegetation but some species inhabit the neuston of lentic systems (Christiansen 1996). Streams may act as a dispersal mechanism. Because springtails were absent from the lakeshore diet, it indicates Chinook salmon may have been feeding on prey items that originated from the creek watershed. Besides chironomid pupae and adults, the June tributary mouth sample included a large number of emerging mayflies (Caenidae; 38% by weight) and the lakeshore sample included large numbers of chironomid larvae.

![Figure 30](image.png)

**Figure 30.**—Total number of Chinook salmon caught with a beach seine at the mouth of three tributaries of south Lake Washington, 2004. Each bar represents the number caught on one sampling effort; at May Creek three sets were conducted during each flow condition, and four at Taylor Creek.
Table 4. — Diet composition of juvenile Chinook salmon at the mouth of Kennydale Creek, 2003. Samples from March 12 were collected under high streamflow conditions. The other dates were collected under base streamflow conditions. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance. Samples on February 19 were combined together in the field and %O and %IRI could not be calculated.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>February 19 (n = 6, range = 38-43 mm FL)</th>
<th>March 12 (n = 6, range = 41-52 mm FL)</th>
<th>April 3 (n = 10, range = 45-54 mm FL)</th>
<th>May 8 (n = 10, range = 57-76 mm FL)</th>
<th>June 3 (n = 10, range = 85-103 mm FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%N</td>
<td>%O</td>
<td>%W</td>
<td>%IRI</td>
<td>%N</td>
</tr>
<tr>
<td>Insecta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>53.4</td>
<td>77.3</td>
<td>-</td>
<td>87.2</td>
<td>83</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>1.1</td>
<td>0.9</td>
<td>-</td>
<td>1.2</td>
<td>17</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
<td>0.5</td>
<td>0.5</td>
<td>-</td>
<td>3.5</td>
<td>50</td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>0.5</td>
<td>1.4</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Collembola</td>
<td>43.4</td>
<td>18.6</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other aquatic insects</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Homoptera (Aphididae)</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other terrestrial insects</td>
<td>1.1</td>
<td>1.4</td>
<td>-</td>
<td>1.2</td>
<td>17</td>
</tr>
<tr>
<td>Crustacea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other crustaceans</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>2.3</td>
<td>17</td>
</tr>
<tr>
<td>Hydrachnida</td>
<td>0</td>
<td>-</td>
<td>0</td>
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<tr>
<td>Oligochaeta</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>4.7</td>
<td>67</td>
</tr>
</tbody>
</table>
Table 5. —Diet overlap indices (C) and diet breadth indices (B) of the mouth of Kennydale Creek and a lakeshore reference site, Lake Washington, 2003. Streamflow data were collected close to the mouth of the creek. ND = no data. Diet overlap index less than 0.6 indicates a significant difference. Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

<table>
<thead>
<tr>
<th>Date</th>
<th>Streamflow (cfs)</th>
<th>Diet overlap index (C) trib. mouth and lake shore</th>
<th>Diet breadth index (B) tributary mouth</th>
<th>Diet breadth index (B) lake shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 19</td>
<td>0.55</td>
<td>0.78</td>
<td>1.58</td>
<td>1.02</td>
</tr>
<tr>
<td>March 12</td>
<td>4.80</td>
<td>0.74</td>
<td>1.97</td>
<td>1.25</td>
</tr>
<tr>
<td>April 3</td>
<td>0.51</td>
<td>0.94</td>
<td>1.05</td>
<td>1.14</td>
</tr>
<tr>
<td>May 8</td>
<td>0.20</td>
<td>0.98</td>
<td>1.05</td>
<td>1.05</td>
</tr>
<tr>
<td>June 3</td>
<td>ND</td>
<td>0.70</td>
<td>2.37</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Three other tributary mouths in Lake Washington were sampled in 2003, which included Kennydale Beach tributary, May Creek, and Taylor Creek; however, we were only able to survey each site under base streamflow conditions. Chironomid pupae and adults were the most important prey item for each tributary mouth as well as the lakeshore reference sites (Table 6). Chironomid larvae and terrestrial insects were more important in the diet at each tributary mouth than at the lakeshore reference sites. However, there was no significant difference in the diet between the tributary mouths and lakeshore sites (Table 7). The diet breadth index was higher at the tributary mouths than the lakeshore (Table 8).

In Lake Sammamish, the mouths of Tibbetts Creek and Laughing Jacobs Creek were sampled in April 2003. Chinook salmon were also collected at one lakeshore reference site, Lake Sammamish State Park boat ramps. Similar to Lake Washington, the diet of Chinook salmon in all Lake Sammamish sites was dominated by chironomid pupae and adults. In contrast to Lake Washington, Daphnia made up a substantial portion of the diet of Chinook salmon in Lake Sammamish sites (Table 9). In Lake Washington, Daphnia usually does not become an important prey item until June (Koehler 2002). The diet at the mouth of Tibbetts Creek was somewhat different than the lake shore (overlap index = 0.68 and a higher diet breadth index). The diet at the creek mouth included several chironomid larvae, mayfly nymphs (Ephemeroptera), oligochaetes, and terrestrial insects. The diet at the mouth of Laughing Jacobs Creek was similar to the lakeshore (Tables 7 and 8).

Several water mites (Hydrachnida) were often found in stomach samples, especially in samples collected in May and June. At the mouth of Kennydale Creek (May and June), they represented about 20% of the prey by number and %IRI was approximately 10%. Ingested water mites were quite small and were generally much smaller than any other prey item. They were probably larval water mites, which are parasites of aquatic insects, especially larval dipterans such as chironomids (Smith et al. 2001). Therefore, they probably were not a true prey item of Chinook salmon.
**TABLE 6.** —Diet composition of juvenile Chinook salmon along the shoreline of Lake Washington and at three tributary mouths of Lake Washington, April 2003. *n* = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>Lake shoreline</th>
<th>Kennydale Beach trib.</th>
<th>May Cr.</th>
<th>Taylor Cr.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%N</td>
<td>%O</td>
<td>%W</td>
<td>%IRI</td>
</tr>
<tr>
<td><strong>Insecta</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>93.4</td>
<td>95</td>
<td>92.9</td>
<td>97.3</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>2.7</td>
<td>55</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
<td>0.1</td>
<td>5</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>Ephemeroftera</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Collembola</td>
<td>0.4</td>
<td>15</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Other aquatic insects</td>
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<td>0.02</td>
<td>0.01</td>
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<tr>
<td>Homoptera (Aphididae)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other terrestrial insects</td>
<td>1.1</td>
<td>15</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Crustacea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other crustaceans</td>
<td>0.2</td>
<td>10</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Hydrachnida</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.0</td>
<td>25</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>1.0</td>
<td>40</td>
<td>4.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Table 7. —Diet overlap indices (C) of tributary mouths in Lake Washington and Lake Sammamish. Comparisons were made between two different streamflow conditions and between a lakeshore reference site and the two flow conditions. Samples were collected in either March or April in 2003 and 2004. Diet overlap index numbers in bold indicate a significant difference in diet ($C < 0.6$). ND = no data.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Year</th>
<th>Base flow and lake shore</th>
<th>High flow and lake shore</th>
<th>Base flow and high flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Washington</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennydale Cr.</td>
<td>2003</td>
<td>0.80</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.70</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Kennydale Beach trib.</td>
<td>2003</td>
<td>0.76</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>May Cr.</td>
<td>2003</td>
<td>0.66</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.82</td>
<td>0.69</td>
<td>0.67</td>
</tr>
<tr>
<td>Taylor Cr.</td>
<td>2003</td>
<td>0.90</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.74</td>
<td><strong>0.34</strong></td>
<td><strong>0.45</strong></td>
</tr>
<tr>
<td>Lake Sammamish</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laughing Jacobs Cr.</td>
<td>2003</td>
<td>0.87</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Tibbetts Cr.</td>
<td>2003</td>
<td>0.68</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Table 8. —Diet breadth indices (B) of tributary mouths and lakeshore reference site in Lake Washington and Lake Sammamish. Samples were collected in either March or April. ND = no data. Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

<table>
<thead>
<tr>
<th>Tributary</th>
<th>Year</th>
<th>Base flow and lake shore</th>
<th>High flow and lake shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Washington</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennydale Cr.</td>
<td>2003</td>
<td>1.05</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>2.49</td>
<td>1.42</td>
</tr>
<tr>
<td>Kennydale Beach trib.</td>
<td>2003</td>
<td>1.70</td>
<td>1.12</td>
</tr>
<tr>
<td>May Cr.</td>
<td>2003</td>
<td>2.17</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>1.55</td>
<td>1.35</td>
</tr>
<tr>
<td>Taylor Cr.</td>
<td>2003</td>
<td>1.47</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>1.74</td>
<td>1.35</td>
</tr>
<tr>
<td>Lake Sammamish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laughing Jacobs Cr.</td>
<td>2003</td>
<td>1.65</td>
<td>2.01</td>
</tr>
<tr>
<td>Tibbetts Cr.</td>
<td>2003</td>
<td>2.88</td>
<td>2.01</td>
</tr>
</tbody>
</table>
TABLE 9. —Diet composition of juvenile Chinook salmon at three locations (one shoreline site and two sites at the mouths of tributaries) in south Lake Sammamish, April 16 to 21, 2003. \(n\) = the number of stomach samples analyzed; the range of Chinook salmon lengths is also given; \(%N\) = percent number; \(%O\) = percent occurrence (%); \(%W\) = percent weight; \(%IRI\) = percent index of relative importance.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>Lake shoreline (n = 10, \text{range} = 60-85\text{ mm FL})</th>
<th>Laughing Jacobs Cr. (n = 10, \text{range} = 52-80\text{ mm FL})</th>
<th>Tibbetts Cr. (n = 11, \text{range} = 53-74\text{ mm FL})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%N %O %W %IRI</td>
<td>%N %O %W %IRI</td>
<td>%N %O %W %IRI</td>
</tr>
<tr>
<td><strong>Insecta</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>69.7 90 67.1 81.3</td>
<td>65.8 100 76.5 81.6</td>
<td>48.9 100 56.3 70.6</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>4.1 50 0.9 1.6</td>
<td>4.8 100 3.1 4.5</td>
<td>19.1 63.6 2.7 9.3</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
<td>0 0 0 0</td>
<td>0.1 10 0.02 0.01</td>
<td>2.1 18.2 0.2 0.3</td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>0.1 10 0.2 0.02</td>
<td>0 0 0 0</td>
<td>8.5 45.5 8.0 5.0</td>
</tr>
<tr>
<td>Collembola</td>
<td>0.4 20 0.1 0.1</td>
<td>0 0 0 0</td>
<td>3.2 18.2 5.4 1.0</td>
</tr>
<tr>
<td>Other aquatic insects</td>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>Homoptera (Aphididae)</td>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>Other terrestrial insects</td>
<td>0 0 0 0</td>
<td>0.2 20 0.1 0.03</td>
<td>4.3 36.4 10.8 3.7</td>
</tr>
<tr>
<td><strong>Crustacea</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>16.6 40 19.3 9.5</td>
<td>27.2 50 8.2 10.1</td>
<td>1.1 9.1 0.04 0.1</td>
</tr>
<tr>
<td>Other crustaceans</td>
<td>5.5 40 0.7 1.6</td>
<td>0.4 20 0.6 0.1</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td><strong>Hydrachnida</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>2.5 50 0.1 0.9</td>
<td>1.1 30 0.2 0.2</td>
<td>3.2 18.2 0.1 0.4</td>
</tr>
<tr>
<td>Other</td>
<td>0.3 10 0.01 0.02</td>
<td>0 0 0 0</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8 60 11.7 4.9</td>
<td>0.4 50 11.3 3.4</td>
<td>9.6 54.5 16.6 9.6</td>
</tr>
</tbody>
</table>

In 2004, two tributaries, May Creek and Taylor Creek, were surveyed under high streamflow conditions as well as base streamflow conditions. During high streamflow conditions at May Creek, the percent of the diet of chironomids pupae and adults decreased from base flow conditions, while the percent of chironomid larvae, oligochaetes, and mayflies increased (Table 10). The diet at May Creek during high flow conditions also included some prey items that are usually only found in flowing waters. These prey items included the immature stages of rhyacophilid caddisflies, black flies (Simuliidae), and heptagenid mayflies. Diet breadth was approximately 60% higher than at the lakeshore and base flow condition (Table 8); however, the diet overlap index was not significantly different (lakeshore, 0.69; base flow, 0.67). Cutthroat trout (\(n = 9\)) at the mouth of May Creek during the high flow event were foraging primarily on terrestrial prey items, which included terrestrial isopods or sow bugs (36% by weight), oligochaetes (28%) and insects (4%).

Several larval longfin smelt (\(Spirinchus thaleichthys\)) were consumed by Chinook salmon at the mouth of May Creek on April 1 (baseflow conditions), which represented 8% of the diet by weight. Much of the consumption of larval smelt was observed in one individual (64 mm FL), which had consumed 29 smelt. Adult longfin smelt have been documented to spawn in May Creek (Moulton 1974; Martz et al. 1996).
TABLE 10.—Diet composition of juvenile Chinook salmon at the mouth of May Creek, 2004 under two streamflow conditions. Base streamflow samples were collected on March 31 and April 1 and the high streamflow samples were collected on March 26. n = the number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>Base flow n = 10, range = 40-64 mm FL</th>
<th>High flow n = 10, range = 51-62 mm FL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%N</td>
<td>%O</td>
</tr>
<tr>
<td><strong>Insecta</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>62.7</td>
<td>100</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>3.7</td>
<td>40</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Ephemeroptera</strong></td>
<td>1.5</td>
<td>20</td>
</tr>
<tr>
<td><strong>Collembola</strong></td>
<td>4.5</td>
<td>30</td>
</tr>
<tr>
<td>Other aquatic insects</td>
<td>0.7</td>
<td>10</td>
</tr>
<tr>
<td>Homoptera (Aphididae)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other terrestrial insects</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Crustacea</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other crustaceans</td>
<td>0.7</td>
<td>10</td>
</tr>
<tr>
<td><strong>Hydrachnida</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Oligochaeta</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>26.1</td>
<td>50</td>
</tr>
</tbody>
</table>

The diet at the mouth of Taylor Creek during high streamflow conditions was significantly different than the lakeshore on the same date as well as Taylor Creek during base flow conditions (Table 11). Chironomid larvae were the most important prey item and represented approximately half of the prey items consumed. Other prey items included chironomid pupae and adults, oligochaetes, springtails, and mayflies. The diet breath index was 4.09, which was higher than any other creek mouth or lake sample.

Supplemental surveys of Kennydale Creek and Taylor Creek were conducted on April 20, 2004. Chinook salmon were also collected at a lakeshore reference site, north Gene Coulon Park. At the mouth of Taylor Creek, little else was present in the diet except chironomid pupae and adults (97% by weight). Chironomid pupae and adults were also the dominant prey item at the mouth of Kennydale Creek (58% by weight) and the lakeshore reference site (83% by weight). However unlike Taylor Creek, aphids made up a substantial part of the diet (Kennydale Creek, 25% by weight; lakeshore, 7% by weight).
TABLE 11.—Diet composition of juvenile Chinook salmon at the mouth of Taylor Creek, March 2004 under two streamflow conditions. Base streamflow samples were collected on March 30 and the high streamflow samples were collected on March 25. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>Base flow</th>
<th>High flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 5, range = 47-61 mm FL</td>
<td>n = 2, range = 42-57 mm FL</td>
</tr>
<tr>
<td>Insecta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>65.0 100  73.2 72.3 31.6 100 24.9 30.1</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>32.5 100  18.3 26.6 48.7 100 37.5 45.9</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
<td>0.6 20  0.1 0.1 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>0.6 20  6.1 0.7 3.9 50 11.9 4.2</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Collembola</td>
<td>0 0 0 0 0 0 0 0</td>
<td>9.2 100 4.5 7.3</td>
</tr>
<tr>
<td>Other aquatic insects</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Homoptera (Aphididae)</td>
<td>0.6 20  0.1 0.1 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Other terrestrial insects</td>
<td>0.6 20  0.2 0.1 1.3 50 1.1 0.6</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Crustacea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Other crustaceans</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Hydrachnida</td>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>0 0 0 0 0 0 0 0</td>
<td>3.9 100 15.3 10.2</td>
</tr>
<tr>
<td>Other</td>
<td>0 20  2.0 0.2 1.3 50 4.7 1.6</td>
<td>0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

Discussion

Although differences in the diet between the lake shore and the tributary mouth were not pronounced, Chinook salmon at tributary mouths do appear to utilize prey from the tributary. At tributary mouths, benthic insects (chironomid larvae and mayfly nymphs) and terrestrial insects were more prevalent in the diet than at lakeshore sites. Occasionally, some prey types (i.e., larval black flies and rhyacophilid caddisflies) are consumed that should have only come from a stream. Consumption of larval longfin smelt was also documented at May Creek. Longfin smelt are known to spawn in the lower reaches of rivers and large streams of Lake Washington. There is no evidence of lake spawning by smelt. Longfin smelt eggs have been observed in Cedar River, May Creek, Coal Creek, Juanita Creek, and McAleer Creek (Moulton 1970; Martz et al. 1996) and therefore, juvenile Chinook salmon may be able to take advantage of this prey source at the mouths of these streams. The diet breadth was usually broader at the tributary mouths than along the lakeshore. Using all baseflow samples (2003 and 2004), the diet breadth was significantly higher at tributary mouths than the lakeshore (Wilcoxon test, n = 9, P = 0.038).
The lack of a large difference between the diet of lakeshore and tributary mouth fish may be because chironomid pupae and adults are an important dietary item regardless of location. Even in an upstream location of Johns Creek, chironomid pupae and adults were the most important prey item (Chapter 6). The high composition of chironomids in the diet of juvenile Chinook salmon has been observed in both lentic (Johnson 1983; Koehler 2002) and riverine systems (Becker 1973; Merz and Vanicek 1996; Martin and Saiki 2001; Petrusso and Hayes 2001; Sommer et al. 2001). To determine the origin of ingested chironomids from Lake Washington Chinook salmon, we may need to identify them to genus or species to determine if they are largely lake dwelling or stream dwelling prey. Samples of stream drift would also add information on the types and sizes of potential prey entering the lake from the stream.

In general, juvenile Chinook salmon appear to be opportunistic feeders. They consume a wide variety of prey items and probably can quickly switch to a locally abundant prey source. Chironomids are extremely abundant in the nearshore areas of Lake Washington (Koehler 2002) and it’s not surprising they are important in the diet of juvenile Chinook salmon. As other prey items become abundant, Chinook salmon continue to feed on chironomids but also prey on these other prey items. For example, Chinook salmon did not feed heavily on mayflies of the family Caenidae until June when the mayflies were emerging. In Lake Ontario, Johnson (1983) found that subyearling Chinook salmon fed predominantly on fish eggs when emerald shiners (*Notropis atherinoides*) were spawning; however, in another year, Chinook salmon were collected prior to spawning of emerald shiners and they preyed predominantly on chironomids. Because juvenile Chinook salmon are opportunistic feeders, they can forage at the mouths of tributaries and take advantage of a wide variety of prey types from both the lake and tributary.

In 2002, we found strong differences in the diet between Kennydale Creek mouth and lakeshore (Tabor et al. 2004b). The diet overlap index was 0.17 and diet breadth was much higher at the tributary mouth ($B = 9.0$) than the lakeshore ($B = 1.2$). In contrast, differences between tributary mouth and lakeshore samples were generally small in 2003 and 2004 except during high flow events. The sample collected at Kennydale Creek in 2002 did not appear to be during a high flow event. Also, weather records do not indicate any measurable precipitation during the 2 days before the sample was taken. In 2002, Chinook salmon at the mouth of Kennydale Creek were collected at night with small dip nets on the interior part of the delta, close to the tributary mouth. Samples in 2003 and 2004 were collected primarily during the day with a beach seine, which sampled the entire delta area. Therefore, Chinook salmon that are closer to the tributary may be feeding to a larger extent on prey from the tributary and fish on the outer part of the delta may be feeding primarily on prey that originated in the lake. Additionally, Chinook salmon collected at night near the mouth may include some fish that were foraging in the stream (convergence pool) during the day and then moved downstream to rest in quiet waters of the delta. In the Cedar River, small Chinook salmon appear to move to low velocity sites at night and rest near the bottom (R. Peters, USFWS, unpublished data).
Tributary mouths appear to be especially valuable habitat for Chinook salmon during high streamflow conditions. Chinook salmon appear to respond both functionally (change in diet) and numerically (change in abundance) to increased streamflow. At all three tributary mouths, the diet breadth was higher at high streamflow than at base streamflow conditions. A large percentage of the diet during high streamflow conditions consisted of benthic prey such as chironomid larvae and oligochaetes. These prey items may become more available due to streambed scour and prey are displaced downstream. At May Creek, we found the abundance of Chinook salmon can increase during a high flow event. An increase in prey availability as well as flow may attract Chinook salmon and other salmonids such as cutthroat trout. At Taylor Creek, we were unable to demonstrate an increase in Chinook salmon abundance due to an increase in streamflow. Taylor Creek is much smaller than May Creek and thus the amount of prey and attraction flow is most likely less. Also, May Creek may have been easier to sample with a small beach seine than Taylor Creek because the delta of May Creek is confined between two riprap banks and fish may be easily encircled with a beach seine.
CHAPTER 6. USE OF NONNATAL TRIBUTARIES

Introduction and Methods

The lower reaches of several nonnatal tributaries were surveyed in 2002. Juvenile Chinook salmon commonly used the tributary delta areas within the lake but they were only found in the lotic environments of a few tributaries (Tabor et al. 2004b). Nonnatal tributaries that had a high abundance of juvenile Chinook salmon were small- to medium-sized streams, which had a low gradient and were close to the mouth of the natal system. In 2003 and 2004, we surveyed Johns Creek and Culvert Creek to collect additional information on the use of nonnatal tributaries. Johns Creek was surveyed to determine if the tributary is used extensively from year to year and to collect some information on Chinook salmon habitat use that could be used to design restoration projects of other nonnatal tributaries. For example, the City of Seattle has proposed to daylight the mouth and lower 100 m of Mapes Creek (currently in a culvert and enters the lake a few meters below the lake surface), yet little information is available on what type of habitat conditions would be best for Chinook salmon. In 2004, we also surveyed Culvert Creek because it is also a small, low-gradient creek that is close to the mouth of the Cedar River; however, the creek is located entirely within a culvert. The creek is located approximately 0.65 km north of Johns Creek.

Johns Creek. — Johns Creek is located in Gene Coulon Park in the southeast corner of Lake Washington, 1.5 km from the mouth of the Cedar River. Typical winter streamflow is about 0.8 cfs (Tabor et al. 2004b). Juvenile Chinook salmon use the lower 460 m of the stream (Tabor et al. 2004b). Upstream of this, there are two equal-sized streams that appear to be completely in culverts.

In 2003 and 2004, we repeatedly surveyed the same 260-m long reach that was surveyed in 2002 (Tabor et al. 2004b). The downstream end of the study reach was the lake. There was no developed delta unlike other tributaries to Lake Washington. The upstream end was a large culvert near the entrance to Gene Coulon Park. The study reach was delineated into habitat units, which were either classified as a convergence pool, scour pool, glide, or riffle. The convergence pool was the lower 61 to 136 m of the index reach that the water level was directly influenced by the lake level (Figure 3). As the lake rose from February to June, the convergence pool grew progressively larger. Scour pools were other pools upstream of the convergence pool that had a maximum depth > 0.35 m. Glides or shallow pools were other slow water habitats that had a maximum depth < 0.35 m (Figure 31). The maximum pool depth of 0.35 m was adapted from Timber-Fish-Wildlife (TFW) stream ambient monitoring methodology (Pleus et al. 1999). For a stream the size of Johns Creek (5- to- 10-m bankfull stream width), the authors recommended pools have a residual pool depth of 0.25 m (residual pool depth = max. pool depth – outlet pool depth). Because the outlet depth of pools was approximately 0.1 m deep, we used a maximum pool depth as > 0.35 m. Riffles were
areas that had noticeable surface turbulence with increased water velocities. Length and width was measured for each habitat unit. The maximum depth and average depth was also determined for each habitat unit.

![Image of glide habitat and convergence pool of Johns Creek, Gene Coulon Park.](image)

**Figure 31.**—Photos of glide habitat (upper photo) and the convergence pool (lower photo) of Johns Creek, Gene Coulon Park. In the background of the convergence pool photo is Lake Washington.

Fish surveys of Johns Creek were conducted during the day primarily by a snorkeler who slowly moved upstream and counted fish. In small- and medium-sized streams, juvenile Chinook salmon appear to be easily observed and counted during the daytime. At night, the snorkeler’s light is usually close to the fish and often causes fish to scatter, thus making it difficult to count the fish. Pools and most glides were surveyed by snorkelers. In 2003, shallow habitat units (riffles and some glides) that were too
shallow to snorkel were surveyed through surface observations by walking slowly along
the stream bank. Because fish are often difficult to observe in riffles when using surface
observations, we used electrofishing equipment to sample this habitat in 2004. The
number of Chinook salmon and other fish were recorded for each habitat unit. At the
location of individual or groups of Chinook salmon, we also measured the water column
depth (surface to bottom). In 2003, surveys of Johns Creek were done once every 2
weeks from March to June while in 2004, surveys were conducted once every 3 weeks
from February to May.

Stomach samples of Chinook salmon from Johns Creek were also collected in
2003 to compare their diet to Chinook salmon collected from the lakeshore. Chinook
salmon in Johns Creek were collected with a small beach seine. Lakeshore fish were
collected at a site in the north end of Gene Coulon Park, approximately 1 km from the
mouth of Johns Creek. Stomach samples were taken once a month from the end of
February to the end of May. Fish processing, laboratory analysis, and data analyses for
stomach samples were done the same as tributary mouth sampling (see Chapter 5).

Culvert Creek. —In addition to Johns Creek, we also surveyed a small unnamed
creek or seep in Gene Coulon Park (Figure 27). It begins on the east side of the railroad
tracks about 100 m from Lake Washington. Except for a section under the railroad
tracks, the upper 35 m are daylighted. Sixty-five meters from the lake, the creek runs
through a small drain and drops 2.1 m into a culvert. The lower 65 m was available to
juvenile Chinook salmon and was located entirely in a culvert (Figure 32), thus we
referred to this creek as Culvert Creek. The outlet of the creek is along a riprap bank
(Figure 32). The creek has a small sandy delta. The delta has a steep gradient similar to
the riprap bank. In the summer and fall, the creek is usually dry. During the winter and
spring, base streamflows appear to be approximately 0.04 cfs.

Snorkel surveys were conducted along four transects at this location: 1) creek
(entirely inside culvert), 2) delta (4 m long by 3 m wide), 3) an adjacent 18-m-long riprap
shoreline and, 4) a 14-m-long gravel beach 40 m north of the creek’s mouth. The length
of the creek that we were able to snorkel varied with lake level. In February, the lake
level was low and the lower end of the culvert was perched above the lake level and the
creek was one long riffle. We assumed no Chinook salmon could use the creek during
this time period. As the lake rose, water was backed up in the culvert and we were able
to snorkel inside the culvert. Transects were surveyed four times, approximately once
every three weeks from March to May.
Results

Johns Creek. — In both 2003 and 2004, large numbers of juvenile Chinook salmon were present in the index reach of Johns Creek in February and March (Figure 33). Peak abundance was 632 Chinook salmon on March 5, 2003. Numbers gradually decreased from late March through May and few Chinook salmon were present by the beginning of June. In February, the mean length of juvenile Chinook salmon in Johns Creek was approximately 40 mm FL and by the end of May they averaged 74 mm FL (Figure 34). As they grew they used progressively deeper areas of the creek, from 0.28 m in February to approximately 0.5 m in May (Figure 35).
Figure 33. — Number of juvenile Chinook salmon observed in the lower 260 m of Johns Creek in 2003 and 2004. Data are based primarily on snorkel counts. Habitats that were too shallow to snorkel were surveyed with surface observations or electrofishing surveys.

Figure 34. — Mean fork length (mm, ± 2 SE) of juvenile Chinook salmon in the lower 260 m of Johns Creek, 2003. Fish were collected with beach seines.
A total of only six Chinook salmon were collected in riffles (only sampled in 2004). They were collected in February and early March and were located in small pocket water behind boulders. Juvenile Chinook salmon density was highest in glides in February and early March. In both 2003 and 2004, the density in the beginning of March was about twice as high in glides than scour pools. The density in glides declined dramatically in late March and after the beginning of April, few Chinook salmon were present in glides and those that were present were almost always under overhanging vegetation. In April and May, the density in scour pools was 3 to 65 times higher than in glides. Juvenile Chinook salmon were present in scour pools throughout the study period (Figure 36). In February, they were located in shallow areas of the pool such as the edges and tailouts. After February, they were found in deeper water and by the end of March they were usually in the deepest part of the pool (Figures 37 and 38).

Similarly to scour pools, Chinook salmon were present in the convergence pool throughout the study period, albeit at a much lower density (Figure 39). Chinook salmon in the convergence pool were usually close to the edge and associated with shoreline vegetation. One notable exception was in February, 2004 when most Chinook salmon in the convergence pool were located under the footpath bridge. Large numbers of juvenile Chinook salmon were also observed under the bridge in 2002. The March and April abundance of Chinook salmon in the convergence pool was higher in 2004 than 2003, even though the abundance in all habitats combined was higher in 2003. To compare the use of the convergence pool to the rest of the index reach, we calculated the number per stream length because the convergence pool is wide and Chinook salmon do not appear to use the large area in the middle of the stream channel. The number of Chinook salmon per stream length was 3 to 26 times lower in the convergence pool than the rest of the stream in 2003; however, in 2004 it was only 2 to 7 times lower (Figure 36). The water
column depth used by Chinook salmon in the convergence pool was similar to the average depth available. The deep areas (> 0.9 m deep) of the convergence pool did not appear to be used extensively by Chinook salmon. Instead these areas were often inhabited by large trout or largemouth bass (*Micropterus salmoides*), which may have influenced the distribution of juvenile Chinook salmon.

![Graph 2003](image)

![Graph 2004](image)

**Figure 36.** Density (number /m²) of juvenile Chinook salmon in three habitat types in the lower 260 m of Johns Creek, 2003 and 2004. Density in riffles is not shown because few fish were observed. Note different scales between years.
Figure 37. — Water column depth (m) where juvenile Chinook salmon were located and maximum depth of two scour pools in the index reach of Johns Creek, February – May, 2004. max. depth = maximum depth.

Figure 38. — Mean water column depth (m) in scour pools and glides (environment) and the mean water column depth where juvenile Chinook salmon were located in those habitats, lower Johns Creek, February-May, 2004. Figure only includes dates when at least 10 Chinook salmon were observed.
Other salmonids in Johns Creek consisted primarily of sockeye salmon fry. Other fish observed in Johns Creek included trout, prickly sculpin, coastrange sculpin (*C. aleuticus*), threespine stickleback, juvenile brown bullhead (*Ameiurus nebulosus*), juvenile suckers (*Catostomus* sp.), juvenile sunfish (*Lepomis* sp.), juvenile peamouth (*Mylocheilus caurinus*), and largemouth bass. Salmonids and sculpins were found throughout the index reach and throughout the study period; whereas, the other fish species were observed primarily in the convergence pool in May and June.

In general, the diet of juvenile Chinook salmon in Johns Creek was similar to the diet from Lake Washington. Chironomid pupae and adults had the highest %IRI on each sampling date in both Johns Creek and the lakeshore (Table 12). However, on two of the four dates (March 20 and April 22), the diet in Johns Creek was substantially different than the lake shore at north Gene Coulon Park (Table 12). In Johns Creek, chironomid pupae and adult made up less than 30% of the diet by weight on both dates, whereas they made up over 80% of the diet from the lake shore during that time period. On March 20, oligochaetes were the most important prey item by weight and on April 22 other terrestrial invertebrates (centipedes, isopods, and gastropods) made up over half of the diet by weight. The diet breadth index was also much higher for Johns Creek fish than the lakeshore fish on these two dates (Table 13).
TABLE 12. —Diet composition of juvenile Chinook salmon in Johns Creek, 2003. \( n \) = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; \%N = percent number; \%O = percent occurrence; \%W = percent weight; \%IRI = percent index of relative importance. Samples on February 21 were combined together in the field and \%O and \%IRI could not be calculated.

<table>
<thead>
<tr>
<th>Prey group</th>
<th>February 21</th>
<th>March 20</th>
<th>April 22</th>
<th>May 30</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n = 10, \text{range} = 37-45 \text{mm FL} )</td>
<td>( n = 11, \text{range} = 47-54 \text{mm FL} )</td>
<td>( n = 10, \text{range} = 48-54 \text{mm FL} )</td>
<td>( n = 10, \text{range} = 72-81 \text{mm FL} )</td>
</tr>
<tr>
<td></td>
<td>%N</td>
<td>%O</td>
<td>%W</td>
<td>%IRI</td>
</tr>
<tr>
<td><strong>Insecta</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diptera</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chironomid pupae and adults</td>
<td>63.9</td>
<td>47.0</td>
<td>-</td>
<td>36.8</td>
</tr>
<tr>
<td>Chironomid larvae</td>
<td>11.5</td>
<td>4.0</td>
<td>-</td>
<td>8.8</td>
</tr>
<tr>
<td>Other aquatic diptera</td>
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<td>0</td>
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<td><strong>Ephemeroptera</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Collemba</strong></td>
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<td>5.0</td>
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<td>16.7</td>
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<tr>
<td><strong>Other aquatic insects</strong></td>
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<td>-</td>
<td>0</td>
</tr>
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<td><strong>Homoptera (Aphididae)</strong></td>
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<td>0</td>
<td>-</td>
<td>0</td>
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<td>4.0</td>
<td>-</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Crustacea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladocera - Daphnia</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Other crustaceans</td>
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<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td><strong>Acarina</strong></td>
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<td>0</td>
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<td>1.8</td>
</tr>
<tr>
<td><strong>Oligochaeta</strong></td>
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<td><strong>Other terrestrial invertebrates</strong></td>
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<td>0</td>
<td>-</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>6.6</td>
<td>40.0</td>
<td>-</td>
<td>9.6</td>
</tr>
</tbody>
</table>
TABLE 13.—Diet overlap index (C) and diet breadth index (B) of juvenile Chinook salmon from Johns Creek and Lake Washington, 2003. Lake Washington Chinook salmon were collected in the north part of Gene Coulon Park, approximately 1 km from Johns Creek. Diet overlap index numbers in bold indicate a significant difference in diet (C < 0.6). Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

<table>
<thead>
<tr>
<th>Date</th>
<th>Diet overlap index (C)</th>
<th>Diet breadth index (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Johns Cr. and lake shore</td>
<td>Johns Cr. lake shore</td>
</tr>
<tr>
<td>February 21</td>
<td>0.70</td>
<td>1.98</td>
</tr>
<tr>
<td>March 20</td>
<td>0.21</td>
<td>3.39</td>
</tr>
<tr>
<td>April 22</td>
<td>0.29</td>
<td>5.03</td>
</tr>
<tr>
<td>May 30</td>
<td>0.62</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Culvert Creek.—A total of only five Chinook salmon were observed in Culvert Creek (inside the culvert); however, the amount of available habitat was relatively small. The few Chinook salmon observed inside the culvert were located close to the downstream end of the culvert (mouth of the creek), presumably because light levels at the mouth were higher and more conducive for foraging. Few other fish were observed inside the culvert. Out of four surveys, only one sockeye salmon fry, one small trout, and three sculpin were observed. No Chinook salmon were ever observed on the creek delta. Instead other fish, such as largemouth bass, prickly sculpin, pumpkinseed (*Lepomis gibbosus*), and small trout, were usually present. Few Chinook salmon were observed along the riprap transect. On three of the four surveys, large adult bass (either largemouth bass or smallmouth bass *M. dolomieu*) were present. Other fish observed included trout, pumpkinseed, and large prickly sculpin. The highest abundance of Chinook salmon (#/m) was observed along the gravel beach transect (Figure 40). Except for some small sculpin, few other fish were observed along this transect.

![Graph](image_url)

**Figure 40.**—Abundance (number per m) of juvenile Chinook salmon in Culvert Creek (inside culvert) and at two nearby shoreline transects in Lake Washington, 2004.
Discussion

Johns Creek.—Results from Johns Creek indicated that Chinook salmon extensively use this nonnatal tributary from year to year. Several nonnatal tributaries of Lake Washington and Lake Sammamish were surveyed in 2002 and the number of Chinook salmon found in Johns Creek was higher than all the other tributaries combined. Johns Creek appears to be an ideal nonnatal tributary because it has a low gradient, is a small- to medium-sized stream, and is close to the natal system, the Cedar River. Preliminary results from Lake Quinault in 2004 indicate there are also several nonnatal streams that are used by juvenile Chinook salmon. We plan to conduct additional surveys of these streams in 2005 to identify important factors that influence their use of these streams. In the lower part of the Fraser River, British Columbia, juvenile Chinook salmon used nonnatal tributaries that had low gradients and had no fish barriers such as waterfalls, culverts, bridge footings, or flood control gates (Murray and Rosenau 1989). The use of the lower reaches of nonnatal tributaries by juvenile Chinook salmon has also been documented in the upper Fraser River system in British Columbia (Scriven et al. 1994), the Taku River system in Alaska (Murphy et al. 1989) and the Umpqua River system in Oregon (Scarnecchia and Roper 2000).

Based on the habitat use patterns of Johns Creek, a suitable stream for juvenile Chinook salmon should have a wide variety of habitat features, which would take into account the change in habitat use of Chinook salmon as they grow. Shallow, slow water habitats (< 0.35-m depth) or glides were used extensively in February and early March. We also observed small Chinook salmon in pocket water of riffles, thus using cobbles and small boulders in riffles might provide additional rearing habitat. After late March, Chinook salmon were usually in deeper pools but we did not observe them in pools greater than 0.9 m depth. Throughout the study period, juvenile Chinook salmon appeared to often use overhead cover.

The density of Chinook salmon in the convergence pool was considerably lower than in the upstream reach. Low density in the convergence pool may be due to a combination of suboptimal habitat conditions and presence of other fish species. Much of the convergence pool had riprap banks and there was little woody debris and little riparian vegetation to provide overhanging cover. Potential predators of Chinook salmon, such as largemouth bass, smallmouth bass, large trout, and prickly sculpin, were commonly observed in the convergence pool, thus Chinook salmon may avoid this area. Besides predators, the convergence pool also had large numbers of potential competitors (juvenile peamouth, juvenile sunfish, threespine stickleback, and prickly sculpin), which could reduce the food available for Chinook salmon. In the upstream reach, few other fish species were present and the habitat conditions appeared to be better than the convergence pool.

Culvert Creek.—Although few Chinook salmon were present at Culvert Creek, it does provide evidence that small creeks or seeps could be potential Chinook salmon rearing habitat. The number observed at Culvert Creek in 2004 was higher than the number observed in 2002 in much larger tributaries such as May Creek (Tabor et al. 2004b). Use of these small tributaries has not been well documented; however, in the Nooksack River system, Chinook salmon fry were frequently caught in several spring seeps and small tributaries but not along the river edge.
(P. Castle, WDFW, unpublished data). Use of these small tributaries in Lake Washington is probably most beneficial for newly emerged fry. These tributaries would provide shallow water habitat and large predatory fish would most likely be absent. As they grow and move into deeper habitats their use of these small tributaries would be greatly reduced.

The number of juvenile Chinook salmon in Culvert Creek may actually be high considering the poor condition of the habitat. The creek could be significantly improved if it was daylighted and riparian vegetation was planted. Additionally, the creek delta was adjacent to riprap and the abundance of predatory fishes (bass and large sculpin) appeared to be much higher than at other tributary deltas. Any stream restoration project would probably also need to include removing the riprap. If the creek was restored, perhaps it could support as many as 50 juvenile Chinook salmon (based on densities observed in Johns Creek).
CHAPTER 7. WOODY DEBRIS AND OVERHANGING VEGETATION EXPERIMENT

Introduction

In 2001 and 2002, habitat manipulation experiments were conducted in Gene Coulon Park to test the use of small woody debris (SWD) by juvenile Chinook salmon. In all experimental tests, no preference for SWD was found (Tabor and Piaskowski 2002, Tabor et al. 2004b). However during snorkel surveys, juvenile Chinook salmon were found to extensively use natural small woody debris when associated with overhanging vegetation (OHV) in south Lake Washington and Lake Sammamish. Since no preference was shown for SWD by itself during experimental tests, then OHV may be an important element of preferred habitat for juvenile Chinook salmon. In 2003, we conducted the final phase of our habitat manipulation experiments by examining the use of OHV in combination with SWD.

Methods

We used the same site in Gene Coulon Park that we used in 2001 and 2002 (Figure 14). The shoreline was divided into six 15-m shoreline sections: two with SWD, two with OHV/SWD and two with no structure of any kind. The structures within the SWD only sections and OHV/SWD sections were 8 m long and located in the middle of the 15-m shoreline section. In the sections with OHV, we placed four fence posts in the water at a 0.3 m depth and then a rope was tied between them, approximately 0.4 meter above the water. Scotch broom (Cytisus scoparius) cuttings (1.5 to 2 m long) were then laid down such that the base of each cutting was close to the edge of the shore and the top part of the cutting rested on the rope (Figure 41). The cuttings were anchored with sand bags on shore and cable ties along the rope. The small woody debris consisted of tree branches placed in two rows parallel to shore. Each row was approximately 1 to 2 m wide. The rows were approximately 1.5 m apart, which allowed room for a snorkeler to swim between the rows. Small woody debris was placed along 0.4 and 0.7 m depth contours and was tied together and anchored with sand bags. Snorkel surveys were conducted within each shoreline section. Surveys were done during both day and night. Surveys were done along the 0.4 m depth contour. At the beginning of each snorkel survey, the temperature (°C) and light intensity (lumens/ft²) was measured. Light intensity measurements were taken at the water surface with an International Light Inc., model IL1400A radiometer/photometer.

During the day, Chinook salmon were active and often moved away from snorkelers. To get a more accurate count and insure that snorkelers did not push fish into an adjoining section, two snorkelers slowly swam toward each other from the outer edges of each shoreline section. After surveying each section, snorkelers compared notes on fish observed and adjusted fish counts to reduce the likelihood that fish were double counted. At night, shoreline sections could be surveyed by one snorkeler. Fish were inactive and usually did not react to the snorkeler. Occasionally, a Chinook salmon was startled but usually only swam away a short distance in any direction. Therefore, it was possible for a fish to have moved into an adjoining section, but we considered this number to be insignificant in comparison to the total number of fish observed. Within each shoreline section with structure, we also estimated the number of Chinook salmon
that were closely associated with OHV or SWD or were located on the periphery of the structure (3.5-m shoreline length on each side of the structure).

We conducted the experiment during two time periods, an early period (March 24 to April 9) and a late period (May 2 to 16). To compare between treatments, we used a one-way analysis of variance test (ANOVA).

**Results**

A total of ten daytime surveys were conducted during the early time period between March 24 and April 9. On each survey date, both the OHV/SWD sections had a substantially higher number of Chinook salmon than any other section. The daytime abundance of Chinook salmon was significantly different between shoreline types (Figure 42; ANOVA, $F = 87.7$, df = 2,3, $P = 0.002$). Results from a post hoc Fisher’s LSD test showed a significantly higher abundance in the OHV/SWD sections than either the SWD sections or open sections. No difference was detected between SWD and open sections. Large numbers of Chinook salmon were often observed directly under OHV (Figure 43). On average, 86.7% of the Chinook salmon within the OHV/SWD sections were most closely associated with the OHV part of the structure, while 6.3% were associated with the SWD and 6.8% were in the open on the periphery of the structure. Three nighttime surveys were conducted during the early time period. There was no significant difference in nighttime Chinook salmon abundance between shoreline types.
(ANOVA, $F = 5.6$, df = 2,3, $P = 0.098$). However, 46% of all the Chinook salmon were present in the open sections and 65% of those within sections with structure (OHV/SWD and SWD) were located in the open, away from the structure.

During the late time period (May 2–16), seven daytime and four nighttime snorkel surveys were conducted. There was no significant difference in Chinook salmon abundance between shoreline types during either the daytime (Figure 42; ANOVA, $F = 0.02$, df = 2,3, $P = 0.98$) or nighttime (ANOVA, $F = 6.0$, df = 2,3, $P = 0.089$). Unlike the early time period, few Chinook salmon used OHV during the daytime of the late time period. On average, only 7.2% of the Chinook salmon within the OHV/SWD sections were most closely associated with the OHV while 30.2% were associated with the SWD and 62.6% were in the open on the periphery of the structure. During the early time period, only 17% more Chinook salmon were observed at night than during the day; however, twice as many were observed at night as during the day during the late time period. This suggests that either snorkelers were less able to observe the Chinook salmon during the day of the late time period or many of the Chinook salmon were further offshore during the day of the late time period and not close to snorkelers.

Figure 42. —Mean number (±range) of juvenile Chinook salmon observed in three habitat types during an early and late time period, Gene Coulon Park, south Lake Washington (2003). Bars represent the mean of two replicates. $n =$ the number of snorkel surveys used to calculate the mean number observed for each replicate. OHV = overhanging vegetation; SWD = small woody debris.
A variety of different surveys from Lake Washington, Lake Sammamish, and Lake Quinault have indicated that overhead cover (alone or in combination with small woody debris) is an important habitat feature for small Chinook salmon. In March 2001, small Chinook salmon were often found under south Lake Washington docks during the day (Tabor and Piaskowski 2002). No SWD was present under these docks. Surveys of natural OHV/SWD sites in Lake Washington and Lake Sammamish found large numbers of small Chinook salmon were often present (Tabor and Piaskowski 2002; Tabor et al. 2004b). In Lake Quinault, we also found Chinook salmon directly under LWD and OHV. In 2004, we undertook a field experiment to test its importance, and results clearly showed that large numbers of Chinook salmon use sites with overhead cover. Use of overhead cover by juvenile Chinook salmon has also been observed in Cedar River (R. Peters, USFWS, unpublished data). Brusven et al. (1986) used an artificial stream channel to test the importance of overhead cover and found it was an important habitat component for juvenile Chinook salmon. Meehan et al. (1987) covered sections of a side-channel of the South Fork Salmon River and found the number of juvenile Chinook salmon was substantially higher in the covered sections than open sections.

The use of overhead cover has also been documented for other juvenile salmonids. Juvenile Atlantic salmon preferred overhead cover when light levels were greater than 300 ft-c (Gibson and Keenleyside 1966). Fausch (1993) found juvenile steelhead selected habitat
structures that provided overhead cover; however, juvenile coho salmon did not select overhead cover. The use of overhead cover has also observed in adult salmonids such as brown trout, rainbow trout, and brook trout (Gibson and Keenleyside 1966; Butler and Hawthorne 1968).

The main function of overhead cover for juvenile Chinook salmon was most likely predator avoidance. It would seem unlikely that Chinook salmon selected the overhanging vegetation because of food availability. In our experiments, we used freshly-cut scotch broom and it’s doubtful if there was any increase in prey abundance. Besides, there probably would not be enough food production for the large number of Chinook salmon in such a small area. Chinook salmon associated with the overhead cover were inactive and did not appear to be actively foraging. In contrast, fish in open areas were often observed foraging. The overhead cover probably provides a visual refuge from avian predators as well as fish predators. Helfman (1981) proposed that fish utilize overhead cover because they are better able to see approaching predators and it is hard for predators to see into the shade.

Similar to 2002 results, no significant difference was detected between experimental SWD sites and open sites. Overall, there was five times as many fish in the SWD sites as the open sites; however, there was large variability between survey dates. For example, on seven occasions, there were no fish in a SWD section but on four occasions were more than 30 fish. Small woody debris does not appear to provide resting habitat like OHV/SWD but still may be important as a refuge from predators. Chinook salmon may retreat to the SWD if a predator approaches and only use the SWD for a short period of time until the predator has moved away. The addition of SWD adds structural complexity and may reduce the foraging ability of predators (Glass 1971).

In May, juvenile Chinook salmon were rarely found associated with OHV or SWD. Previous work in Lake Washington also indicated Chinook salmon do not appear to extensively use cover as they increase in size (Tabor et al. 2004b). In the Cedar River, juvenile Chinook salmon were located further from cover as they became larger (R. Peters, USFWS, unpublished data). Allen (2000) also found that juvenile Chinook salmon in the Yakima River were further away from instream cover as they grew larger. As Chinook salmon grow they inhabit deeper waters and may not need to use cover. Deeper water may act as a visual barrier from some predators such as avian predators. Gibson and Power (1975) found that juvenile Atlantic salmon used overhead cover in shallow water but if they were in deeper water it was not used. Additionally, juvenile Chinook salmon may not need to use cover because they will have much faster burst swimming speed as they increase in size (Webb 1976) and thus can quickly move away from some types of predators. Alternatively, juvenile Chinook salmon may be further away from cover in May but complex structures such as OHV and SWD may still be important as a refuge from predators. As Chinook salmon increase in size and have faster burst swimming speed, they can move further from cover and still be able to retreat to cover if a predator approaches. For example, in 2001 we observed a large school of juvenile Chinook salmon feeding offshore in the open but later they quickly moved to OHV/SWD that was close to shore when they were pursued by two mergansers (Tabor and Plaskowski 2002).
CHAPTER 8. LAKE QUINAULT SURVEYS

Introduction

Some habitat features such as LWD and emergent vegetation are difficult to study along the highly developed shorelines of Lake Washington and Lake Sammamish because they are rare. Outside of the Lake Washington basin, the only other major run of ocean-type Chinook salmon that spawn above a large lake in the State of Washington occurs in the Quinault River above Lake Quinault. In 2003, we conducted a preliminary investigation of Lake Quinault to determine if the lake could be used to study the habitat features that are rare in the Lake Washington basin. A few day and night snorkel surveys were conducted in April and July. Large numbers of Chinook salmon were found along the lake shoreline and the lake had large areas with LWD and emergent vegetation. Additionally, the shoreline is relatively undeveloped and the only introduced fish species is common carp, which do not appear to be abundant. Therefore, the lake appeared to be an excellent site to study juvenile Chinook salmon habitat use in a pristine lentic environment and examine some habitat features not found in the Lake Washington basin.

Methods

Chinook salmon habitat use was studied during two periods in 2004; one in late April and another in late June. The nearshore area was divided in one of five habitat types (Figure 44): open beach (gentle slope) with small substrate (sand and gravel), bedrock and large substrate (steep slope), emergent vegetation (Figure 45), LWD (Figure 45), or tributary mouths. Except for deltas of some small tributaries, we only used nearshore areas where the shoreline habitat was the same for at least 50 m.

The maximum transect length was 120 m. Only one area of the lake had bedrock and three transects were established at this location (Figure 44). These transects were surveyed on each study period during both day and night. Seven tributary mouths were chosen, three (Gatton Creek, Falls Creek, and Willaby Creek) are spawning streams for Chinook salmon, the other four tributaries are considered nonnatal streams. For the other three habitat types, we used a stratified random sampling design to select transects to survey. Sampling consisted of both day and night snorkel surveys. We tried to survey the same transects on each study period during both day and night; however, we were not able to survey a few transects due to time constraints or weather issues. On low to moderate sloping shorelines, two depth contours (0.4- and 0.7-m depth) were surveyed, while on steep sloping shorelines only one depth contour (0.4-m depth) was surveyed. Chinook salmon (separated into those greater than and less than 60 mm FL) and other fish were counted along each transect. A habitat survey was also done at each transect. Information collected included: substrate type, length, slope, and amount of structure (woody debris or emergent vegetation).
FIGURE 44. —Location of nearshore transects used to study habitat use of juvenile Chinook salmon in Lake Quinault, 2004.
We compared day and night Chinook salmon counts with a sign rank test. The abundance of fish at each site was calculated two separate ways; 1) nearshore abundance (number of fish per 100 m of shoreline), and 2) shoreline density (number of fish per m$^2$). The nearshore abundance is the estimated number of fish to 1-m depth and is based on fish counts along one or two transects (depending on the bottom slope) and then expanded based on the distance from the shoreline to 1-m depth. The shoreline density is the number of fish along the 0.4-m transect. We used a transect width of 2.5 m for the 0.4 contour depth and 2 m for the 0.7-
m depth contour, which are the same widths used for index sites in Lake Washington (Chapter 1). Abundance of fish in different habitat types for April and June were compared with an one-way ANOVA and Fisher’s LSD test. Separate tests were performed for the nearshore abundance (#/100 m of shoreline) and shoreline density (#/m$^2$).

**Results**

In April 2004, large numbers of juvenile Chinook salmon were observed during both day and night. Comparison of sites that were surveyed day and night (n = 12) indicated there was no difference in the number of Chinook salmon (sign rank test, $P = 0.39$). Of all day and night transects in April (n = 47), there was only one day transect where no Chinook salmon were observed. In June, few Chinook salmon were observed during the day except at tributary mouths. Overall, significantly more Chinook salmon were observed at night than during the day in June (sign rank test, $P = 0.002$). No Chinook salmon were observed along 11 of the 25 (44%) day transects. In contrast, Chinook salmon were observed along every night transect (n = 26).

Both daytime nearshore abundance (number/100 m of shoreline) and daytime shoreline density (#/m$^2$) of juvenile Chinook salmon in April was significantly different between habitat types (Figure 46; ANOVA, df = 3,7; #/100 m, $F = 4.2, P = 0.008$; #/m$^2$, $F = 6.6, P = 0.001$). Results of a post-hoc Fisher’s LSD test indicated that tributary mouths generally had higher numbers of Chinook salmon than the other habitat types and bedrock sites often had a lower number (Figure 46). Beach, emergent vegetation, and LWD sites were not significantly different from each other. The abundance of Chinook salmon in emergent vegetation sites was highly variable, which appeared to be due to differences in the type of emergent habitats. Sites with soft, silty sediments and a gentle slope tended to have a lower abundance than sites with a sand/gravel substrate and a moderate slope. If emergent sites are removed from the ANOVA model, the nearshore abundance at LWD sites becomes significantly higher than at beach sites as well as bedrock sites. Within LWD sites, juvenile Chinook salmon were often resting directly under a large piece of LWD.

Only 12 transects were snorkeled at night in April. No significant differences were detected between habitat types for either number/100 m of shoreline (ANOVA, $F = 3.1$, df = 3,7, $P = 0.099$) or shoreline density (ANOVA, $F = 2.1$, df = 3,7, $P = 0.19$). However, the average number/100 m of shoreline at bedrock sites was considerably lower than the other habitat types.

Ninety percent of Chinook salmon observed during the day in June were at tributary mouths. The number of Chinook salmon/m was 1.14 at the tributary mouths; whereas it was only 0.02 at the other sites. Chinook salmon were observed at all tributary mouth sites (n = 6) but only observed at 5 of 19 (28%) other sites. Because no Chinook salmon were observed at most sites except at the tributary mouths, no statistical test was preformed. At tributary mouth sites, most Chinook salmon were located directly in the current, close to where the stream enters the lake.

The nighttime nearshore abundance (#/100 m of shoreline) of Chinook salmon in June was not significantly different between habitat types (ANOVA, $F = 7.4$, df = 4,21, $P = 0.001$).
Similar to April surveys, the nearshore abundance in emergent sites was also highly variable between sites. If emergent sites are removed from the ANOVA model, abundance at beach sites and tributary mouths becomes significantly higher than at bedrock sites. The June nighttime shoreline density (#/m$^2$) was significantly different between habitat types (ANOVA, $F = 3.1$, df = 3,7, $P = 0.099$). Results of a post-hoc Fisher’s LSD test indicated that tributary mouths generally had higher shoreline densities than the other habitat types and bedrock sites had lower shoreline densities than beach sites (Figure 47).

Chinook salmon observed in June were a wide range of sizes. There appeared to be two distinct groups, a group of large individuals that were approximately 70-90 mm FL and a group of smaller individuals (45-60 mm FL). We made separate counts for each group. We divided them into two size categories (less than and greater than 60 mm FL). During the day, Chinook salmon were mostly observed at tributary mouths and 68% were large Chinook salmon. The large Chinook salmon were located in the current of the tributary and slightly offshore, while the small Chinook salmon were located close to shore on the periphery of the delta. The few Chinook salmon observed at the other habitat types during the day were all small. At night, 69% of the Chinook salmon were small and there was no large difference in the ratio of small to large Chinook salmon between the habitat types.

At many sites, we also observed large numbers of juvenile coho salmon. Small juvenile coho salmon and coho salmon presmolts were observed in April, while in June only juvenile coho salmon were observed. Most juvenile coho salmon appeared to be smaller than Chinook salmon and were more closely associated with LWD, especially during the day. During the day in April, the number of juvenile coho salmon per shoreline length was 0.63 fish/m for LWD sites, whereas it was 0.23 fish/m for beach, bedrock, and emergent sites, combined. No coho salmon were observed at the seven tributary mouth sites. At night in April, the highest abundance of coho salmon was observed in beach sites, 0.91 fish/m. Coho salmon presmolts were observed primarily at night at beach and tributary mouth sites. Sixty-six percent of all coho salmon observed during the day in June were in LWD sites. The abundance of coho salmon at LWD sites was 1.0 fish/m; however, at the other sites combined it was only 0.14 fish/m. At night in June, good numbers of juvenile coho salmon were observed in each habitat type. The highest abundances were observed in LWD (0.88 fish/m) and tributary mouth sites (0.80 fish/m).

Besides juvenile Chinook salmon and coho salmon, other fish commonly observed included speckled dace (*Rhinichthys cataractae*), threespine stickleback, prickly sculpin, trout, and suckers. Speckled dace were especially abundant at night. During the day, they appeared to usually be closely associated with some type of cover such as woody debris or emergent vegetation; while at night, they were in the open areas of each habitat type. Large numbers of threespine stickleback were observed in emergent vegetation sites as well as beach and tributary mouth sites. A few small sculpin (< 75 mm TL) were observed during the day; while at night, large numbers of small and large (> 75 mm TL) sculpin were observed in all habitat types. Trout were observed primarily at night. The only place we observed large trout (> 150 mm) during the day was at tributary mouths. Adult suckers were observed primarily at tributary mouths (day and night) and juvenile suckers were observed at night primarily at beach and emergent sites.
Figure 46. —April daytime nearshore abundance to 1 m depth (mean ± 2SE; top panel) and shoreline density (mean ± 2SE; lower panel) of juvenile Chinook salmon in Lake Quinault, 2004. Bars with different letters are significantly different (ANOVA and Fisher’s LSD; P < 0.05). Numbers in parentheses indicate the number of replicates.
Discussion

Except for tributary mouths, few significant differences were observed in the use of different habitat types in Lake Quinault. Lack of pronounced differences may have been due to small sample sizes and high variability in Chinook salmon abundance between sites. There is little bedrock shoreline in Lake Quinault and only three bedrock sites were established. The abundance of Chinook salmon at bedrock sites was substantially lower than other habitat types, yet we detected few significant differences between bedrock sites and other habitat types.
High variability in the April surveys may have been due to differences in the distance to natal streams. For example, sites in the northeast corner of the lake near the mouth of Quinault River appeared to have a higher abundance of Chinook salmon than other sites. Adjusting the counts of Chinook salmon based on distance to natal streams would be difficult because there are several natal streams spread around the east and south shoreline of the lake. In June, Chinook salmon were probably well distributed around the lake and distance to the natal stream probably had little influence on their abundance.

The abundance of Chinook salmon at emergent vegetation sites was highly variable. Much of the variability appeared to be due to the substrate type and bottom slope. Sites with sand and gravel substrates (hard substrates) tended to have a higher abundance (1.5 times higher in April and 21 times higher in June) than emergent sites with silt and mud (soft substrates). Areas with soft substrates also had a more gradual slope than areas with hard substrates. In 2001 and 2002, we made some preliminary observations on the use of soft substrates (silt and mud) by juvenile Chinook salmon in Lake Washington (Tabor and Piaskowski 2002; Tabor et al. 2004b), which suggested that they tend to avoid this substrate type. Results from surveys at Beer Sheva Park provided further evidence that Chinook salmon do not extensively use soft substrates. The reasons why soft substrates are avoided is unclear. We hypothesized that Chinook salmon may avoid soft substrates in Lake Washington because these areas may have a higher density of predators such as largemouth bass and brown bullhead. However, in Lake Quinault these predators do not occur. Soft substrates also appear to have a higher density of macrophytes than other substrate types and Chinook salmon may prefer a more open environment. Other possible explanations include competition with threespine stickleback, which were predominantly found in emergent vegetation sites with soft substrate. Other potential competitors, including speckled dace and juvenile coho salmon, were also common in these sites. Also, the soft substrate sites appear to often have higher turbidity than other sites which could reduce foraging success of juvenile Chinook salmon.

In comparing fish abundance, we assumed that Chinook salmon could be observed equally between the different habitat types. However, it is certainly possible that there was some degree of bias. The distance at which a fish will react to a potential predator (reactive distance) may be much longer in open areas than in complex habitats such as LWD and emergent vegetation sites (Grant and Noakes 1987). Alternatively, fish can be difficult to observe in complex habitats because they can easily hide from the observer. Additionally, emergent vegetation sites with soft substrates appeared to have higher turbidity from wave action and/or common carp activity, which may also have reduced our ability to observe juvenile Chinook salmon. Some additional sampling techniques such as beach seining could be employed to confirm the results but other techniques may also have some bias between habitats types.

Although we did not document a strong preference for LWD or emergent vegetation in Lake Quinault, these habitats may still be more beneficial than open beach habitat if survival rates are higher in structurally complex habitats. The addition of LWD or emergent vegetation adds structural complexity and reduces the foraging ability of predators (Glass 1971). Research in warm-water systems has been found that structural complexity is important for survival of many species of juvenile freshwater fishes (Savino and Stein 1982; Werner and Hall 1988).
Tabor and Wurtsbaugh (1991) concluded that nearshore structural complexity improved the survival of juvenile rainbow trout in reservoirs because trout strongly selected this habitat feature and improved survival was demonstrated in a pond experiment.

The benefit of LWD in Lake Washington and Lake Sammamish has been debated because it may provide valuable salmonid habitat but it may also be used extensively by smallmouth bass and other introduced predatory fish. Fresh et al. (2001) found that smallmouth bass occurred primarily in areas with cobble and were usually near some type of structure such as a dock. Smallmouth bass generally prefer areas with a steep sloping bottom (Hubert and Lackey 1980). Therefore, LWD could be placed in areas with fine substrates and a gentle slope, which is what juvenile Chinook salmon prefer. However, LWD sites with a gentle slope could also be used by largemouth bass. At a natural OHV/SWD site (gentle slope with sand substrate) in Lake Washington we observed juvenile Chinook salmon for a few weeks until an adult largemouth bass was observed. Another possible management scenario would be to only have LWD placed in the south end of the lake. From February to mid-May, juvenile Chinook salmon are located primarily in the south end of the lake. Smallmouth bass and largemouth bass do not appear to become very active until May when water temperatures are greater than 10°C and by then many of the juvenile Chinook salmon have moved into deeper waters. Also, by only having the LWD in the south end, the total population of bass in Lake Washington may not increase substantially.

Experiments in Lake Washington in 2001 (Tabor and Piaskowski 2002), 2002 (Tabor et al. 2004b), and 2003 (Chapter 7) indicated SWD is not preferred habitat for juvenile Chinook salmon. Similarly, LWD was not strongly preferred over open beach areas in Lake Quinault. It is difficult to make comparisons between the SWD and LWD because they were not directly compared in the same study. However within LWD sites, juvenile Chinook salmon were commonly located directly under pieces of LWD that had a large diameter. Therefore in Lake Quinault, LWD may be more beneficial than SWD because it provides more overhead cover. Small woody debris provides some structural complexity but provides little overhead cover. Ideally, a study of different diameter woody debris would be valuable to determine the best size of woody debris to use in restoration projects. A simpler approach would be to measure the diameter of the piece of woody debris that Chinook salmon were associated with and compare to the sizes of woody debris available.
CHAPTER 9. SURFACE OBSERVATIONS OF MIGRATING JUVENILE CHINOOK SALMON IN LAKE WASHINGTON

Introduction and Methods

On June 19, 2001, several schools of Chinook salmon were observed migrating along the Seattle shoreline of Lake Washington (Tabor and Piaskowski 2002). Observations were made from a pier at Stan Sayres Park. These schools were observed swimming north in approximately 2.1- to 2.5-m deep water and as they approached the pier they moved to deeper water (3.1-m deep water) and swam around the pier. Occasionally, we looked for migrating Chinook salmon at this pier and other piers during the months of May and June in 2002 but no Chinook salmon were seen. In 2003 and 2004, we undertook a more systematic sampling approach to determine when they can be observed migrating along the shore. Additionally, we wanted to collect additional information on their behavior in relation to piers. In 2003, weekly observations (May-July) were conducted at one site, a public pier near McClellan Street. This site was selected because no other piers were nearby to alter the fishes’ behavior and the offshore end of the pier was relatively deep (9.5 m) compared to other piers. The pier is perpendicular to the shoreline and is 42 m long, 2.4 m wide, and 0.45 m above the water surface. There were few aquatic macrophytes at this site. Additional observations were also taken on June 26, 2003 at Mt. Baker Park and Stan Sayres Park when juvenile Chinook salmon appeared to be abundant. In 2004, the McClellan Street pier was again monitored weekly in May through July. In addition, several other piers (Table 14; Figure 48) were surveyed within a few days of the moon apogee when we expected juvenile Chinook salmon would be abundant (DeVries et al. 2004).

Table 14. —Dates surveyed and general habitat conditions of south Lake Washington piers used to observe migrating juvenile Chinook salmon in June 2004. Percent slope was measured from the toe of the shoreline armoring to the offshore end of the pier. Milfoil density is a description of the density of Eurasian milfoil; A = abundant; R = rare or absent.

<table>
<thead>
<tr>
<th>Shoreline</th>
<th>Site</th>
<th>Dates surveyed</th>
<th>Length (m)</th>
<th>Distance from shore (m)</th>
<th>Width (m)</th>
<th>Maximum depth (m)</th>
<th>Slope (%)</th>
<th>Milfoil density</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>West shore</strong></td>
<td>Beer Sheva boat ramp</td>
<td>June 17</td>
<td>12</td>
<td>12</td>
<td>1.9</td>
<td>1.9</td>
<td>15.7</td>
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<tr>
<td></td>
<td>Island Drive</td>
<td>June 17</td>
<td>20</td>
<td>20</td>
<td>1.5</td>
<td>3.5</td>
<td>15.7</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Seward Park</td>
<td>June 18</td>
<td>26</td>
<td>19</td>
<td>2.4</td>
<td>4.2</td>
<td>22.1</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Stan Sayres Park</td>
<td>June 17</td>
<td>32</td>
<td>32</td>
<td>2.5</td>
<td>2.6</td>
<td>7.7</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Mt. Baker Park</td>
<td>June 16, 17, 18</td>
<td>74</td>
<td>50</td>
<td>1.8</td>
<td>7.5</td>
<td>15.0</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Jefferson Street</td>
<td>June 15, 17</td>
<td>59</td>
<td>42</td>
<td>2.4</td>
<td>7.5</td>
<td>18.0</td>
<td>A</td>
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<tr>
<td></td>
<td>Madison Park</td>
<td>June 17, 18</td>
<td>25</td>
<td>25</td>
<td>3.7</td>
<td>3.0</td>
<td>10.4</td>
<td>R</td>
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<tr>
<td></td>
<td>Edgewater Apartments</td>
<td>June 17</td>
<td>9</td>
<td>9</td>
<td>9.0</td>
<td>2.1</td>
<td>11.7</td>
<td>A</td>
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<tr>
<td><strong>East Shoreline</strong></td>
<td>Chism Park</td>
<td>June 18</td>
<td>39</td>
<td>34</td>
<td>2.4</td>
<td>3.5</td>
<td>8.2</td>
<td>R</td>
</tr>
<tr>
<td><strong>Mercer Island</strong></td>
<td>Groveland Park - A</td>
<td>June 18</td>
<td>65</td>
<td>32</td>
<td>1.8</td>
<td>7.3</td>
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<td>A</td>
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<tr>
<td></td>
<td>Groveland Park - B</td>
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<td>28</td>
<td>19</td>
<td>2.8</td>
<td>3.0</td>
<td>12.9</td>
<td>A</td>
</tr>
</tbody>
</table>
FIGURE 48.—Location of south Lake Washington piers used to conduct visual observations of migrating Chinook salmon. The McClellan Street pier was surveyed weekly from May to July, 2003 and 2004. The other piers were only surveyed during the peak migration period in June.
Observations were conducted primarily in the morning when the water was calm and fish could be easily observed. On windy days, no observations could be conducted. Observations were made by standing on the pier and observing schools of Chinook salmon as they swam near the pier (Figure 49). The time each school was observed and the direction they are swimming was noted. The size of each school of Chinook salmon was categorized as either small (< 50 fish), medium (50-100 fish), large (100-200 fish) or very large (> 200 fish). How Chinook salmon responded to the pier was determined by estimating the depth of each school as the approached the pier and the depth they were at as they past under or around the pier.

Results

Surface observations at the McClellan Pier were conducted once a week from May 21 to July 3 in 2003 and May 19 to July 9 in 2004. During the first five surveys in 2003 (May 21 to June 18), few juvenile salmonids were observed and no obvious movements were seen. Similarly in 2004, few Chinook salmon were observed until June 16. On June 26, 2003 and June 16, 2004, large numbers of salmonids were observed moving along the shoreline. Based on fish size and date, we assumed they were juvenile Chinook salmon. Snorkel surveys conducted in 2004 also indicated they were Chinook salmon. To better understand fish movements, we conducted additional surface surveys during the period when Chinook salmon were abundant. The timing of the migration appeared to coincide with the moon apogee, which has been also suggested to be related to the passage of Chinook salmon smolts at the Ballard Locks (DeVries et al. 2004).

When Chinook salmon were abundant at McClellan Pier, we took extended observations to collect additional information on migrating Chinook salmon. In 2003, extended observations were conducted twice (June 26 and July 1) and in 2004 they were conducted three times (June 16 to 18). On all five dates, observations were conducted from at least 0730 h to 1100 h (Figure 50). Peak number of schools was observed between 0800 h and 0830 h and the lowest abundance was at the end of the survey between 1030 h and 1100 h. However, results of an ANOVA test indicated there was no significant difference in abundance for any half hour period between 0730 h and 1100 h. Additional observations were conducted if weather conditions and personnel schedules permitted. On one date, June 16, 2004, we were able to make observations from 0600 h to 1200 h (Figure 51). On this date, few schools of Chinook salmon were observed before 0730 h and after 1100 h. Observations on other dates showed the same general trend; little activity before 0700 h and a reduction in activity after 1100 h or 1200 h.
FIGURE 49.—Conducting visual observations of migrating Chinook salmon at the McClellan Street pier, Lake Washington.

FIGURE 50.—Percent of Chinook salmon schools occurring in half hour intervals between 0730 h and 1100 h, McClellan Pier, Lake Washington. Bars represent the mean percent of five dates, June 26, 2003, July 1, 2003 and June 16 to 18, 2003.
At McClellan Pier, Chinook salmon were observed moving along the shore in both a northerly and southerly direction. In 2003, we observed 64% of the schools moving in a northerly direction; whereas, in 2004 we observed 85% moving north. Combined (2003 and 2004), 47% of the schools were small (0 to 50 fish), 36% were medium-sized (50 to 100 fish), 16% were large (100-200 fish) and 1% were very large schools (>200 fish).

As Chinook salmon approached McClellan Pier they were typically in water that was 1.5 to 2 m deep (Figure 52) and 12 to 15 m from the shore. When they got to within 3 to 4 m of the pier, they swam to deeper water and usually swam under the pier where the water depth was about 2.1 to 4.5 m deep. On a few rare occasions, fish did not go under the pier but headed into deeper waters and appear to turn around and head in the opposite direction. After most fish swam under the pier, they usually swam back towards shore and returned to the same depth as they were before encountering the pier. On some occasions, Chinook salmon continued to move to deeper water after they past under the pier. We could not tell if they eventually returned to the shoreline.
Figure 52.—Photo of a group of juvenile Chinook salmon moving along the shore at McClellan Pier, Lake Washington, June 2003. Water depth at this location was about 1.7 to 2 m deep.

Besides McClellan Pier, we surveyed 11 other piers. They were all surveyed close to the moon apogee, the time period (2003 and 2004) when Chinook salmon were abundant at McClellan Pier. The location of juvenile Chinook salmon appeared to be related to the presence of Eurasian milfoil (*Myriophyllum spicatum*). If milfoil was present, Chinook salmon were in deeper water and further from shore; however, the depth of Chinook salmon above the milfoil appear to be similar as the total water column depth if the milfoil was absent (i.e., McClellan Pier). Therefore the top of the milfoil appeared to act as the bottom of the water column to Chinook salmon. Milfoil was absent or rare at four locations, McClellan Pier, Beer Sheva Park, Island Drive, and Madison Park, and the mean water column depth of Chinook salmon before encountering the pier was 2.1 m. In contrast, the mean water column depth of Chinook salmon at piers with milfoil was 4.0 m. At Edgewater Apartments and Stan Sayres Park, the top of the milfoil was close to the water surface along the entire length of the dock and few Chinook salmon were observed. At Groveland Park, Jefferson Street, and Seward Park, milfoil was close to the water surface along the length of the dock except at the offshore end of the pier and therefore Chinook salmon were only seen at the end of the dock and they did not appear to change their behavior in response to the pier. Movement of Chinook salmon to deeper water as they approached the pier was observed at Mt Baker and Madison Park piers. At the Island Drive pier, Chinook salmon were observed moving closer to shore as they approached the dock. This
was probably caused by other nearby docks, which may have caused Chinook salmon to be further from shore.

**Discussion**

When migrating Chinook salmon approach a pier they appear to move to slightly deeper water and either pass directly under the structure or swim around the pier. Most likely they move to deeper water as a way of reducing their predation risk. Both smallmouth bass (Fresh et al. 2001) and largemouth bass (Colle et al. 1989) can be found directly under piers. As Chinook salmon approach the pier, they probably have a difficult time seeing under the structure and bass may be better able to see approaching prey fish (Helfman 1981). In deeper water, Chinook salmon will probably have more space to avoid a bass predator. Also, Chinook salmon may move to a greater water column depth and will be further away from the pier and thus there may be more ambient light to help detect the presence of a predator.

Our results appear to support work by DeVries et al. (2004), who found that Chinook salmon smolt emigration past the Ballard Locks was related to the moon apogee. However, in 2003 we only detected movements on or shortly after the June 25 apogee. In contrast, DeVries et al. (2004) observed most Chinook salmon emigrated shortly after the May 28 apogee and little movement was observed after June 25. Taken together, these results suggest that there was a large movement of Chinook salmon following the May apogee and then a much smaller migration following the June apogee. Why we did not observe any Chinook salmon activity on or shortly after the May apogee is unclear. Water temperatures were cooler in May and Chinook salmon may have behaved differently and selected deeper water and were further offshore.

Although visual observations of migrating Chinook salmon can provide useful information, it does have several limitations. Observations can only be conducted when the water surface is calm; this usually means surveys can only be conducted in the morning hours. Only a small area near the shore can be effectively surveyed. Fish in deeper waters are hard to observe. There also may be large differences between observers. The observer may also have some influence on the behavior of Chinook salmon. To get a more complete picture of the behavior of migrating Chinook salmon other techniques are needed. Tracking fish with acoustic tags and obtaining accurate positions appears to be the most promising technique. Efforts in 2005 will focus on this technique.
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REFERENCES


workshop, Shoreline, Washington, November 8-9, 2000, King County, Seattle, Washington.


CITY OF MERCER ISLAND
RESOLUTION NO. 1347

A RESOLUTION RATIFYING THE WATER RESOURCE INVENTORY AREA (WRIA) 8 CHINOOK SALMON CONSERVATION PLAN

WHEREAS, in March 1999, the National Oceanic and Atmospheric Administration (NOAA) Fisheries listed the Puget Sound Chinook salmon evolutionary significant unit as a threatened species under the Endangered Species Act (ESA); and

WHEREAS, in November 1999, the United States Fish and Wildlife Service (USFWS) listed the Puget Sound bull trout distinct population segment as a threatened species under the ESA; and

WHEREAS, under the ESA, it is illegal to take a listed species, and the ESA defines the term “take” to include actions that could harm listed species or their habitat; and

WHEREAS, under the ESA, Section 4(f), NOAA Fisheries (for Chinook salmon) and USFWS (for bull trout) are required to develop and implement recovery plans to address the recovery of the species; and

WHEREAS, an essential ingredient for the development and implementation of an effective recovery program is coordination and cooperation among federal, state, and local agencies, tribes, businesses, researchers, non-governmental organizations, landowners, citizens, and other stakeholders as required; and

WHEREAS, Shared Strategy for Puget Sound, a regional non-profit organization, has assumed a lead role in the Puget Sound response to developing a recovery plan for submittal to NOAA Fisheries and the USFWS; and

WHEREAS, local jurisdictions have authority over some habitat-based aspects of Chinook survival through land use and other policies and programs; and the state and tribes, who are the legal co-managers of the fishery resource, are responsible for addressing harvest and hatchery management in WRIA 8; and

WHEREAS, in WRIA 8, habitat actions to significantly increase Chinook productivity trends will be helpful, in conjunction with other recovery efforts, to avoid extinction in the near term and restore WRIA 8 Chinook to viability in the long term; and

WHEREAS, Mercer Island supports cooperation at the WRIA level to set common priorities for actions among partners, efficient use of resources and investments, and distribution of responsibility for actions and expenditures;

WHEREAS, 27 local governments in WRIA 8 jointly funded development of The WRIA 8 Steering Committee Proposed Lake Washington/Cedar/Sammanish Watershed Chinook Resolution No. 1347
Salmon Conservation Plan (the Plan), published February 25, 2005 following public input and review; and

WHEREAS, while the Plan recognizes that salmon recovery is a long-term effort, it focuses on the next 10 years and includes a scientific framework, a start-list of priority actions and comprehensive action lists, an adaptive management approach, and a funding strategy; and

WHEREAS, Mercer Island has consistently implemented habitat restoration and protection projects, and addressed salmon habitat through its land use and public outreach policies and programs over the past five years; and

WHEREAS, it is important to provide jurisdictions, the private sector and the public with certainty and predictability regarding the course of salmon recovery actions that the region will be taking in the Lake Washington/Cedar/Sammamish Watershed, including the Puget Sound nearshore; and

WHEREAS, if insufficient action is taken at the local and regional level, it is possible that the federal government could list Puget Sound Chinook salmon as an endangered species, thereby decreasing local flexibility.

NOW, THEREFORE, BE IT RESOLVED BY THE MERCER ISLAND CITY COUNCIL AS FOLLOWS:

Section A: The Mercer Island City Council hereby ratifies The WRIA 8 Steering Committee Proposed Lake Washington/Cedar/Sammamish Watershed Chinook Salmon Conservation Plan, dated February 25, 2005, a copy of which is on file with the Mercer Island City Clerk (the Plan). Ratification is intended to convey the city’s approval of the Plan.

Section B: Mercer Island recognizes that negotiation of commitments and assurances/conditions with appropriate federal and state agencies will be an iterative process. Full implementation of this Plan is dependent on the following:

1. NOAA Fisheries will adopt the Plan, as an operative element of its ESA Section 4(f) recovery plan for Puget Sound Chinook salmon.

2. NOAA Fisheries and USFWS will:
   a) take no direct enforcement actions against Mercer Island under the ESA for implementation of actions recommended in or consistent with the Plan,
   b) endorse the Plan and its actions, and defend Mercer Island against legal challenges by third parties, and
   c) reduce the regulatory burden for Mercer Island activities recommended in or consistent with the Plan that require an ESA Section 7 consultation.
3. Federal and state governments will:
   a) provide funding and other monetary incentives to support Plan actions and monitoring activities,
   b) streamline permitting for projects implemented primarily to restore salmonid habitat or where the actions are mitigation that further Plan implementation,
   c) offer programmatic permitting for local jurisdiction actions that are consistent with the Plan,
   d) accept the science that is the foundation of the Plan and support the monitoring and evaluation framework,
   e) incorporate actions and guidance from the Plan in future federal and state transportation and infrastructure planning and improvement projects, and
   f) direct mitigation resources toward Plan priorities.

Section C: This resolution does not obligate the Mercer Island City Council to future appropriations beyond current authority set forth in its 2005-2006 biennial budget. All future appropriations are subject to review and approval by the then seated City Council.


[Signature]
Bryan Cairns, Deputy Mayor

ATTEST:

[Signature]
Allison Spietz, City Clerk
**Proposed Timeline for Planning Commission Completion of SMP**

- May 19, 2010 – Post hearing discussion and review of public comment and science provided by Dr. Pauley. The Planning Commission to direct any revisions to staff.
- June 2* - Review of code recommendations by Robert Thorpe, AICP, if available. The Planning Commission to recommend any revisions to staff.
- June 16, 2010 Anticipated final review of any revisions made, with recommendation to the City Council.
- July 7, 2010 – No items anticipated at this time.

*Although staff had previously anticipated Title 19 code housekeeping items being provided to the Planning Commission on June 2nd, it appears that this will be brought forward at a later date, to be determined.
Per Dr. Pauley, “these papers support that small mouth bass and large mouth bass utilize home ranges, utilize structures (not just docks), they are opportunistic feeders on salmon when three specific conditions are met, and that they have minor impact on the salmon populations of these urban lakes. There are other references to support these things also.”
THE MOVEMENT AND HOMING OF SMALLMOUTH BASS, Micropterus dolomieu, IN LAKE SAMMAMISH, WASHINGTON

DAVID E. PFLUC 1 AND GILBERT B. PAULEY
Washington Cooperative Fishery Research Unit
College of Ocean and Fishery Science
University of Washington
Seattle, Washington 98195

Smallmouth bass were tagged and released at new locations between 0.8 to 11.3 km away from the initial capture location on the lake. The recaptured bass showed a homing tendency with 41% returning to the site of capture, 38% were apparently on their way back to the point of capture, and only 21% showed a sedentary response by staying in the new release area. Smallmouth tagged and released at the site of capture showed a definite affinity for a home area, with 81% recaptured in the area of capture and release. Of the 19% that moved out of this area, 4.8 km was the farthest distance any fish moved.

The home range tendency of smallmouth bass has potential management implications when considering expanding a smallmouth fishery within a large lake, when stocking a lake for the first time with smallmouth bass, or when evaluating bass tournament release procedures.

INTRODUCTION

Lake Sammamish, a large mesotrophic lake (2000-ha) in western Washington, presently supports a significant population of smallmouth bass, Micropterus dolomieu, in addition to other game fish.

Largemouth bass, Micropterus salmoides, was the only documented black bass species inhabiting Lake Sammamish between the early 1900's and 1960. The unsanctioned introduction of smallmouth bass into Lake Sammamish occurred sometime in the mid-1960's. By 1973 they began showing up in angler catches and now appear to be the dominant bass species in both numbers and lake area occupied (Pflug 1981).

Smallmouth bass have been studied throughout much of North America (Watson 1965, Forney 1972, Coble 1975, Woodbury 1975, Schneberger 1977). Henderson and Foster (1956) investigated age, growth, movements, and spawning requirements of smallmouth bass in the Columbia River near Richland, Washington. Additional studies of smallmouth bass spawning and movements in the mid-Columbia River area have been performed (Montgomery and Fickeisen 1978; Montgomery, Fickeisen and Becker 1980), while Munther (1970) studied the movement and distribution of smallmouth in the middle Snake River. These studies were conducted on the Columbia River system, located in the eastern portion of Washington state. This study is the first research devoted exclusively to natural lake-dwelling smallmouth in Washington state.

Many of Washington's lowland lakes are inhabited by largemouth bass, but only a few, such as Lake Sammamish, support smallmouth bass. However, a large number of Washington's lowland lakes are mesotrophic and ideally suited

1 Part of a thesis submitted by the senior author to the University of Washington in partial fulfillment of the master of science degree. Accepted for publication June 1982.
2 Mr. Pflug's present address is: R. W. Beck and Associates; Tower Building; Seventh and Olive Way; Seattle, Washington 98101.
to support smallmouth bass. The potential exists for the successful introduction of smallmouth bass into a number of carefully selected Washington lakes that exhibit the proper smallmouth habitat requirements. When transplanting any fish it can be a valuable management tool to know the potential movement tendencies of the fish involved. Therefore, this study was designed to investigate the movement and homing tendencies of smallmouth bass within Lake Sammamish.

MATERIALS AND METHODS

Lake Sammamish was subdivided into 23 littoral sections of various sizes. Sectional boundaries were established where visual changes occurred in the littoral habitat type such as depth profile transition, presence or absence of aquatic vegetation, and littoral substrate changes.

Electrofishing and hook and line sampling were the two methods used to collect smallmouth bass in Lake Sammamish. These sampling techniques are the most effective methods for securing large numbers of live smallmouth bass (Bennett 1970). Smallmouth bass were found in abundance throughout the littoral areas of the lake at night. As a result, electrofishing was conducted nocturnally to increase effectiveness. Hook and line sampling typically occurred diurnally throughout the spring and summer months and usually involved artificial lures. The use of these two sampling methods reduced sampling biases such as size selectivity. Collections were made between March and September of 1979 and 1980.

This study utilized an alternating current electrofishing boat designed and constructed specifically for water exhibiting low conductivity, an inherent characteristic of Lake Sammamish (Birch 1976). The system has an effective sampling range to a depth of 3.7 m, dependent upon water clarity and conductivity. Boat design originated from an unpublished Washington State Department of Game manuscript prepared by Bill Zook, Regional Fish Biologist, Ephrata Regional Office.

Sport fishing for bass on Lake Sammamish generally begins in April and extends through August, with peak effort occurring in May and June. Samples were secured by Coop Unit biologists or from organized bass tournaments conducted during the sampling seasons. The capture and release location was noted for each smallmouth and Floy Anchor Tags (Model FD-86) were attached to each fish greater than 20 cm in total length (TL). A total of 478 smallmouth bass was tagged and released during the 2-yr period, 187 in 1979, and 291 in 1980.

Smallmouth bass homing behavior was determined from 240 bass captured within one lake section and transported and released at another randomly selected lake section. Homing responses were categorized: (i) Specific Homing Response—relocated smallmouth bass that returned to the initial capture section from the randomly chosen release site; (ii) Sedentary Response—relocated smallmouth bass recaptured within the release section; and (iii) Mobile Response—relocated smallmouth bass that had moved outside the release section when capture took place. The smallmouth bass used in the homing phase of the study were relocated 0.8 to 11.3 km away from the point of initial capture.

Smallmouth bass movement behavior within a home range was determined from 238 bass captured, tagged, and released within the same lake section. The recapture data derived from these bass were used to determine the degree of
SMALLMOUTH BASS MOVEMENT AND HOMING

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territoriality elicited by smallmouth bass. Movement responses fell under two categories: (i) Sedentary Response—smallmouth bass that maintained a residence within the initial capture-release section; and (ii) Mobile Response—smallmouth bass that were recaptured outside of the initial capture-release section.

Homing behavior and home range movement patterns as defined by Gerking (1959) were monitored for smallmouth bass from March to September during 1979 and 1980 in Lake Sammamish. All recaptures were obtained by electrofishing and hook and line sampling. Any tagged bass recaptured within 5-d of release were not included in the analysis. These bass were defined as having inadequate time to elicit an accurate homing or movement response.

RESULTS

Of the 478 smallmouth bass tagged during the study (187 in 1979 and 291 in 1980), 69 were recovered, 19 between April and August of 1979 and 50 between May and August of 1980. However, nine of these recoveries were not used in the movement and homing portion of the study due to incomplete or inaccurate recovery data or because the recapture was made within 5-d of the release date. Two smallmouth bass were recaptured three times, while three were recaptured twice.

Thirty-three of the total smallmouth recoveries originated from the 240 that had been transported out of the initial capture section before release occurred. The other 27 recoveries were from 238 smallmouth bass that had been tagged and then released into the same lake section.

Of the 33 recovered smallmouth bass that had been released between 0.8 to 11.3 km away from the initial capture section, 41% returned back to their initial capture section before the recovery took place (Figure 1). These smallmouth displayed a direct homing response by returning specifically to their initial residence areas and by traveling as far as 9.7 km to return to the initial capture area. Many of these fish returned to the exact location, such as a dock, or other notable landmark, from which they had originally been captured.

Another 38% of the total recaptures responded by moving out of the offsite release section and into a new section of the lake, other than the initial capture section, when the recovery took place (Figure 1). Some of these smallmouth were possibly returning to the initial capture section when recovery occurred, because they were most often collected at sites located between the area of original capture and subsequent release. The remaining 21% of these relocated smallmouth were recaptured within the new section where they were released, indicating a sedentary response (Figure 1). All sedentary bass were recaptured within 6 to 10-d after the release date. Long-distance homing responses of smallmouth bass were observed to occur both across the lake in an east-west direction (Figure 2) and along the lake’s length in a north-south direction (Figure 3). The smallmouth bass in Lake Sammamish returned to their home areas after release at random locations outside their original capture sites (Figure 2) and after release from a central weigh-in area following organized bass tournaments (Figure 3).
Twenty-seven smallmouth bass were recaptures of fish originally captured, tagged, and released within the same lake section. Six of these were recaptured during 1979 and the other 21 during 1980. Of these recaptured bass, 81% were recovered from the section of the lake where they were released, indicating a territorial response (Figure 4). The remaining 19% of the recaptures were recovered outside the capture and release section. The distances these bass moved ranged from 0.8 to 4.8 km from the original section of capture and release.

![Bar chart showing homing responses](chart)

**FIGURE 1.** The homing responses from 33 recaptured smallmouth bass transplanted out of the initial capture section before release occurred.
FIGURE 2. The direct homing response of a tagged smallmouth bass initially captured in Section 10W, released in Section 3E approximately 4.8 km away, and recaptured in Section 10W.
FIGURE 3. The direct homing response of a tagged smallmouth bass initially captured in Section 8E and released in Section 1, 11.3 km away, and recaptured in Section 8E.
FIGURE 4. The responses of 27 recaptured smallmouth bass released after tagging within the same lake section as their initial capture.

DISCUSSION

Smallmouth bass recapture locations determined by electrofishing provided accurate information on the movement and homing of individual bass. Angler recapture data were also used to determine the movement and homing patterns of smallmouth bass, but only when the angler could identify the recapture site accurately. Angler accuracy was typically contingent upon familiarity with the lake or previous exposure to the recapture procedures of the study. The majority of the anglers were able to supply accurate accounts of recaptured smallmouth bass. Nineteen of the 187 smallmouth bass tagged and released within Lake Sammamish during the spring and summer of 1979 were recaptured before November of the same year. During the following spring and summer only one of the smallmouth tagged in 1979 appeared in the 1980 recaptures. Van Woert (1980) noted a high percentage of smallmouth bass tags were returned by anglers within a 3-yr period following tagging. Pelzman, Rapp, and Rawstron
have indicated a conscientious effort by anglers to return tags, noting that smaller fish with tags were retained that otherwise would have been released. In this study, Lake Sammamish anglers seemed very conscientious about getting information to us about tagged fish.

Lake Sammamish smallmouth that were captured, tagged, and released within the same lake section apparently remain within a distinct residence area, since 81% were recaptured inside the lake section of initial capture and release. The remaining 19% moved relatively short distances outside the initial capture section, usually less than 1.6 km. Fraser (1955) and Forney (1961) encountered similar findings in Lake Huron, Michigan, and Lake Oneida, New York respectively. In Lake Huron, 72% of the lake-dwelling smallmouth bass that were tagged and released back to the same area were recaptured within 3.2 km of the point of release (Fraser 1955), while in Lake Oneida, 80% of the bass tagged and released within the same area were recaptured by anglers within 2.4 km of the tagging site (Forney 1961). At Folsom Lake, California, Rawstron (1967) reported that seven recaptured smallmouth bass out of 23 originally tagged fish had moved an average of only 1.1 km from the point of tagging.

Smallmouth bass inhabiting rivers also appear to occupy distinct home areas (Paragamian and Coble 1975). Reynolds (1965) found tagged smallmouth bass in rivers moved very little from the site where they were tagged with maximum movement only 3.2 km away. Movement within streams by smallmouth bass is normally restricted to a limited section of water, usually one distinct pool, and any movement can be directly correlated with the physical stability of the stream substrate (Fajen 1962). Henderson and Foster (1956) noted that marked smallmouth bass returned to areas from which they were first captured, but felt a random wandering back into a preferred type of habitat was occurring rather than a definite homing instinct. Of all fish free at least 7-d, 99 (76%) of the recovered smallmouth were found in the same location in which they were tagged and released, while 22 of 31 fish recovered outside the pool in which they were marked had moved less than 1.6 km according to Munther (1970). Smallmouth in the Columbia River entered sloughs to spawn in Mid-March and remained there until August at which time they returned to the closest deep water habitat available, which can be a considerable distance from the spawning area (Montgomery and Fickeisen 1978, Montgomery et al. 1980).

Smallmouth bass in Lake Sammamish demonstrated the ability to return specifically to their original residence areas after displacement. Smallmouth bass captured within one lake section and released from 0.8 to 11.3 km away, showed a tendency to return to the original site. In fact, some of these recaptures were made precisely at specific landmarks where the initial capture had been made. This demonstrates the ability of the smallmouth bass to home back to the original residence area and perhaps recognize a precise niche (Gerking 1959). Another 38% of the displaced smallmouth bass had moved out of the release section and into new areas of the lake and were recaptured from areas that were in a position that logically appeared to be enroute to their original capture site. Therefore, it is suggested that many, if not all, of these smallmouth were moving back toward their original residence area when recapture occurred.

From our data and that of others (Fraser 1955, Forney 1961, Reynolds 1965, Munther 1970) it is apparent that smallmouth bass show a strong tendency to establish a home base or territory. Omand (1951) found that a drastic reduction
of the population in one area of a lake is not followed by migration into that area by smallmouth from outside the area. This tendency has strong management implications when either of two situations for expanding the fishery is considered. First, the expansion of existing fish stocks within a lake into other sections where they do not exist may be a difficult task to accomplish, even in a large lake or reservoir because of the tendency of smallmouth to return to their original site of residence. Second, if small numbers of adult smallmouth are transplanted from one body of water to another for the purpose of establishing a new fishery, it may take an extremely long time for the fishery to develop if the fish are planted only at one location. This of course assumes that the adult fish would establish residence at the location where they are first introduced into the lake and not move around much prior to establishing a home residence area. The assumption also is made that juvenile smallmouth bass resulting from adult introductions will imprint and establish a home area very quickly and therefore will not disperse throughout the environment.

Therefore, due to the strong tendency of smallmouth bass to establish a home area we recommend that expansion of an existing population be accomplished with smallmouth bass from a separate body of water. Also, because of the possibility that stocked smallmouth bass and their offspring could quickly establish a home area residence at the location of introduction, waters not containing any existing smallmouth bass should be considered for stocking at several different locations to obtain maximum dispersal of the fish.

The movement of smallmouth bass within their home lake may have important implications for managing bass tournaments. If approximately 80% of all smallmouth bass brought to a central weigh-in location and subsequently released at that site could be expected to move rapidly back to their original capture location (home area), then possibly it would not be important to require tournament officials to transport smallmouth bass to some central lake location for release. Blake (1981) indicates that smallmouth bass displaced by tournament anglers tend to move and disperse more from a central release point than smallmouth bass released at their capture location after trapnetting. It is possible that the angler caught and displaced fish in Blake's (1981) study were moving back toward their original home area, such as those tournament caught fish did that were released at a central weigh-in area on Lake Sammamish.

It appears that tournament caught smallmouth bass will disperse from a central weigh-in area. However, in addition to the number of smallmouth leaving a tournament weigh-in location, the amount of time it takes for this to occur should also be considered by fishery managers when evaluating whether or not to move fish from the weigh-in area to a central dispersal location.

ACKNOWLEDGEMENTS

This work was supported under a Cooperative agreement between the U.S. Fish and Wildlife Service, the Washington State Department of Game, and the University of Washington.

LITERATURE CITED


Biology of Smallmouth Bass (Micropterus dolomieu) in Lake Sammamish, Washington

Abstract

Smallmouth bass (Micropterus dolomieu) grew very rapidly in Lake Sammamish, with mean averages of 10.1 cm (1-year), 18.5 cm (2-year), 26.0 cm (3-year), 31.4 cm (4-year), 35.7 cm (5-year), 38.3 cm (6-year) and 41.4 cm (7-year). Most of the fish were 2- and 3-year-old bass, representing 39 and 24 percent of the total population respectively. Incremental growth was greatest between the ages of 1 and 3 and progressively decreased between the ages of 4 and 7. The growth rate exceeds that observed in most other North American waters. While crayfish (Paispastaus teniusculus) and sculpins (Cottus sp.) made up a major part of the diet in most months, migratory salmon (Oncorhynchus sp.) were the most important prey item in the month of May, at the peak of the salmonid outmigration. Evidence is presented to support the theory that smallmouth bass do not selectively feed on salmon but are random feeders, eating whatever prey item is available. A regression line plot of prey length versus smallmouth bass size showed a positive correlation between prey size and predator size. The preferred habitat of the smallmouth bass was characterized by a hard substrate combined with a dropoff from an overbank and the absence of aquatic vegetation.

Introduction

Because of the growing interest in smallmouth bass (Micropterus dolomieu) by anglers in the state of Washington, a study was undertaken to learn more about the life history of this fish in a natural lake in Washington. Research concerning this important game fish in the Northwest has been confined to the Columbia and Snake Rivers and their associated tributaries (Henderson and Foster 1956, Keating 1970, Munther 1970, Montgomery et al. 1980).

Lake Sammamish has a thriving stock of smallmouth bass, as evidenced by the growing number of anglers each year on the lake, which is situated in an urban setting 16 km east of Seattle. Significant game fish populations of other species exist in the lake; these include resident trout (Salmo sp.) and anadromous salmon (Oncorhynchus sp.), most of which originate in the Issaquah Creek Salmon Hatchery at the South end of the lake. The lake is used as a transportation route for the massive outmigration of smolts from the hatchery each spring and the subsequent return of adult salmon to the hatchery.
each fall (Pflug 1981). Since one of the major concerns in transplanting smallmouth bass into new waters is their potential impact on any resident trout or anadromous salmon populations, Lake Sammamish offers a unique setting for the study of smallmouth bass biology. The objectives of this study were to provide data on the following life history parameters: age and growth; spawning and nesting areas; habitat preference; food and feeding; and impact on existing salmon and trout populations in the lake. This paper describes these various aspects of the life history of smallmouth bass in Lake Sammamish, Washington.

Materials and Methods

For this study, Lake Sammamish was subdivided into 23 littoral sections of various sizes (Fig. 1). Sectional boundaries were established where visual changes occurred in the littoral habitat type, such as a depth profile transition, presence or absence of aquatic vegetation, and littoral substrate changes.

Shoreline habitat assessments, based on identifiable physical elements, were conducted on each section of the lake. Three distinct elements were used to make these sectional assessments: (1) littoral substrate type, (2) littoral depth profile, and (3) aquatic vegetation type and density. Four distinct substrates were identified: (1) silt, (2) sand, (3) gravel (6 to 40-mm diameter), and (4) cobble (40 to 250-mm diameter). Four littoral depth profile types were: (1) shallow flats—small depth change with increasing distance from shoreline; (2) gradual slope—moderate depth change with increasing distance from shoreline; (2) drop-off from overbank—moderate slope yielding to a steep drop-off; and (4) drop-off—steep drop starting directly from the shoreline. Aquatic vegetation densities were classified visually as dense, moderate, spotty, or absent (Goodpasture 1979).

Electrofishing and angling were the two methods used for collection of smallmouth bass in Lake Sammamish since these sampling techniques have been shown to be the most effective for securing large numbers of live bass (Bennett 1970). Electroshocking was conducted nocturnally and angling occurred diurnally between March and September of both 1979 and 1980. Additional samples of smallmouth bass were obtained from organized bass tournaments that were conducted during both sampling seasons.

During the 1979 and 1980 sampling seasons the following information and samples were obtained from each of 734 smallmouth bass: (1) total length in centimeters, (2) weight in grams, (3) a scale sample taken near the base of the pectoral fin, and (4) the stomach contents extracted for identification. Corollary information taken from 695 fish (Table 3) included sections of capture and release, maturity, date, and method of capture.

Scales were soaked and cleaned in a water solution and non-regenerative scales were selected and mounted on strips of clear cellulose acetate with a heated vertical hydraulic press (Campbell and Witt 1953). The plastic slide impressions of the scales were viewed with a microfiche reader at 48X magnification. Age determinations were made by interpreting and counting the growth zones (annuli) that appeared on each non-regenerative scale. To determine the length of smallmouth bass at younger ages, the scale radius was measured between the mid-point of the focus and the outer margin, along the primary radii. A back calculation technique was used (June 1979), measuring the distance from the focus to each annulus on the scale to estimate the corresponding
Figure 1. Map of Lake Sammamish (King County, Washington) showing the 23 lake sections used during the study with the location and distribution of the three different shoreline habitat types. (See Table 1 for an explanation of the three habitats.)
body length for that scale measurement. The body-scale relationship in smallmouth bass was linear.

The food and feeding preferences of smallmouth bass were determined through a numerical analysis in which the number of each prey type in each stomach was counted (Windell 1971). These were summed to yield a total for each food type in the entire sample, and a grand total for all items. The totals gave the representative percentage, by number, of each prey type consumed. This method also furnished data that were used to determine the seasonal variation in food types and associated feeding rates. Prey lengths (cm) were used to evaluate food size specificity for smallmouth bass age groups. As an alternative to killing smallmouth bass, a pulsed gastric lavage technique described by Foster (1977) was modified to remove all stomach contents (Pflug 1981).

Spawning surveys were conducted along the lake shoreline periodically between April and July in 1979 and 1980. Bass nest sites were counted by lake section and water depth, substrate type, and cover type were recorded for each nest. Smallmouth bass nests were distinguished visually by identifying the adult species in attendance.

Results
Age and Growth
The majority of the smallmouth bass population was composed of 2- and 3-year-old fish, representing 39 and 24 percent of the total sample, respectively (Fig. 2). Smaller percentages of the population were composed of 1-year-olds (14 percent), 4-year-olds (12 percent) and 5-year-olds (6 percent), while 6- and 7-year-olds combined represented 5 percent.

Total length ranged from 7 cm to 48 cm. The 2-year-olds, 18 to 23 cm long, clearly represented the major year class in 1979, which predictably became a major year class in 1980 as 3-year-old fish. A small year class was represented by the 3-year-old fish in 1979 and 4-year-old fish in 1980. The prominent 4-year-olds of 1979 still composed the largest group older than 3 in 1980.

The back-calculation procedures conducted on all year classes to determine lengths at various ages showed that mean total lengths increased rapidly from the 10.1-cm average for 1-year-olds to average 18.5, 26.0, 31.4, 35.7, 38.3, and 41.4-cm for each successive year class (Fig. 3). The annual growth curve for Lake Sammamish smallmouth bass in 1979-1980 combined reveals the exceptionally good growth of these fish compared to smallmouth bass in other waters of North America (Fig. 3). The length-weight relationship mode $W = aL^b$, with $b = 3.0$, demonstrates that young smallmouth bass gain additional weight but length progression is depressed (Fig. 4).

Food and Feeding Habits
Sculpins (Cottus sp.) were the major prey item for age one bass, although juvenile salmon and crayfish (Pacifastacus leniusculus) were eaten also (Table 1). Surprisingly, no aquatic insects were observed in the stomachs of yearling bass. Smallmouth bass between ages 2 and 3 fed most on sculpins, while 4- and 5-year-olds most frequently ate crayfish and juvenile salmon. Aquatic insects were most abundant in age 2 fish. Incidental prey items included zooplankton, smallmouth bass fry, sqawfish (Ptychocheilus oregonensis), peamouth (Mylocheilus caurinus), and brook lamprey (Lampetra richard-
Figure 2. Age group for smallmouth bass captured during the 1979 and 1980 sampling periods.

soni). Partly digested unidentifiable fish made up a large percentage of the prey items in all age groups of smallmouth bass.

Monthly changes in the diet of smallmouth bass for April-July showed a marked
Figure 3. A comparison of growth rates from seven different populations of smallmouth bass in North America.

### TABLE 1. Total prey items taken from the stomachs of each smallmouth bass age group during March-August, 1979-80.

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<td>30</td>
<td>286</td>
<td>192</td>
<td>72</td>
<td>58</td>
</tr>
<tr>
<td>Percent empty stomachs</td>
<td>33%</td>
<td>61%</td>
<td>61%</td>
<td>64%</td>
<td>50%</td>
</tr>
</tbody>
</table>

Biology of Smallmouth Bass 123
TABLE 2. Total number of prey items counted in smallmouth bass stomachs for each month, April-July, 1979-80.

<table>
<thead>
<tr>
<th>Prey Items</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonid</td>
<td>7</td>
<td>76</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>Sculpin</td>
<td>2</td>
<td>30</td>
<td>24</td>
<td>93</td>
</tr>
<tr>
<td>Crayfish</td>
<td>16</td>
<td>36</td>
<td>27</td>
<td>47</td>
</tr>
<tr>
<td>Aquatic insects</td>
<td>14</td>
<td>26</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>Unidentified fish</td>
<td>7</td>
<td>52</td>
<td>54</td>
<td>26</td>
</tr>
<tr>
<td>Total prey items</td>
<td>44</td>
<td>229</td>
<td>168</td>
<td>176</td>
</tr>
<tr>
<td>Total number stomachs examined</td>
<td>93</td>
<td>217</td>
<td>205</td>
<td>170</td>
</tr>
<tr>
<td>Percent empty stomachs</td>
<td>37%</td>
<td>55%</td>
<td>57%</td>
<td>72%</td>
</tr>
</tbody>
</table>

Importance of salmon in May (Table 2). This prominence was a result of the outmigration of young salmon from the Issaquah hatchery at the south end of the lake. Crayfish and sculpins made up the majority of food items observed in July. There was a dramatic increase in feeding that occurred between April and May and continued at a high level through July (Table 2).

Prey size preference was determined by measuring the total length of the recovered prey items to the nearest centimeter. Smallmouth bass selected prey items in relation to their size, with a preference toward progressively larger prey items of all types (Fig. 5). A positive, linear relationship existed between the prey size consumed and the size of the smallmouth bass, which was best described by the linear regression function:

\[ Y = 2.596 + 0.793X \]

where,  
Y = size of the prey item  
X = age group of the smallmouth bass  
The correlation coefficient of 0.374 was significant (P < 0.05).

Habitat Preference

Three clearly definable shoreline habitat types exist in Lake Sammamish (Fig. 1 and Table 3). Type I habitat made up approximately 65 percent of the shoreline, which was characterized by a hard substrate, combined with a drop-off from an overbank, and the absence of aquatic vegetation. Approximately 25 percent of the littoral area available in the lake was classed as Type II habitat, characterized by sand or gravel substrate, light to dense growths of aquatic vegetation, with a gradual or moderate depth profile that terminated with steep drop-offs. Type III habitat, which made up approximately 10 percent of the littoral area, possessed moderate to dense aquatic vegetation in shallow water over silt and sand substrate, and was located exclusively at the northern and southern ends of the lake.

Smallmouth bass display a definite predilection for shoreline areas devoid of vegetation and composed of gravel and cobble that had a gradual slope with a drop-off (Table 3). The 12 areas classed as Type I produced 599 of our smallmouth bass; the 7 Type II areas yielded 85 smallmouth bass; and the 4 Type III areas produced only 11 smallmouth bass (Table 3).

Typical smallmouth bass spawning areas also were categorized as Type I habitat (Table 3). The preferred spawning substrate consisted of gravel and cobble devoid of
aquatic vegetation. However, nest sites were typically associated with a benthic structure such as an isolated boulder, log, or dockpiling. Nest depths ranged from 1 to 4 meters, but most were in 1.5 to 2.5 meters of water. Counts of nest sites showed that spawning began in early May, peaked late May, and ended in mid-June. May and June surface water temperatures ranged between 13°C and 17°C. The major spawning areas of smallmouth bass were along the eastern shore of the lake from Section 3E northward to Section 9E (Fig. 1), where 125 nest sites were counted during spawning in 1979 and 1980. The western shore from Section 9W northward to Section 14W was a less important spawning area and contained 45 smallmouth bass nests during the two-year study period. Type I habitat accounted for 85 percent of the nests observed (Table 3).

Discussion

Growth rates of smallmouth bass in Lake Sammamish were exceptionally rapid when compared with growth rates reported for this species in other regions of North America (Fig. 3). Faster growth has been observed only by Stroud (1948). The rapid growth
### TABLE 3. Habitat and spawning areas of smallmouth bass in Lake Sammamish during 1973 and 1980.

<table>
<thead>
<tr>
<th>Section</th>
<th>Number of fish sampled</th>
<th>Number of nests counted</th>
<th>Substrate type</th>
<th>Depth profile type²</th>
<th>Aquatic vegetation density</th>
<th>Habitat type²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>7</td>
<td>sand:gravel</td>
<td>2</td>
<td>moderate</td>
<td>II</td>
</tr>
<tr>
<td>2E</td>
<td>2</td>
<td>0</td>
<td>gravel:coyble</td>
<td>2</td>
<td>moderate</td>
<td>III</td>
</tr>
<tr>
<td>3E</td>
<td>65</td>
<td>14</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>4E</td>
<td>80</td>
<td>7</td>
<td>gravel</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>5E</td>
<td>47</td>
<td>18</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>6E</td>
<td>90</td>
<td>13</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>7E</td>
<td>138</td>
<td>24</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>8E</td>
<td>60</td>
<td>25</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>9E</td>
<td>88</td>
<td>21</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>10E</td>
<td>0</td>
<td>0</td>
<td>silt</td>
<td>1</td>
<td>dense</td>
<td>III</td>
</tr>
<tr>
<td>2W</td>
<td>20</td>
<td>0</td>
<td>sand</td>
<td>3</td>
<td>light</td>
<td>II</td>
</tr>
<tr>
<td>3W</td>
<td>9</td>
<td>0</td>
<td>silt</td>
<td>3</td>
<td>dense</td>
<td>III</td>
</tr>
<tr>
<td>4W</td>
<td>3</td>
<td>4</td>
<td>sand:gravel</td>
<td>1</td>
<td>moderate</td>
<td>II</td>
</tr>
<tr>
<td>5W</td>
<td>0</td>
<td>0</td>
<td>silt</td>
<td>3</td>
<td>dense</td>
<td>III</td>
</tr>
<tr>
<td>6W</td>
<td>8</td>
<td>3</td>
<td>gravel</td>
<td>3</td>
<td>light</td>
<td>I</td>
</tr>
<tr>
<td>7W</td>
<td>7</td>
<td>0</td>
<td>sand:gravel</td>
<td>2</td>
<td>moderate</td>
<td>II</td>
</tr>
<tr>
<td>8W</td>
<td>12</td>
<td>4</td>
<td>gravel</td>
<td>3</td>
<td>moderate</td>
<td>II</td>
</tr>
<tr>
<td>9W</td>
<td>18</td>
<td>7</td>
<td>gravel:coyble</td>
<td>2</td>
<td>light</td>
<td>II</td>
</tr>
<tr>
<td>10W</td>
<td>2</td>
<td>8</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>11W</td>
<td>1</td>
<td>9</td>
<td>gravel:coyble</td>
<td>3</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>12W</td>
<td>16</td>
<td>5</td>
<td>gravel:coyble</td>
<td>4</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>13W</td>
<td>4</td>
<td>7</td>
<td>gravel:coyble</td>
<td>4</td>
<td>absent</td>
<td>I</td>
</tr>
<tr>
<td>14W</td>
<td>5</td>
<td>9</td>
<td>sand:gravel</td>
<td>2</td>
<td>moderate</td>
<td>II</td>
</tr>
</tbody>
</table>

¹Depth Profile Types: (1) Shallow flats
(2) Gradual slope
(3) Drop-off from overbank
(4) Drop-off from shoreline

²Habitat Types: (I) Hard substrate, drop-off, lack aquatic vegetation.
(II) Sand or gravel, gradual depth profile leading to a drop-off, varying aquatic vegetation.
(III) Silt or sand, shallow depth, dense aquatic vegetation.

In Lake Sammamish is probably attributable to an excellent food supply, abundant suitable habitat, favorable water temperatures, and a presumed lack of competitive and predatory fish species (Pflug 1981). The two most important influences on growth are probably temperature and abundant food (Coble 1975). Lake Sammamish appears to have both at optimal levels.

Studies conducted on the Columbia River have shown that within this geographical area smallmouth bass sometimes attain an age of 12 years (Henderson and Foster 1956). The oldest smallmouth bass captured in Lake Sammamish had just begun its eighth growing season. The exact introduction date of smallmouth bass into the lake is unknown, but smallmouth bass did not begin to appear in angler catches until the early 1970s (Pflug 1981). Johnson and Hale (1977) observed that smallmouth bass do not reach maximum abundance until 9-15 years after introduction into new lakes. Therefore, Lake Sammamish may be 2-5 years away from its maximum potential as a producer of smallmouth bass.

Littoral water temperatures in Lake Sammamish ranged from 13°C to 25°C during the smallmouth growing season (Pflug 1981), indicating that growth occurs over a broad range of temperatures, as observed by other investigators (Coble 1967, Wrenn 1980). Although total annual growth and water temperature are probably related, it
appears that factors other than temperature are important in influencing growth in smallmouth bass, especially in older fish (Coble 1967).

In Lake Sammamish, the major prey of smallmouth bass were juvenile salmon, crayfish, and sculpins, with young smallmouth bass feeding primarily on smaller versions of the same prey types that the adults fed on, rather than different food types. Prey size and smallmouth bass size were positively correlated in Lake Sammamish. In other waters, the diet of smallmouth bass changes from small to large items, but often involves a distinct shift of food type as the fish grow larger. Often there is a progression from zooplankton to insects to small fish, finally culminating in crayfish and larger fish (Coble 1975). Guillory (1979) claimed that this shift in type of prey is due to the size of the prey selection rather than any other factors. However, this does not appear to be the case with smallmouth bass in Lake Sammamish, which showed a size preference in the prey selected at all ages with a distinct prey type preference noted only during the month of May, when migratory juvenile salmon were abundant.

Salmon are not abundant in April and July, because release from the Issaquah hatchery has not taken place yet in April, while in July outmigration from Lake Sammamish is completed. As would be expected, the number of salmon in the stomachs of smallmouth bass was lowest in April and July, and highest in May and June.

Resident trout did not appear in any of the smallmouth bass stomachs (Pflug 1981). Bass in other waters do not appear to selectively feed on trout or salmon (Lachner 1950, Stoeck and McCrimmon 1965, Warner et al. 1968). However, it has been shown that an influx of young salmon or trout into a body of water will yield a higher than normal predation rate by smallmouth bass (Warner 1972), largemouth bass (Micropterus salmoides) (Stoeck and McCrimmon 1965, Warner 1972), spotted bass (Micropterus punctulatus) (Axon 1971), and striped bass (Morone saxatilis) (Deppert 1979). Similarly, the influx of a large number of vulnerable salmon smolts into a system like Lake Sammamish should aid in accelerating predation by smallmouth bass and may be a major reason for the excellent growth of Lake Sammamish smallmouth bass.

Smallmouth bass in Lake Sammamish are apparently feeding "generalists" that follow the "numbers maximizer" feeding strategy, which assumes that the predator eats prey items as they are encountered, so that the most numerous prey in the environment should be the most numerous in the stomach (Griffiths 1975). This theory assumes that prey size and abundance are the only factors of importance to predators.

Smallmouth bass were observed spawning during the months of May and June in both 1979 and 1980, when water temperatures ranged from 13°C to 18°C in Lake Sammamish (Pflug 1981). Similar spawning temperatures were reported by Stone et al. (1954) from Lake Ontario. Although an occasional smallmouth bass was taken from heavily vegetated Type III habitat, smallmouth spawning nests were never observed in that type of habitat. Lake Sammamish bass utilized gravel and cobble shoreline areas devoid of aquatic vegetation for nest building sites, which usually were situated next to some isolated object such as a rock, piling, or log. This is the same situation that Voge (1980) observed with smallmouth bass in Bull Shoals Reservoir. Smallmouth bass spawning nests generally appear to be made in water less that 2 m deep (Watson 1965, Schneberger 1977), but deeper nests have been noted (Forney 1972, Voge 1980), which are considere atypical for this species and attributed to heavy wave action occurring during spawning combined with extreme water clarity. Lake Sammamish small-
mouth bass probably spawn at 2 to 4 m depths because of the extremely clear water and severe wave action created by heavy boat traffic on the lake during May and June.

Smallmouth bass in Lake Sammamish exhibited unmistakable habitat preferences for gravel and cobble substrate with access to drop-offs. Habitat of this type appears to be preferred by smallmouth bass in many areas of the United States (Munther 1970, Schneberger 1977, George and Hadley 1979, Hubert and Lackey 1980). This preference for rocky habitat is possibly thought to be due to the preference smallmouth bass have for crayfish in some areas (Munther 1970, Johnson and Hale 1977). We did not detect a distinct preference for crayfish by smallmouth bass in Lake Sammamish. Juvenile salmon frequented the littoral area of the entire lake (Pflug 1981), and sculpins were found on all substrate types without preference for gravel or rock (Richard 1980). Since salmons, sculpins, and crayfish make up most of the diet of smallmouth bass, it appears that food items are not the major reason for the distinct smallmouth bass preference of gravel and rock in Lake Sammamish. Watson (1965) noted a strong need by smallmouth bass for gravel to spawn, and this may be the determining factor for habitat preference in Lake Sammamish since an abundant food supply exists in the rocky areas also. Smallmouth bass show an extremely strong home area tendency in Lake Sammamish (Pflug and Pauley 1983), and this may be related to the availability of adequate spawning habitat combined with an abundant and accessible food supply.

Literature Cited
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Influence of Waterway Development on Migrational Characteristics of Juvenile Salmonids in the Lower Willamette River, Oregon

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Abstract.—We investigated the effects of Portland Harbor development in the lower Willamette River on the migration and behavior of juvenile salmonids (Oncorhynchus spp.), the habitat occupied by juvenile salmonids, and predation on juvenile salmonids by northern squawfish (Ptychocheilus oregonensis). Juvenile salmonids were abundant in the lower Willamette River during spring; radio-tagged juvenile steelhead O. mykiss and yearling chinook salmon O. tshawytscha usually migrated through the harbor in 1–3 d. We did not detect any spatial pattern in the downstream migration of radio-tagged fish or any difference in behavior of radio-tagged fish among the developments. Habitat used by juvenile salmonids at an undeveloped site was unavailable at developed sites, especially at a site with a vertical-wall shoreline. We caught more northern squawfish in areas without development, and we found no difference in the frequency of northern squawfish digestive tracts containing juvenile salmonids between developed and undeveloped areas. We concluded that waterway developments presented few risks to migrating juvenile salmonids. However, whenever possible, activities such as dredging and construction should be avoided in spring when juvenile salmonid abundance is high. The location of developments need not be weighted heavily when considering their effects on juvenile salmonids. Further research is needed to determine the effects on juvenile salmonids of altering bottom slopes, water depths, and water current velocities at developments. Predation by northern squawfish in Portland Harbor is not enhanced by development.

The lower Willamette River, near Portland, Oregon, is a migration corridor for large numbers of juvenile and adult anadromous salmonids (Oncorhynchus spp.). In 1989, hatcheries released 5.1 million spring-run chinook salmon O. tshawytscha, 5.1 million fall-run chinook salmon, 1.1 million coho salmon O. kisutch, 700,000 summer-run steelhead O. mykiss, and 400,000 winter-run steelhead into the Willamette River system. Adult returns of spring chinook salmon past Willamette Falls, 43 km from the Columbia River, numbered 69,200 in 1989. Spring chinook salmon from the Willamette River make an important contribution to recreational and commercial fisheries. Willamette River adult spring chinook salmon contributed 10,900 fish to the 1989 lower Columbia River commercial catch and 29,100 fish to the sport catch in the Columbia and Willamette rivers (Oregon Department of Fish and Wildlife, unpublished data).

The lower Willamette River also serves as a harbor to a busy commercial shipping industry. Development of Portland Harbor has resulted in substantial alterations to the morphology of the lower 19 km of the Willamette River. The river has been deepened and widened by dredging, and numerous structures have been built to receive and service large commercial vessels. Some areas of natural shoreline have been replaced by riprap or by bulkheads (vertical walls).

The effects of shoreline development, dredging, and harbor traffic have long been a concern of fishery managers (Allen and Hardy 1980; Linfield 1985; McCarthy 1985; Nielsen et al. 1986; Gardner 1988). Several studies have examined the effects on resident fish or rearing salmonids (Burrell et al. 1982; Levings 1985; Morton 1989), but little is known about the effects of harbor developments on migrating fish populations. The effects of development on resident fish or rearing anadromous fish may be at least partially assessed by differences in species composition, abundance, or biomass associated with developments (Pennington et al. 1983; Farabee 1986; Sandheinrich and Atchison 1986; Knudsen and Dilley 1987), by changes in food supply associated with developments (Levings 1985), or by changes in distribution associated with harbor traffic (Holland 1986). However, the effects of harbor development on migrating juvenile salmonids may be much more subtle and difficult to detect.

Littoral areas are important habitats for small migrating juvenile salmonids, such as subyearling (fall) chinook salmon (Lister and Genoe 1970;
Changes to littoral areas resulting from dredging may create habitat unsuitable by some juvenile salmonids (Levings 1985). Furthermore, replacement of natural shoreline with bulkheads may reduce the variety of habitats, eliminate some habitats preferred by juvenile salmonids, and disrupt salmonid migration (Lister and Genoe 1970; Bustard and Narver 1975; MacDonald et al. 1987). Such development divides the remaining shoreline into isolated, less valuable sections of habitat that are vulnerable to further degradation (Nielsen et al. 1986). Although shelter created by pilings and ripraps may deflect current and create habitat for migrating salmonids, it may also create habitat for predators of juvenile salmonids (Haines and Butler 1969).

We investigated the effect of harbor development in the lower Willamette River on the migration and behavior of juvenile salmonids, the type of habitat available to juvenile salmonids, and predation on juvenile salmonids by northern squawfish Ptychocheilus oregonensis. Our sample was designed to (1) determine the periods, rates, and routes of juvenile salmonid migration; (2) detect changes in the behavior of migrating juvenile salmonids associated with developments; (3) evaluate habitat available to juvenile salmonids at developments; and (4) compare abundance of northern squawfish in undeveloped and various developed areas. We used our findings to describe the potential effects of harbor developments on juvenile salmonids and categorized developments based upon associated risks to juvenile salmonids.

Study Area

Portland Harbor includes the Willamette River from river kilometer (rmk) 0 to rmk 19 (river kilometers are measured from the river’s mouth). Most of the development within Portland Harbor lies between rmk 5 and rmk 17. The study area included the harbor and extended upstream to rmk 27 (Figure 1). The physical characteristics of the shoreline and nearshore habitat downstream of rmk 27 have been altered to varying degrees by the different types of development present in and along the river (Table 1). In the harbor the river, which is approximately 300–600 m wide, has mostly a clay, silt, or sand bottom that is steeply sloped because of dredging. From 1987 to 1989 river flow averaged between 673 and 809 m³/s, with a high of over 4,730 m³/s in January 1988 and a low of 192 m³/s in August 1988 (U.S. Geological Survey, unpublished data). Water velocity is relatively low and is similar throughout the harbor, except where affected by structures. At the surface, water velocity ranged from 0.05 to 0.17 m/s and averaged 0.10 m/s during a flow of 1,775 m³/s in April 1989. In June 1989 water velocity at the surface ranged from 0.04 to 0.08 m/s and averaged 0.06 m/s during a flow of 281 m³/s.

Methods

From 1987 through 1990 we collected juvenile salmonids in nine areas of the lower Willamette River (Figure 1). We randomly selected five areas that contained development (structures) and four areas that contained no development. Developed areas were stratified by the type of structure present so that each area contained a different structure (Table 1). All major types of development present in the lower Willamette River were included.

We used a purse seine and vertical gill nets to collect juvenile salmonids during periods of expected migration (March–June and November). We also sampled in January, February, and July 1987. Gear specifications were described by Farr and Ward (1993). In 1987 and 1988 we purse seine nearshore and offshore in each area during daylight. The nearshore areas were less than 6 m
Table 1.—Physical habitat characteristics (percent) for each sampling area in the lower Willamette River (from Ward and Nigro 1992). Types of structures present at developed areas were: an offshore wharf supported by pilings at rkm 1.9, a wharf supported by landfill at rkm 8.0, a floating platform at rkm 8.2, piers supported by pilings at rkm 12.2, and a wharf supported by pilings at rkm 15.9.

<table>
<thead>
<tr>
<th>Habitat characteristic, category</th>
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<th>Developed</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>0.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Substrate</td>
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<td></td>
</tr>
<tr>
<td>Smooth</td>
<td>94</td>
<td>77</td>
</tr>
<tr>
<td>Gravel</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>Rubble</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Boulder</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bottom slope</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>Cover</td>
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<tr>
<td>Instream</td>
<td>0</td>
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</tr>
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<td>Overhead</td>
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<td>0</td>
</tr>
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</tr>
<tr>
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<tr>
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<td>58</td>
</tr>
<tr>
<td>Wall</td>
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<td>0</td>
</tr>
</tbody>
</table>

Deep, allowing the entire water column to be sampled. Effort consisted of 206 purse-seine hauls in 1987 and 290 purse-seine hauls in 1988. In 1989 and 1990 we fished vertical gill nets at night through the water column at various randomly selected distances from shore (and, therefore, at various depths). Effort consisted of 309 1-h sets in 1989 and 244 1-h sets in 1990. We measured habitat variables (distance from shore, water depth, depth of capture, and water velocity) associated with the catch (or no catch) of juvenile salmonids in the vertical gill nets.

We used radio telemetry to monitor the downstream migration of yearling chinook salmon and juvenile steelhead in the lower Willamette River. In 1988 we radio-tagged and released 13 yearling chinook salmon during March and April, and 6 yearling chinook salmon during November. In 1989 we tagged and released 14 yearling chinook salmon and 4 juvenile steelhead from March through May and 5 yearling chinook salmon in November. In 1990 we tagged and released 19 yearling chinook salmon during March and 11 juvenile steelhead during May. Each radio tag weighed approximately 2.3 g in air, was equipped with an antenna that measured 15 cm in length, transmitted at an individual frequency, and had a 10-d minimum life. Radio tags were inserted into the stomachs of fish that measured at least 175 mm fork length (FL) and weighed at least 40 g. We held radio-tagged fish 24–48 h prior to release to ensure they recovered from anesthetic and handling. In March and April 1988 we released radio-tagged fish at rkm 32 to ensure that their behavior in the harbor would not be affected by stress from handling and release. However, to reduce the number of fish that were lost due to tag failure or nondetection prior to entering the harbor we then moved the release site to rkm 22. We usually released 2–7 fish at a time; however, in 1990 we released all 11 juvenile steelhead at once. We tracked radio-tagged fish from a boat and recorded the location of each fish every 1–3 h when possible. To find a radio-tagged fish we first searched its last known location, then searched a short distance upstream, and finally searched downstream.

From 1988 through 1990 we used bottom gill nets and electrofishing to collect northern squawfish in the designated sampling areas of the lower Willamette River. Sampling methods and gear specifications were described by Ward and Nigro (1992). Nets were set for 1 h, whereas electrofishing consisted of 15-min power-on shocking runs. All sampling was conducted after sunset, and the monthly effort was similar from March through June. The sampling effort was usually greater at developed areas than at undeveloped areas. We examined the digestive tracts of all northern squawfish at least 200 mm FL. for juvenile salmonids and, when possible, noted the presence of absence of juvenile salmonid parts. The contents of digestive tracts containing unidentifiable fish or
Figure 2.—Species composition of juvenile salmonid catch by month in spring 1987–1990. Fish were collected in purse seine in 1987 and 1988, and in vertical gill nets in 1989 and 1990. No sampling was conducted in April 1988, March 1990, or June 1990.

Fish parts were examined microscopically, and a key to fish bones (Hansel et al. 1988) was used to identify ingested juvenile salmonids.

Catches in vertical gill nets and purse seines were summarized to determine the migration periods and routes of juvenile salmonids. The catch in vertical gill nets and associated habitat characteristics were used to compare the availability and use of habitat between sampling areas.

Radio telemetry data were used to determine migration rates and migration routes of juvenile salmonids, and to evaluate changes in behavior between sampling areas. Mean migration rate (rkm/24 h) was used to estimate the length of stay in the harbor of radio-tagged yearling chinook salmon and juvenile steelhead. We plotted the locations of radio-tagged fish on a grid system overlaid on a map of the lower Willamette River, with each grid side representing approximately 180 m. We designated grid squares as nearshore if any part of the square contacted the shore; otherwise, we designated them as offshore. We used a test of significance of binomial proportions (Snedecor and Cochran 1967) to determine if the proportion of nearshore locations for each species differed significantly (P ≤ 0.05) from the proportion of nearshore surface area.

We summarized catches in bottom gill nets and used analysis variance to compare mean catch per unit effort (CPUE) of northern squawfish 200 mm FL and larger between the sampling areas. We chose the 200 mm FL because juvenile salmonids may be consumed by northern squawfish as small as 175 mm FL and because juvenile salmonids...
Table 2.—Migration rates of radio-tagged yearling chinook salmon and juvenile steelhead through Portland Harbor (km 0–19). Only fish that left the immediate vicinity of the release site and were monitored for at least 12 h are included.

<table>
<thead>
<tr>
<th>Species, year (season)</th>
<th>Number of fish</th>
<th>Migration rate (rkm/24 h)</th>
<th>Range of river flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988 (spring)</td>
<td>8</td>
<td>12.5</td>
<td>11.0</td>
</tr>
<tr>
<td>1988 (autumn)</td>
<td>4</td>
<td>2.4</td>
<td>0.0</td>
</tr>
<tr>
<td>1989 (spring)</td>
<td>9</td>
<td>11.3</td>
<td>8.7</td>
</tr>
<tr>
<td>1989 (autumn)</td>
<td>3</td>
<td>11.7</td>
<td>11.3</td>
</tr>
<tr>
<td>1990 (spring)</td>
<td>13</td>
<td>9.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Steelhead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989 (spring)</td>
<td>4</td>
<td>12.7</td>
<td>17.9</td>
</tr>
<tr>
<td>1990 (spring)</td>
<td>8</td>
<td>13.6</td>
<td>11.9</td>
</tr>
</tbody>
</table>

may compose 15–20% of the diet of 250-mm-FL northern squawfish (Poe et al. 1991). Catch was transformed to log₁₀(catch + 1) before analysis. We used chi-square analysis to determine if the frequency of northern squawfish digestive tracts containing juvenile salmonids was independent of sampling area. We pooled data from both gears and all 3 years to obtain sample sizes necessary for analysis. Prior to pooling data we used chi-square analyses to ensure that there were no differences (P > 0.05) between gears or between years.

Results

Migration Periods

The timing and abundance of juvenile salmonids migrating through Portland Harbor varied between species and races (Figure 2). Abundance of yearling chinook salmon usually peaked in mid to late March, soon after releases from upstream hatcheries. We collected a few subyearling chinook salmon in late March, but abundance usually peaked in mid-May and declined through June. Juvenile coho salmon and steelhead were collected from late April through early June. Only yearling chinook salmon were collected in November, soon after releases from upstream hatcheries. In January and February 1987 we collected less than 50 subyearling chinook salmon, and we collected no juvenile salmonids in July 1987.

Migration Rate

Juvenile steelhead generally migrated through the harbor within 1–2 d. Yearling chinook salmon generally migrated through the harbor within 2–3 d (Table 2), but a few took as long as 8 d. Migration rate was not significantly correlated with river flow in any of the three years (1988 yearling chinook salmon: r² = 0.16, P = 0.22; 1989 yearling chinook salmon: r² = 0.03, P = 0.48; 1989 juvenile steelhead: r² < 0.01, P = 0.99; 1990 yearling chinook salmon: r² = 0.11, P = 0.12; 1990 juvenile steelhead: r² = 0.25, P = 0.10).

Migration Route

We did not detect any spatial pattern in the downstream migration of radio-tagged yearling chinook salmon or juvenile steelhead. Although juvenile steelhead were located offshore more often than yearling chinook salmon, we found no significant difference between the proportion of nearshore locations of radio-tagged fish and the proportion of surface area categorized as nearshore (Table 3). We located yearling chinook salmon and juvenile steelhead in more than 40% of available

Table 3.—Number of times radio-tagged yearling chinook salmon and juvenile steelhead were located in Portland Harbor and percent of locations that were in grid squares designated as nearshore. The last column gives the probability (P) of a difference between percentage of nearshore locations and percentage of surface area in the harbor categorized as nearshore (46%).

<table>
<thead>
<tr>
<th>Species, year</th>
<th>Number of fish</th>
<th>Number of locations</th>
<th>% locations nearshore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All fish</td>
<td>Range</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>1988</td>
<td>7</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>1989</td>
<td>12</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>1990</td>
<td>14</td>
<td>193</td>
</tr>
<tr>
<td>Steelhead</td>
<td>1989</td>
<td>4</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>1990</td>
<td>10</td>
<td>73</td>
</tr>
</tbody>
</table>
potential grid squares. We found five or more yearling chinook salmon in only 10 grid squares, of which 3 were nearshore and 7 offshore (Figure 3). We found three or more juvenile steelhead in only 8 grid squares, of which 2 were nearshore and 4 offshore (Figure 4). Fish of both species were often found within 50 m of shore, suggesting that radio-tagged fish encountered harbor developments.

Catches in purse seines and vertical gill nets also suggested that juvenile salmonids encountered harbor developments. In 1987, of the 1,977 juvenile salmonids collected by purse seining, 1,429 were collected nearshore. Only juvenile steelhead were found more frequently offshore than nearshore (70 of 95), even though in deeper offshore water fish could escape by swimming under the seine. In 1989 and 1990 the mean distance from shore for fish caught in vertical gill nets was approximately 31 m for subyearling chinook salmon, 22 m for yearling chinook salmon, and 25 m for juvenile steelhead.

Behavior of Juvenile Salmonids

Radio-tagged fish generally maintained downstream movement throughout the harbor. However, in 1989 three radio-tagged yearling chinook salmon stopped for at least 24 h at separate nearshore locations: rkm 5.8, rkm 12.2, and rkm 17.4. Fish located at rkm 5.8 and rkm 12.2 were near or within structures (including our sampling area at rkm 12.2), but no structure was present at rkm 17.4. Also in 1989, one radio-tagged juvenile steelhead stopped for more than 24 h at rkm 16.6, an area with no structure.

Habitat Availability

Catches in vertical gill nets indicated that habitat occupied by migrating juvenile salmonids in the undeveloped area at rkm 27.0 differed from that available at developed sites within Portland Harbor. Yearling chinook salmon and juvenile steelhead generally occupied similar habitat at each site (Table 4). At rkm 27.0, both yearling chinook
Table 4.—Mean depth of capture, distance from shore, and water velocity, by sampling area, for juvenile steelhead, and yearling and subyearling chinook salmon captured in vertical gill nets (1-h sets) in the lower Willamette River during 1989 and 1990.

<table>
<thead>
<tr>
<th>Sampling area, species</th>
<th>Number of fish</th>
<th>Depth of capture (m)</th>
<th>Distance from shore (m)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure present</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rkm 1.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>1</td>
<td>1.5</td>
<td>23</td>
<td>0.08</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>2</td>
<td>1.5</td>
<td>21</td>
<td>0.02</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>13</td>
<td>3.7</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>rkm 8.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>1</td>
<td>1.5</td>
<td>12</td>
<td>0.05</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>13</td>
<td>4.9</td>
<td>13</td>
<td>0.02</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>25</td>
<td>3.7</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>rkm 8.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>4</td>
<td>2.0</td>
<td>28</td>
<td>0.04</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>11</td>
<td>3.7</td>
<td>12</td>
<td>0.06</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>8</td>
<td>4.0</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>rkm 12.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>0</td>
<td>3.8</td>
<td>36</td>
<td>0.02</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>22</td>
<td>3.7</td>
<td>34</td>
<td>0.02</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>9</td>
<td>3.4</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>rkm 15.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>2</td>
<td>3.0</td>
<td>2</td>
<td>0.04</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>70</td>
<td>2.7</td>
<td>28</td>
<td>0.01</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>39</td>
<td>4.0</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td><strong>Structure absent</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rkm 0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>3</td>
<td>1.5</td>
<td>30</td>
<td>0.04</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>14</td>
<td>1.5</td>
<td>17</td>
<td>0.09</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>20</td>
<td>3.0</td>
<td>41</td>
<td>0.10</td>
</tr>
<tr>
<td>rkm 10.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>4</td>
<td>3.0</td>
<td>35</td>
<td>0.09</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>4</td>
<td>1.5</td>
<td>35</td>
<td>0.11</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>17</td>
<td>4.0</td>
<td>42</td>
<td>0.09</td>
</tr>
<tr>
<td>rkm 15.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>5</td>
<td>2.7</td>
<td>31</td>
<td>0.10</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>26</td>
<td>2.1</td>
<td>16</td>
<td>0.10</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>36</td>
<td>3.4</td>
<td>33</td>
<td>0.09</td>
</tr>
<tr>
<td>rkm 27.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juvenile steelhead</td>
<td>5</td>
<td>2.1</td>
<td>17</td>
<td>0.05</td>
</tr>
<tr>
<td>Yearling chinook salmon</td>
<td>50</td>
<td>1.5</td>
<td>15</td>
<td>0.13</td>
</tr>
<tr>
<td>Subyearling chinook salmon</td>
<td>40</td>
<td>2.4</td>
<td>30</td>
<td>0.09</td>
</tr>
</tbody>
</table>

salmon and juvenile steelhead were typically found in shallower water, closer to shore, and in areas with higher velocity than at developed areas. We also found subyearling chinook salmon in shallower water at rkm 27.0 than at developed sites. We caught most juvenile salmonids within 6 m of the surface.

Sampling at two developed areas (rm 8.0 and rkm 15.9) revealed juvenile salmonids occupying habitat with some characteristics similar to habitat at rkm 27.0. We caught yearling chinook salmon close to shore (mean = 13 m) at rkm 8.0. The site at rkm 8.0 was characterized by having water up to 14 m deep immediately off a long (about 300 m) vertical-wall shoreline. We caught subyearling chinook salmon in shallow water and close to shore at rkm 15.9. This area contained a wharf that was supported by closely spaced (<3 m apart) pilings and a completely riprapped shoreline. A relatively large backwater with a soft bottom was present at the downstream end of the wharf.

Habitat used by juvenile salmonids at the undeveloped site at rkm 27.0 did not appear to be available at most sites within Portland Harbor. Undeveloped sites within the harbor were deeper and had greater bottom slopes than rkm 27.0 because of dredging. Some developed sites had water depth and bottom slope similar to that at rkm
Table 5.—Number of gill net sets and mean catches of northern squawfish per 1-h set (mean CPUE) at each sampling area in the lower Willamette River, 1988–1990.

<table>
<thead>
<tr>
<th>Sampling area</th>
<th>1988</th>
<th>1989</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sets</td>
<td>CPUE</td>
<td>Sets</td>
</tr>
<tr>
<td>krm 1.9</td>
<td>50</td>
<td>0.7</td>
<td>48</td>
</tr>
<tr>
<td>krm 8.0</td>
<td>50</td>
<td>0.5</td>
<td>47</td>
</tr>
<tr>
<td>krm 8.2</td>
<td>50</td>
<td>0.2</td>
<td>48</td>
</tr>
<tr>
<td>krm 12.2</td>
<td>47</td>
<td>0.6</td>
<td>48</td>
</tr>
<tr>
<td>krm 15.9</td>
<td>47</td>
<td>0.2</td>
<td>54</td>
</tr>
<tr>
<td>krm 0.3</td>
<td>21</td>
<td>1.4</td>
<td>24</td>
</tr>
<tr>
<td>krm 10.9</td>
<td>21</td>
<td>1.2</td>
<td>24</td>
</tr>
<tr>
<td>krm 15.8</td>
<td>21</td>
<td>0.9</td>
<td>24</td>
</tr>
<tr>
<td>krm 27.0</td>
<td>45</td>
<td>1.0</td>
<td>48</td>
</tr>
</tbody>
</table>

27.0, but this habitat was found in associated backwater areas with little or no water velocity. Habitat was much different at krm 27.0 than at the developed site at krm 8.0 where the shoreline consisted of a vertical wall. No shallow water habitat was available at the krm 8.0 location. Although we did not find any evidence to indicate that harbor developments attract juvenile salmonids or slow their migration, developments such as that at krm 8.0 may have affected migration because of the loss of natural habitat.

Predator Distribution and Prey Consumption

We collected 625 northern squawfish (≥ 200 mm FL), including 541 (200–499 mm) in gill nets and 84 (200–503 mm) by electrofishing. Mean CPUE in gill nets varied among years (Table 5) and was significantly higher in 1988 than in other years (P < 0.01). Mean CPUE also varied among sampling areas and was higher (P < 0.01) at undeveloped areas than developed areas each year. Mean CPUE was highest each year at the undeveloped area at krm 0.3. For each year, mean CPUE at the undeveloped area at krm 27.0 was as high or higher than mean CPUE at every developed area that year. Mean CPUE at two other undeveloped areas (krm 10.9 and krm 15.8) were higher than CPUEs at nearby developed areas (krm 12.2 and krm 15.9).

We found no difference (P > 0.05) in mean CPUE between developed areas.

We examined the digestive tracts of 505 northern squawfish (≥ 200 mm FL) and found that 62 (12.3%) contained one or more juvenile salmonids or juvenile salmonid parts (Table 6). Northern squawfish containing juvenile salmonids ranged from 200 to 492 mm FL. The frequency of northern squawfish digestive tracts containing one or more juvenile salmonids varied between areas; however, we found no difference (P = 0.26) between developed and undeveloped areas. We also found no difference between developed areas (P = 0.07) or between undeveloped areas (P = 0.15).

Discussion

Although we concluded that juvenile salmonids encountered waterway developments during their downstream migration to the ocean, we identified few risks to juvenile salmonids associated with development in the harbor (Table 7). We did not detect any appreciable changes in the behavior of radio-tagged yearling chinook salmon or juvenile

Table 6.—Occurrence of juvenile salmonids in digestive tracts of northern squawfish collected at each sampling area in the lower Willamette River, 1988–1990 combined.

<table>
<thead>
<tr>
<th>Sampling area</th>
<th>Number of digestive tracts examined</th>
<th>Number (%) with food</th>
<th>Number (%) with juvenile salmonids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structure present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>krm 1.9</td>
<td>57</td>
<td>24 (42.1)</td>
<td>6 (10.5)</td>
</tr>
<tr>
<td>krm 8.0</td>
<td>45</td>
<td>30 (66.7)</td>
<td>6 (13.3)</td>
</tr>
<tr>
<td>krm 8.2</td>
<td>32</td>
<td>14 (43.8)</td>
<td>7 (21.9)</td>
</tr>
<tr>
<td>krm 12.2</td>
<td>53</td>
<td>22 (41.5)</td>
<td>4 (7.6)</td>
</tr>
<tr>
<td>krm 15.9</td>
<td>24</td>
<td>17 (70.8)</td>
<td>7 (29.2)</td>
</tr>
<tr>
<td></td>
<td>Structure absent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>krm 0.3</td>
<td>108</td>
<td>40 (37.0)</td>
<td>8 (7.4)</td>
</tr>
<tr>
<td>krm 10.9</td>
<td>61</td>
<td>34 (55.7)</td>
<td>11 (18.0)</td>
</tr>
<tr>
<td>krm 15.8</td>
<td>52</td>
<td>18 (34.6)</td>
<td>4 (7.7)</td>
</tr>
<tr>
<td>krm 27.0</td>
<td>73</td>
<td>29 (39.7)</td>
<td>9 (12.3)</td>
</tr>
</tbody>
</table>
TABLE 7.—Summary of risk of harbor developments to juvenile salmonids.

<table>
<thead>
<tr>
<th>Type of development</th>
<th>Effect on juvenile salmonids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change in behavior</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Offshore wharf</td>
<td>No</td>
</tr>
<tr>
<td>Wharf</td>
<td>No</td>
</tr>
<tr>
<td>Floating platform</td>
<td>No</td>
</tr>
<tr>
<td>Pier</td>
<td>No</td>
</tr>
<tr>
<td>Wharf</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delay in migration or attraction to structure as determined by radio telemetry of yearling chinook salmon and juvenile steelhead.</td>
</tr>
<tr>
<td></td>
<td>Nearshore, shallow water habitat.</td>
</tr>
<tr>
<td></td>
<td>Compared to undeveloped areas in the lower Willamette River.</td>
</tr>
</tbody>
</table>

Steelhead when they encountered harbor developments. Although most developments altered habitat in some way, we detected losses of habitat commonly used by juvenile salmonids at only one developed area in the harbor. At km 8.0, where landfill supported a wharf, a vertical-wall shoreline eliminated nearshore, shallow water habitat. Assuming that dredging and construction activities could have negative effects on the migration of juvenile salmonids, if possible, these activities should not occur from March through June or in November when juvenile salmonids are abundant in the lower Willamette River. Knudsen and Dilley (1987) reported short-term detrimental effects of construction, but concluded that these effects may be less serious in large streams than in small streams. If activities such as dredging and construction are necessary from March through June or in November, they should be conducted during periods when juvenile salmonid densities in the harbor are lowest. Because yearling chinook salmon and steelhead migrate through the harbor in less than 3 d, densities will vary directly with numbers entering the harbor. Research is needed to define periods during migrations when numbers entering the harbor, and thus densities, are lowest.

When the effects of developments in Portland Harbor on juvenile salmonids are being considered, location need not be weighted heavily. We demonstrated no clear migration route used by juvenile salmonids, nor did we detect differences in behavior between juvenile salmonids that encountered developments and those that did not. Enhancement of northern squawfish predation on juvenile salmonids is not associated with development. We observed fewer northern squawfish at developed than at undeveloped sites.

Further research is needed to clarify several aspects of harbor effects on juvenile salmonids. This research should include evaluating the effects on juvenile salmonids of altering bottom slopes, water depths, and water current velocities at developments. We detected differences in bottom slopes, water depths, and water current velocities among developed and undeveloped sites where we collected juvenile salmonids. Levings (1983) noted that deep-water habitat, produced by dredging near developments, may not be usable by juvenile salmonids. Although we found no correlation between the migration rate of radio-tagged fish and river flow, our analyses did not include possible confounding factors such as tides, turbidity, and harbor traffic. We learned little about the migration rate of subyearling chinook salmon through Portland Harbor because they were too small to radio-tag. In addition, our knowledge of predation in the lower Willamette River is limited to northern squawfish. Although northern squawfish are the dominant predator in the lower Willamette River (Ward and Nigro 1992), other predators such as largemouth bass Micropterus salmoides, black crappie Pomoxis nigromaculatus, and white crappie P. annularis are also present (Farr and Ward 1993). Predation by walleye Stizostedion vitreum may also be a factor as the species' range continues to expand in the lower Columbia River basin. Finally, the effect of construction on migration of adult salmonids was not addressed.

Although our evaluation was limited to the lower Willamette River, our methods may be applicable wherever harbor development and fish populations coexist. Specific effects of development may differ, depending on the type of water body and fish species present; however, understanding physical and biological changes caused by developments will allow improvements in fish management and habitat protection and increase the predictability of the effects of future development.
Such increased predictability should minimize conflicts between agencies over the design of future developments.

Acknowledgments

This work was partially funded by the Port of Portland. We thank Rollie Montagne, Ken Weber, and Mary Brugo of the Port of Portland for their cooperation. We also thank Doug DeHart, Ray Temple, Patty Snow, Barry McPherson, and Jay Beamesderfer of the Oregon Department of Fish and Wildlife and Howard Horton of Oregon State University for reviewing this paper.

References


Outmigration of Juvenile Chinook Salmon in the Lower Willamette River, Oregon

Abstract

We used direct sampling and radio telemetry to describe the outmigration of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the lower Willamette River downstream of Willamette Falls from 2000 to 2003. Juvenile Chinook salmon were present all year, with peak densities occurring in winter and spring. Small, naturally-produced (and therefore ESA-listed) fish were present in December and January, a period when in-water work (e.g. dredging) is authorized. Small fish were likely spring-run stocks that outmigrated as subyearlings. Juvenile Chinook salmon were significantly larger at downstream sampling sites, suggesting growth occurs, or larger fish entering from the Columbia River use this area as rearing habitat. Radio-tagged fish (>100 mm fork length) migrated at a median rate of 11.3 km/d, and hatchery fish migrated significantly faster than naturally-produced fish (12.4 vs. 8.4 km/d). Fork length and river flow were significant predictors of migration rate. Radio-tagged fish were distributed evenly across the river channel regardless of year, time of day, or origin (hatchery or naturally produced). Except for a possible affinity for pilings, the distribution of radio-tagged fish appeared to closely follow the proportional availability of nearshore habitat types, suggesting they do not select for specific habitats during their outmigration. We recommend that additional work focus on subyearling fish, which may have more specific habitat requirements and are more vulnerable to predation and other limiting factors. Considering the large number of subyearling juvenile Chinook salmon present during winter, restricting in-water work to July–October may help protect and recover these stocks.

Introduction

The lower Willamette River near Portland, Oregon, is unique in providing a major fishery for Pacific salmon (*Oncorhynchus* spp.) near a large metropolitan area. In 2004, anglers harvested approximately 30,000 salmon from the Willamette River and its tributaries. An additional 13,500 Willamette stock spring Chinook salmon *O. tshawytscha* were harvested in lower Columbia River commercial and sport fisheries (Oregon Department of Fish and Wildlife, unpublished data). Salmonids produced in the Willamette basin are also caught by fishers in the Pacific Ocean, provide ceremonial and consumptive fisheries to Northwest Indian tribes, and contribute to the identity of the region.

The Willamette River below Willamette Falls (Figure 1) has been heavily modified, especially near Portland. The channel has been dredged to accommodate commercial shipping, and docks, piers, bulkheads (seawalls), and rock revetment (riprap) have replaced much of the natural bank habitat. Pollution from industrial sources, especially in the river sediments, is a serious concern. A section of this reach, from river kilometer (rk) 5.6 to 15.3, was added to the U.S. Environmental Protection Agency (USEPA) "Superfund" list in December 2000. Primary contaminants include mercury, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, dioxins, furans, and pesticides (USEPA 2000).

In the mid-1980s, concerns about the effects of waterway development on juvenile salmonids led to a cooperative study between the Port of Portland and the Oregon Department of Fish and Wildlife (ODFW) (ODFW 1992). The study focused primarily on the Portland Harbor area (rk 0.0–19.0) and concluded that (1) with the exception of habitat losses caused by seawall construction, development posed little risk to salmonids; (2) the location of developments in the harbor area did not need to be weighed heavily when considering
risks to salmonids; and (3) predation on juvenile salmonids by northern pikeminnow (\textit{Ptychocheilus oregonensis}) was not enhanced by development (Ward et al. 1994). The study also recommended further research to better characterize fish-habitat relationships.

Four evolutionarily significant units (ESUs) of naturally-propagated anadromous salmonids were listed as threatened under the federal Endangered Species Act (ESA) in the late 1990s, including lower Columbia River and upper Willamette River Chinook salmon (NOAA 1999). The lower
Columbia River ESU includes the Willamette River from the mouth to Willamette Falls at rkm 42.6 (Figure 1).

Following the ESA listings and consultations with regional fisheries managers, the City of Portland sponsored a new study directed at describing the relationships of nearshore development and bank treatments on both resident and anadromous fish species. This work was intended specifically to help the City of Portland protect and recover listed species. As part of this research, we examined the migratory characteristics of juvenile Chinook salmon in the lower Willamette River. Where possible, we assessed both hatchery and naturally-produced fish, and focused largely on elements that would have important management implications and increase our understanding of juvenile Chinook salmon behavior: outmigration timing, size structure, growth, migration rate, and nearshore habitat use.

Methods

Field Sampling

Electrofishing and Beach Seining

We used electrofishing and beach seining to collect juvenile Chinook salmon and assess their origin (hatchery or naturally produced), size, run timing, and growth. Repeated sampling was conducted at 27 sampling stations (Figure 1). Of these, 21 were sampled with electrofishing, four were sampled with beach seines, and two were sampled using both gears. Prior to winter 2001, sampling was conducted during a 4-6 week period seasonally (spring, summer, autumn, and winter), resulting in some temporal gaps (sampling did not occur in some months). We corrected this by redesigning the sampling so all months were sampled equally. Beginning in December 2001, electrofishing was conducted four days per month. We sampled all sites once over two consecutive days, then repeated the sampling in a subsequent week. We conducted beach seining once per week (each seining site sampled once).

Boat electrofishing was conducted after sunset. Because one goal of the study was to characterize the effects of nearshore development on juvenile Chinook salmon, we sampled as close to shore as possible. Navigation was difficult in water <1 m deep, and sampling effectiveness was probably reduced at depths >3 m. We therefore adopted a target depth of 1–3 m, though some sites (loading docks, seawalls) were considerably deeper even very close to shore. We sampled for a maximum of 750 sec (continuous energized direct current) at each sample site, and used 30 pulses/sec at 50–100% of the low range, which maximized taxis and minimized tetany. These settings resulted in an electrofisher output of <1.0–2.0 amperes, depending on conductivity. The conservative settings (selected to minimize harming ESA-listed and sensitive species) sometimes prevented us from collecting all fish observed when densities were high.

We conducted daytime beach seining at five sites; a sixth was added in spring 2002. While shoreline habitat varied greatly for electrofishing efforts, beach seine sites were relatively consistent, defined by shallow areas with gentle slope, little or no structure, and small substrate (fines, sand, or gravel). We used a 2.4 x 45.7 m straight-wall, buntless nylon mesh with a weighted line at the bottom and a floating line at the top. The seines were deployed from a boat in a semi-circular fashion and pulled to shore.

Juvenile salmonids collected by electrofishing and beach seining were identified to species when possible; small individuals could not always be identified easily and were recorded as unidentified salmonids. Nearly all (98.3%) of the 18.5 million hatchery Chinook salmon released into the Willamette River from 2001 to 2003 were finmarked (PSMFC 2007), so we assumed fish without missing fins were naturally propagated and are hereafter referred to as “unmarked.” We measured (fork length in mm) a maximum of 30 juvenile Chinook salmon from each group (hatchery or unmarked) after each electrofishing run or beach seine set.

Radio Telemetry

Radio telemetry was intended to provide information on actively migrating juvenile Chinook salmon. We used telemetry data to calculate migration rates, describe the distribution of fish across the river channel, and explore possible habitat associations. We collected juvenile Chinook salmon each spring (2001–2003) for radio tagging. Fish were collected by beach seining or electrofishing within the study area, or were obtained from the
juvenile fish trap at the Portland General Electric Sullivan Plant at Willamette Falls.

We held fish for 16-48 hours following collection to allow for the evacuation of stomach contents, minimizing the risk of infection during tag placement. During 2001 and 2002, the fish were held in 125-L containers suspended by floating frames in Clackamette Cove, located near the confluence of the Clackamas and Willamette rivers (Figure 1). The containers were perforated to allow water to circulate freely. Due to poor conditions (stagnant water and high temperatures) in this area during 2003, the fish were held at the ODFW regional office in Clackamas in large spring-fed tanks with continuous water circulation.

Radio tags were coded microprocessor transmitters (NTC-2-1 NanoTags®) manufactured by Lotek Engineering, Inc. We programmed all tags with a continuous 4 sec burst rate, and the minimum estimated battery life was 11 d. Tag size was 4.5 x 6.3 x 14.5 mm and averaged 0.8 g (air weight) including antennae. During 2001, some fish were also tagged with MCFT-3KM tags measuring 7.3 x 18 mm with an air weight of 1.4 g. Adams et al. (1998a) and Brown et al. (1999) recommended tag weight should not exceed 5.0% of the weight of the fish; we attempted to collect and tag fish ≥16 g for NTC-2-1 tags, and ≥28 g for MCFT-3KM tags.

Prior to implantation, each tag was activated and checked with a receiver. We surgically implanted the tags into the ventral body cavity as described in Adams et al. (1998b). Following the procedure, we retained the fish for 12-36 hours to ensure complete recovery and tag retention.

We released radio-tagged fish between 14 April and 27 June of each year. Releases occurred pre-dawn in the upper portion of the study area between rkm 27.0 and 39.1 in 2001, rkm 32.5 and 39.6 in 2002, and rkm 39.4 and 39.6 in 2003. Only fish that appeared to be in good physical condition were released. We matched water temperatures in the holding containers as closely as possible to river temperatures, and released the fish via a water-to-water transfer.

We tracked radio-tagged fish by boat, traveling at approximately 8.0 km/h, using a six-element yagi-style antenna and Lotek receiver. Tracking was conducted in an upstream to downstream direction. Upstream of Elk Rock Island (rm 30.6) we tracked mid-channel because signals from either shore could be detected. A zigzag tracking pattern was used downstream of Elk Rock Island, where the river becomes wider, to maximize the amount of surface area covered and to ensure random recoveries of fish between nearshore and offshore habitats. We defined nearshore recoveries as those occurring within 10% of the measured channel width of either shore. Total tracking time conducted offshore and nearshore was recorded for each shift to maintain an approximate 50:50 ratio.

We began tracking the fish about one hour after their release, 1.6 km above the release site. On non-release days, tracking began near the mid-point of fish relocations from the previous shift. If no fish were located after two hours of tracking, we employed a search pattern until signals were detected. Tracking was conducted twice per day (day and night) for 8-10 hours per shift, and for at least five consecutive days following a release.

Once a signal was audible on the receiver, we discontinued the tracking pattern and directed the boat towards the signal. The location of the fish was determined by lowering the gain and using the aerial antenna to locate the direction of the strongest power signal. When the signal was sufficiently strong, a coaxial antenna was lowered 1-2 m underwater to pinpoint the location of the fish. Whether we pinpointed the fish or not, we stopped the boat where the signal was strongest and recorded the tag channel and code, time, latitude and longitude, river mile, distance to shore, channel width, final gain and signal power readings, and the quality of the signal. We recorded the general habitat types for all nearshore recoveries; categories included beach, riprap, rock outcrop, other natural rock, seawall, fill, and pilings (Table 1; modified from Greenworks P.C. et al. 2001). A ground survey was conducted in January 2001 to determine the proportional availability (by length) of each habitat type. We also recorded whether fish were recovered in areas outside of the main river channel (e.g. alcoves, lagoons, backwaters, and secondary channels). Nearshore habitat type and other data were recorded in the same manner as main-channel recoveries.

We also employed a variable number of fixed telemetry sites, consisting of a six-element yagi-style antenna attached to a fixed object (buildings or river channel markers), a receiver, and a power supply. The receiver was programmed to continuously monitor the tag frequencies and to record the
TABLE 1. Habitat type definitions used during radio telemetry of juvenile Chinook salmon in the lower Willamette River, 2001–2003. Habitat types were modified from Greenworks P.C. et al. (2001).

<table>
<thead>
<tr>
<th>Habitat type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore</td>
<td>Open water offshore, arbitrarily defined as 11–89% of the river width.</td>
</tr>
<tr>
<td>Neartshore</td>
<td>The portion of the river within ≤10% of the measured river width of either bank.</td>
</tr>
<tr>
<td>Beach</td>
<td>A shallow, shelving shoreline consisting of sand, silt, or fine gravel up to 64-mm diameter. May also include native bank materials in their natural position (e.g. clay bank). Vegetation cover varies but may include canopy, understory, and ground cover.</td>
</tr>
<tr>
<td>Rock outcrop</td>
<td>Natural bedrock formations consisting of angular ledges, protrusions, and sheer rock faces. May include some associated boulders.</td>
</tr>
<tr>
<td>Rock</td>
<td>Natural, round river rock &gt;64 mm in diameter.</td>
</tr>
<tr>
<td>Seawall</td>
<td>Impervious vertical retaining walls, generally composed of concrete, timber, or sheet pile, that extend below the ordinary low water level. These habitats are uniformly deep and homogenous (e.g. building foundations, bulkheads).</td>
</tr>
<tr>
<td>Riprap</td>
<td>Continuous stone revetments placed to curtail erosion and prevent alterations to the main channel. Vegetative cover varies but may include canopy, understory, and ground cover that occupy a minimum of 20% of the bank below flood stage.</td>
</tr>
<tr>
<td>Fill</td>
<td>Areas that have been filled with miscellaneous unconsolidated materials (e.g. cement slabs). The surfaces of banks composed of fill have not been covered with engineered riprap or structures. Such banks generally contain debris of various types and may be unstable due to erosion.</td>
</tr>
<tr>
<td>Piling</td>
<td>Stationary support structures consisting of concrete, metal, or timber used to elevate docks, buildings, or other structures above the water.</td>
</tr>
</tbody>
</table>

date, time, tag code, and signal strength of passing tagged fish. Each week, data was downloaded to a laptop computer and the battery was replaced.

We reduced the number of fixed telemetry sites used each year due to interference from automobile traffic and logistical concerns (e.g., increased security at channel markers maintained by the U.S. Coast Guard). We used eight fixed telemetry sites in 2001, located at rkm 1.1 (2 receivers), 4.8, 9.5 (2 receivers), 18.7 (two receivers), and 26.7. In 2002 we employed one receiver at rkm 9.5 and two at rkm 18.7. A new station was added during 2002 in Multnomah Channel (Figure 1), 2.4 rkm downstream from the head of the channel. This was the only site used in 2003.

Data Analysis

Density and Timing

To assess run timing, we calculated the relative density of juvenile Chinook salmon using an index based on the proportion of zero-fish catches. Although catch per unit effort (CPUE) is the most commonly used index of fish density, Bannerot and Austin (1983) recommended the use of the square root of the relative frequency of zero-fish catches. Zimmerman and Parker (1995) modified the index by using its reciprocal (1/square root of the proportion of zero catches) so the index value would be directly proportional to density. We calculated monthly index values for fish captured by electrofishing and beach seining to provide information on relative density and temporal distribution. Separate indices were calculated for hatchery and unmarked fish.

Growth

Growth of juvenile salmonids implies active feeding and the existence of suitable rearing habitat. We used the Mann-Whitney test (a nonparametric equivalent of the T-test; Zar 1999) to compare fork length (FL) and weight of juvenile salmonids among sampling sites in the upstream and downstream portions of the study area. Catches varied substantially with gear type; we divided this analysis into two components to maximize statisti-
cal power: hatchery fish captured by electrofishing and unmarked fish captured in beach seines. For beach seine catches, we compared downstream sites at km 1.0 and 6.4 to upstream sites at km 26.9 and 39.1 (Figure 1). Electrofishing sites were at km 1.0, 1.6, and 1.9 (downstream) and at km 26.9, 32.2, and 35.2 (upstream). We conducted separate analyses of length and weight for fish captured during spring and winter, and for both seasons combined.

Radio Telemetry

Migration rates. We calculated migration rates (km/d) based on travel time from the initial release point to subsequent downstream relocation points. We established conservative assumptions to ensure we tracked only live, actively migrating fish: 1) fish that were pinpointed multiple times in the same location for >24 hours were presumed dead and not included in subsequent analyses; 2) fish that moved upstream with no subsequent downstream movement were not actively migrating, or may have been consumed by predators; migration rates were calculated using only downstream movements of the fish to the point at which the fish began to move upstream; 3) if the signal strength was of low quality (unable to pinpoint), the data was not included in calculations of migration rate. We verified river kilometer estimates for relocations by plotting the GPS waypoints onto an Oregon Lambert-projected ortho-photo (0.6-m resolution) using ArcView 3.2a (Environmental Systems Research Institute, Inc. 2002).

Factors influencing migration. Because the release timing of radio-tagged fish varied annually, there was some potential for environmental conditions, primarily river flow, to affect telemetry results. To explore this factor, we calculated median, minimum, and maximum flow values (kcf/s) using U.S. Geological Survey (USGS) river flow data collected at the Morrison Bridge gauging station (USGS 2004) for each period we tracked radio-tagged fish. Differences among years were identified using the Kruskal-Wallis one-way ANOVA on ranks and Dunn’s nonparametric multiple comparison test. We similarly compared migration rates between upstream (km 22.6–42.6) and downstream (km 0.0–22.5) sections of the study area. Factors that could influence migration rates, including river flow, water temperature (°C), release day, and fish size (fork length) were assessed using simple linear regressions.

Habitat use. We used distributions of radio telemetry relocations across the river channel to determine if juvenile Chinook salmon were closely associated with nearshore areas, and therefore likely to encounter different bank habitats. For each relocation, we divided the measured river width into 10% increments and assigned the relocation a category (e.g., 0–10%, 11–20%). We analyzed distributions using the chi-square test; samples with expected values of <5 for a single category were not included (Zar 1999). We used the same analysis to determine if nearshore relocations among general habitat types were distributed differently than the habitat types, which could indicate selection or avoidance of specific habitats. Nearshore habitat was defined as the area within 10% of the measured channel width of either shoreline.

Prior to conducting any field work, we set our decision level for statistical analyses at P=0.05. We tested all data for assumptions of normality and constant variance to determine whether to use parametric or non-parametric procedures.

Results

From May 2000 to July 2003, we performed 982 electrofishing runs and 568 beach seine sets. Sampling occurred in all months except October 2000 and July, August, and October 2001. We collected 5,030 juvenile salmonids identifiable to species; 4,383 (87%) were Chinook salmon. Hatchery fish comprised about 54% of the total Chinook salmon catch, but there was a pronounced difference in the proportion of hatchery fish between gear types. The electrofishing catch consisted primarily (81%) of hatchery fish, while unmarked fish dominated (92%) the beach seine catch. We captured juvenile Chinook salmon in every month we sampled except May 2001, when we conducted limited beach seining and no electrofishing.

The mean fork length of hatchery Chinook salmon captured by electrofishing (155 mm) was considerably greater than that of unmarked fish (115 mm), though the unmarked component exhibited greater variance (Figure 2). Few hatchery Chinook salmon were captured with beach seines, and were similar in size to those captured with electrofishing gear. Unmarked fish in beach seine catches were generally much smaller than those captured by electrofishing, and exhibited a
bimodal length distribution, with peak numbers of fish occurring at about 45 and 75 mm FL.

Density and Timing

From May 2000 to July 2003, density index values of both hatchery and unmarked juvenile Chinook salmon captured by electrofishing generally increased beginning in November and declined to near zero by June (Figure 3). Peak densities varied, occurring between January and April. Hatchery Chinook salmon were present at higher densities than unmarked fish during most months, and both hatchery and unmarked fish were present at low densities in August, September, and October of some years.

Juvenile Chinook salmon observed in beach seine catches exhibited similar timing, except peak catches of both hatchery and unmarked fish occurred later (usually one month) than those from electrofishing (Figure 3). Densities of unmarked fish increased sharply in February and declined to near zero in July. Densities of unmarked fish were also much higher than those of hatchery fish, and peak catches of unmarked fish occurred in April or May. We captured unmarked juvenile Chinook salmon in every beach seine set in April 2001 and May 2003, resulting in infinite density index values.

Growth

Median fork lengths of hatchery Chinook salmon were significantly greater at downstream sampling sites than at upstream sites during winter, spring, and for both seasons combined (Mann-Whitney test; all P<0.01; Figure 4). Differences were more
pronounced during winter, when the median fork length was 14 mm greater at downstream sites than at upstream sites (compared to 9 mm greater during spring). Weight comparisons followed the same pattern; fish captured at downstream sites were significantly heavier than those captured at upstream sites (Mann-Whitney test; all $P<0.001$; Figure 4). Length and weight differences for unmarked subyearling Chinook salmon among upper and lower sampling sites were less distinct (Figure 5). Median fork lengths were always greater
Figure 4. Seasonal fork length and weight of juvenile hatchery Chinook salmon captured by electrofishing at uppermost (river kilometer 26.9, 32.2, and 35.2) and downstream (river kilometer 1.0, 1.6, and 1.9) sites in the lower Willamette River, 2000–2003. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, and the error bars indicate 10th and 90th percentiles.

Figure 5. Seasonal fork length and weight of unmarked juvenile Chinook salmon captured by beach seining at uppermost (river kilometer 26.9 and 39.1) and downstream (river kilometer 1.0 and 6.4) sites in the lower Willamette River, 2000–2003. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, and the error bars indicate 10th and 90th percentiles.

TABLE 2. Summary of radio-tagged juvenile Chinook salmon released in the lower Willamette River, 2001–2003. H = hatchery; U = unmarked. Relocations include only those from fish assumed to be alive and actively migrating.

<table>
<thead>
<tr>
<th>Year</th>
<th>Origin</th>
<th>Number released</th>
<th>Number recovered</th>
<th>Number of relocations</th>
<th>Fork length (mm)</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>2001</td>
<td>U</td>
<td>14</td>
<td>13</td>
<td>61</td>
<td>108-125</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>18</td>
<td>18</td>
<td>67</td>
<td>118-150</td>
<td>140</td>
</tr>
<tr>
<td>2002</td>
<td>U</td>
<td>14</td>
<td>12</td>
<td>36</td>
<td>112-166</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>160-186</td>
<td>178</td>
</tr>
<tr>
<td>2003</td>
<td>U</td>
<td>13</td>
<td>13</td>
<td>38</td>
<td>123-156</td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>32</td>
<td>30</td>
<td>77</td>
<td>131-180</td>
<td>154</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>95</td>
<td>89</td>
<td>279</td>
<td>108-186</td>
<td>141</td>
</tr>
</tbody>
</table>

(1–6 mm) at downstream sites but significantly different from upstream sites only where winter and spring data were combined (Mann-Whitney test; T=136313, P=0.01). Median weights were significantly greater at downstream sites during spring and for both seasons combined (Mann-Whitney test; all P<0.05), but were not significantly different during winter.

Radio Telemetry

From 2001 to 2003, we released 95 radio-tagged Chinook salmon, including 54 hatchery fish and 41 unmarked fish (Table 2). Hatchery fish were significantly larger than unmarked fish (Kruskal-Wallis ANOVA; H=33.76, df=1, P<0.001). Due to difficulties in obtaining fish that were heavy
TABLE 3. Boat tracking effort (hours) for radio-tagged juvenile Chinook salmon in the lower Willamette River, 2001–2003. Areas were considered nearshore if they were within 10% of the measured channel width of either riverbank. Off-channel habitats included alcoves, backwaters, side channels, and other areas displaced from the primary river channel.

<table>
<thead>
<tr>
<th>Category</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearshore</td>
<td>54.3</td>
<td>57.1</td>
<td>75.9</td>
<td>187.3</td>
</tr>
<tr>
<td>Offshore</td>
<td>63.7</td>
<td>49.5</td>
<td>100.6</td>
<td>213.8</td>
</tr>
<tr>
<td>Off channel</td>
<td>8.2</td>
<td>8.3</td>
<td>14.3</td>
<td>30.8</td>
</tr>
<tr>
<td>Day</td>
<td>84.8</td>
<td>72.4</td>
<td>106.2</td>
<td>263.4</td>
</tr>
<tr>
<td>Night</td>
<td>33.2</td>
<td>34.2</td>
<td>70.3</td>
<td>137.7</td>
</tr>
<tr>
<td>All locations</td>
<td>118.0</td>
<td>106.6</td>
<td>176.5</td>
<td>401.1</td>
</tr>
</tbody>
</table>

Migration Rates. Juvenile Chinook salmon migrated at a median rate of 11.3 km/d (Figure 6), and hatchery fish migrated significantly faster (12.4 km/d) than unmarked fish (8.4 km/d) (Mann-Whitney test; T=925, P<0.001). Migration rates also varied among years (Figure 7). The median migration rate was significantly faster in 2003 (15.7 km/d) than in 2002 (7.3 km/d) or 2001 (8.6 km/d) (Kruskal-Wallis ANOVA; H=27.04, df=2, P<0.001). The median migration rate for fish tracked in the upstream portion of the study area (11.7 km/d) was significantly faster than in the downstream portion (8.1 km/d; Kruskal-Wallis ANOVA; H=5.86, df=1, P<0.05).

Figure 6. Migration rates for juvenile Chinook salmon >100 mm fork length in the lower Willamette River. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, the error bars indicate 10th and 90th percentiles, and open circles denote outliers.

Figure 7. Migration rate by year for radio-tagged juvenile Chinook salmon in the lower Willamette River. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, the error bars indicate 10th and 90th percentiles, and open circles denote outliers. Bars without a letter in common are significantly different (P<0.05).
Factors Influencing Migration Rate. River flow and the timing of radio telemetry efforts varied among years. In general, the timing of radio tracking corresponded to a period of moderate, relatively stable flows in 2001, relatively low, stable flows in 2002, and higher, more variable flows in 2003. In 2001, median flow during the tracking period (25 April–13 June) was 20 kcfs (range 13-34). Median flow during the 2002 tracking period (1 June–27 June) was 17 kcfs (range 12–25) kcfs, and was 33 kcfs (range 18-63) during 2003 (14 April–23 May). All pairwise comparisons differed significantly (Kruskal-Wallis ANOVA; H=51.72, df=2, P<0.001).

Simple linear regressions identified several variables that helped explain variation in the migration rates of juvenile Chinook salmon. Assumptions of normality and constant variance in the regressions were met when we log-transformed migration rate and fork length; river flow was not transformed. Migration rate increased linearly with both flow ($r^2=0.408$) and fork length ($r^2=0.353$) (Figure 8). Independently, release date and water temperature were linearly related to migration rate, but were strong covariates of flow (Spearman $r=-0.893$ and -0.697; all $P=0.00$).

Habitat Use. The majority (76.3%) of Chinook salmon radio telemetry relocations occurred
in the lower Willamette River (primarily from the Clackamas River) were extirpated by 1934 (WRI 2004). A small number of introduced fall Chinook salmon persist; adults are observed annually at Willamette Falls. In 2005, 964 adult fall Chinook salmon were counted, compared to 35,453 adult spring-run fish (ODFW 2005). Some production of fall Chinook salmon occurs in the upper watershed; Schroeder et al. (2003) estimated 6% of subyearling Chinook salmon seen in the Willamette River during 2002 were fall-run fish.

Chinook salmon captured in our study were approximately half hatchery fish and half unmarked fish, though there was a clear dichotomy between gear types. Large (>100 mm FL) hatchery fish dominated the electrofishing catch; small (<100 mm FL) unmarked fish were offshore (>10% of the measured channel width), and nearshore relocations varied significantly with the relative availability of habitat types (chi-square=16.0, df=6, P=0.01; Figure 9). Radio-tagged fish were recovered at lower-than-expected rates (based on the proportional distribution of habitat types) at rock and riprap habitats and at a higher-than-expected rate near pilings.

Relocation frequencies of radio-tagged juvenile Chinook salmon across the river channel indicated they were distributed relatively evenly from the west bank to the east bank (Figure 10), except in 2003, when relocations tended to occur more frequently towards the east bank (chi-square=30.7, df=9, P<0.005). Day and night channel distributions were similar (Figure 11). We detected no significant differences in channel distribution patterns between hatchery and unmarked fish (Figure 11); relocations of both groups were evenly distributed across the river channel.

Discussion

We concluded the juvenile Chinook salmon we collected were largely spring-run stocks, as fall Chinook salmon are not indigenous to the upper Willamette River basin and wild fall Chinook salmon offshore (>10% of the measured channel width), and nearshore relocations varied significantly with the relative availability of habitat types (chi-square=16.0, df=6, P=0.01; Figure 9). Radio-tagged fish were recovered at lower-than-expected rates (based on the proportional distribution of habitat types) at rock and riprap habitats and at a higher-than-expected rate near pilings.

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prevalent in beach seine catches. We acknowledge that gear selectivity and our sampling scheme likely contributed to this pattern. Electrofishing typically selects for larger individuals of a species (Reynolds and Simpson 1978; Reynolds 1996), and we frequently could not conduct boat electrofishing in the shallowest water, where seine catches indicated smaller fish were abundant. Large juvenile Chinook salmon were likely able to avoid our beach seine more effectively than smaller fish. Finally, diurnal patterns may have biased some of the catch data; seineing occurred during daytime hours, where electrofishing was performed primarily at night (though radio telemetry results showed no difference in the distribution of juvenile Chinook salmon >100 mm FL between day and night).

We were concerned about handling stress and incidental mortality, so we did not attempt to collect scales or other structures for aging. We assumed that fish >100 mm FL were generally yearlings (age 1) and smaller fish were subyearlings (age 0). Spring Chinook salmon are generally regarded as "stream type" fish; they rear in fresh water for a year or more before migrating to the ocean, while fall Chinook salmon are considered "ocean type", rearing for only a few months before migrating (Wydoski and Whitney 2003). Considering the large number of small Chinook salmon we collected, and the apparent low abundance of fall Chinook salmon, we concluded that most small Chinook salmon in the lower Willamette River are spring-run fish that outmigrate as subyearlings. The bimodal distribution of length frequencies in beach seine catches also suggested several age-classes were present; these could include older subyearlings from upper basin tributaries (e.g., Santiam River) and younger subyearlings from lower basin tributaries (e.g., Clackamas River). Future studies should analyze length-at-age and address the origin and race of these fish.
Timing

The outmigration period for Chinook salmon, both hatchery and unmarked, was surprisingly long. The presence of fish often increased in late autumn and persisted into the next summer. Juvenile Chinook salmon were present during every season and 34 of 35 months we sampled. Winter and spring were clearly the periods of greatest abundance, though the presence of different races (spring and fall), size classes, and stocks undoubtedly confounded our ability to completely assess timing.

The nearly constant presence of juvenile Chinook salmon may have implications for activities such as dredging, bank stabilization, and construction in the lower Willamette River. Primary considerations for recommending in-water work periods are given to important fish species, including anadromous fish and those receiving protection under federal or state ESAs. Adverse impacts of in-water work can include any modification (physical, chemical, or biological) that reduces the quality or quantity of essential fish habitat (NOAA 2004). The existing work period for the lower Willamette River and Multnomah Channel is 1 July–31 October and 1 December–31 January (ODFW 2000). Our findings indicated juvenile Chinook salmon (including a large number of unmarked fish) were present during December and January, often at high densities. Restricting in-water work in the lower Willamette River to July through October will help minimize risks to listed stocks of Chinook salmon.

Growth

The increases in size we observed in juvenile Chinook salmon from upper to lower sampling sites were generally greater than the range described in the literature, especially for hatchery fish. For example, we observed a median fork length increase of 9 mm for hatchery Chinook salmon from upper to lower sampling sites, where the mean distance between upper and lower sites was 29.9 km. Radio-tagged Chinook salmon traveled at a median rate of 11.3 km/d, so their travel time between the upper and lower sites was about 2.6 d. Fisher and Peary (1995) documented growth rates of 0.75–1.05 mm/d for juvenile (hatchery) Chinook salmon in the lower Columbia River; applying their results to our estimated travel time would result in observed growth of 2.0–2.7 mm. However, due to technical limitations (e.g., weight and battery life of radio transmitters) our telemetry efforts focused on larger, actively migrating fish, which may have biased our migration rate estimates (high). We eliminated some fish from migration rate calculations because they stopped moving or moved upstream. Even among fish that consistently moved downstream, we estimated individual migration rates as slow as 1.8 km/d, and the median migration rate was significantly slower below rkm 22.6. Considering these factors, it is plausible that some juvenile Chinook salmon spend extended amounts of time in the study area, and the growth we observed is realistic.

Fork length and weight of small, unmarked juvenile salmonids, while not always statistically significant, were consistently greater at downstream sites, again suggesting growth occurs. We observed increases in fork length from one to six mm. As with hatchery fish, this amount of growth was generally greater than observed in other areas. Published growth rates for subyearling Chinook salmon (including ocean-type fish) range from 0.48 mm/d (Sommer et al. 2001) to 1.2 mm/d (Conner and Burge 2003). We did not radio tag subyearling juvenile Chinook salmon, but Giorgi et al. (1997) estimated age-0 Chinook salmon migrated at 15.6 km/d in the mid-Columbia River (Rock Island Dam to McNary Dam). Applying these figures to the mean distance between our upper and lower sites (29.3 km) yielded growth estimates of 0.9–2.3 mm from upper to lower sites. This calculation is largely speculative, lacking migration and growth studies specific to the Willamette or lower Columbia rivers, but provides a general comparison. Future studies in the lower Willamette River addressing migration rates of age-0 fish would be helpful to assess risks associated with their exposure to predation, toxins, and degraded habitat.

Differential mortality resulting from size-selective predation or other factors may have contributed to the size changes we observed; higher mortality rates for smaller fish would result in larger observed sizes at downstream locations. In the Columbia River, smallmouth bass preyed on relatively small juvenile Chinook salmon, and consumed far more subyearling fish in spring than yearling fish in summer (Zimmerman 1999). However, predation on juvenile salmonids by resident fish in the Willamette River appears to be minimal (Buchanan 1981; FES 2001; Pribyl et al. 2004), and we observed no other evidence
of differential mortality. Survival estimates for various size classes and life stages of juvenile salmonids in our area would help clarify this issue and improve analyses of growth.

Other fish entering the study area from a tributary or the Columbia River could have biased the observed lengths and weights of fish in our study. However, no major streams enter the Willamette River below rkm 39.9 (the Clackamas River; Figure 1). All of the sampling sites used in the analysis were downstream of this point, though one (rkm 39.1) was relatively close and on the opposite shore, so some influence from the Clackamas River is possible. Fish entering from the Columbia River would have to migrate about 2-10 km in an upstream direction. Considering also the large sample size, consistent pattern, and statistical strength of the length and weight analyses, we felt there was sufficient evidence to conclude that juvenile salmonids exhibit changes in size during migration through the lower Willamette River. Some amount of growth undoubtedly occurs, as Vile et al. (2004) documented extensive feeding by juvenile salmonids on *Daphnia* spp. and other invertebrates in our study area. Schreck et al. (1994) also documented feeding by hatchery Chinook salmon in the Willamette River above Willamette Falls.

**Migration Rate**

The migration rates we calculated for juvenile Chinook salmon >100 mm FL (presumably yearlings) were very similar to those reported in the Port of Portland study (ODFW 1992, Ward et al. 1994). Ward et al. (1994) documented median migration rates of 9.8 (1990), 8.7 (1989), and 11.0 km/d (1988) during spring in the lower Willamette River, where we estimated a median rate of 11.3 km/d from 2001–2003.

In general, spring migration rates for juvenile Chinook salmon were faster (19.6–43.0 km/d) in Columbia and Snake river impoundments (Giorgi et al. 1997; Adams et al. 1998c; Hockersmith et al. 2003; Smith et al. 2003) and slower (4.1 km/d) in the Columbia River below rkm 75.0 (Fisher and Pearcy 1995). Dawley et al. (1986) observed that tagged coho salmon (*O. kisutch*) in the Columbia River traveled faster when they were released farther upstream. We observed a similar pattern in the lower Willamette River; radio-tagged Chinook salmon traveled faster in the upstream portion of the study area. This pattern of slower migration rates as juvenile salmonids move downstream in the Columbia basin suggests the lower Willamette River may play a role in rearing as the fish prepare to transition to salt water.

The implications of migration rates are uncertain. Delayed migration due to hydropower development, low river flows, and other factors have been cited as causing serious impacts to salmonids in the Columbia and Snake rivers (Bentley and Raymond 1976; Raymond 1979). Rapid travel through watersheds altered by human activity presumably increases survival, as fish spend less time exposed to degraded or suboptimal habitat, predation by introduced species, poor water conditions, and toxins. Schreck et al. (1994), noting many resting and feeding areas in the Willamette River have been eliminated by channelization, speculated that quick downstream movement is currently the most successful evolutionary strategy for juvenile Chinook salmon. However, observations from our study, including the growth of juvenile salmonids, their presence throughout much of the year, extensive feeding (Vile et al. 2004), and low predation rates and predator densities (Buchanan et al. 1981; FES 2001; Pribyl et al. 2004) suggest the lower Willamette River has value as rearing habitat. If this is the case, the importance of rapid migration rates may be negligible. The uptake of contaminants remains a potential risk for juvenile salmonids in the lower Willamette River, and a full assessment is planned (Windward Environmental 2004).

**Factors Influencing Migration Rate**

Our study corroborates other evidence indicating river flow and outmigration rate are positively correlated. Schreck et al. (1994) showed migration rates of hatchery Chinook salmon that traveled 280 km from the upper Willamette basin to Willamette Falls were strongly correlated (r²=0.66) with river flow. Dawley et al. (1986) observed migration rates for both juvenile Chinook and coho salmon in the Columbia River estuary increased with river flow; and Giorgi et al. (1997) found that flow in the mid-Columbia River basin explained 42, 36, and 31% of the variation in migration rates of sockeye salmon (*O. nerka*), hatchery steelhead (*O. mykiss*), and wild steelhead.

We also observed a relatively strong positive linear relationship between fork length and migration.
rate. Our results were similar to those of Giorgi et al. (1997), who noted a positive relationship between migration rate and fish length for ocean-type juvenile Chinook salmon ($r^2=0.59$). Hatchery Chinook salmon in our study migrated significantly faster than unmarked fish. This was likely an effect of the size of the fish, as migration rate increased with size and the hatchery fish we radio tagged were significantly larger than unmarked fish.

Habitat Use

Telemetry data indicated large, actively migrating Chinook salmon were not highly associated with nearshore areas; they were distributed evenly across the river channel regardless of year (except in 2003), time of day (day or night), or origin (hatchery or unmarked). Very few studies have addressed the cross-sectional distribution of juvenile salmonids in lotic systems. Dauble et al. (1989) examined spatial distributions in the Hanford Reach of the Columbia River and reached conclusions similar to ours: yearling spring Chinook salmon (and steelhead) were found primarily in midchannel areas, and smaller fish (age-0 Chinook salmon) were most abundant near shore.

Radio-tagged Chinook salmon located near shore were distributed unevenly with respect to the availability of different habitat types. However, these fish did not show clear selection for, or avoidance of, particular habitat types. Except for a possible affinity for pilings, associations with specific habitats were weak, and the distribution of telemetry recoveries appeared to closely follow the proportional availability of habitat types. In addition, because a relatively small proportion (about 24%) of the radio-tagged Chinook salmon were relocated near shore, we concluded the influence of shoreline habitat on large (>100 mm FL), actively migrating fish was minimal.

Much of the original off-channel habitat (alvoces, lagoons, backwaters, and secondary channels) has been eliminated from the Willamette River (Schreck et al. 1994). In our study, the remaining off-channel areas were used by migrating yearling salmonids, and a considerable proportion of our radio-tagged fish entered the Multnomah Channel. These areas should be considered when planning future development or habitat improvement activities near Portland.

An important observation in our study was the large number of subyearling Chinook salmon present. Because we did not often capture these fish with electrofishing gear, and beach seining efforts occurred at a single bank habitat type, we could not effectively analyze their habitat preferences. However, based on the high numbers of fish and their extended temporal distribution in seine catches, beaches were clearly an important habitat type for subyearling Chinook salmon. This is supported by numerous studies which are unanimous in concluding that younger age classes of juvenile salmonids are highly associated with shallow, nearshore areas in both lotic and lentic environments (e.g., Lister and Genoe 1970, Johnsen and Sims 1973, Dauble et al. 1989, Kahler 2000, Tabor and Pioskowski 2002). Recent work also suggests the quality and composition of nearshore habitat is important to subyearling salmonids. Garland et al. (2002), for example, concluded substrate size was the most important factor in determining the presence of subyearling fall Chinook salmon in the Columbia River above McNary Dam; fish were more likely to be present at unaltered shorelines than at riprapped sites. Very little is known about the origin and race, habitat use, migration rate, diet, and survival of age-0 Chinook salmon in the lower Willamette River, and we strongly recommend additional studies focus on these topics. Our observations indicated subyearling Chinook salmon were abundant and used beach habitats extensively, but we focused largely on yearling fish and did not answer critical questions pertaining to smaller age classes (especially habitat use and migration rates). Subyearling fish may be particularly important because nearly all are naturally produced (and therefore federally protected), and unlike older fish, appear to be associated with a specific habitat type.

We found little evidence to suggest that nearshore habitat as it currently exists is a critical factor affecting larger (>100 mm FL), actively migrating juvenile Chinook salmon. However, the effects of development are incompletely explored, especially with respect to subyearling fish. Anecdotally, the lower Willamette River has been described as a simple “migration corridor,” implying that it has little value as rearing habitat. While large juvenile Chinook salmon do appear to pass relatively quickly through this area, they feed (Vile et al. 2004), exhibit changes in size, and utilize a variety of habitats. Unaltered nearshore habitats (beaches) appear to be important to smaller fish. Additional habitat modifications are highly likely,
as Oregon's population is expected to increase by about 1.8 million people in the next 35 years (Oregon Department of Administrative Services 2004). Considering the historic reductions in natural habitat and the threatened status of wild Chinook salmon stocks in the lower Willamette River, future development should be planned carefully to avoid further detrimental impacts and encourage recovery.

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The influence of littoral zone coarse woody habitat on home range size, spatial distribution, and feeding ecology of largemouth bass (*Micropterus salmoides*)

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**Abstract** Coarse woody habitat (CWH) may be a critical feature of lakes that influences fish distributions, movement patterns, and feeding habits. We used radio telemetry to examine the role of CWH in determining the movements of largemouth bass (*Micropterus salmoides* Lacepede) in the context of two whole-lake experiments that provided a gradient of four lake basins varying in natural and manipulated CWH. We also conducted diet studies on largemouth bass in these lakes to test for correlates among consumption rate and prey selectivity with bass behavior. Our results indicated that largemouth bass in basins with lower CWH abundances had larger home ranges, spent more time in deep water, were more selective predators, and showed lower consumption rates. Largemouth bass in basins with higher CWH abundances showed the opposite patterns. Low CWH abundances were correlated with a shift in largemouth bass foraging behavior from sit-and-wait to actively searching. This increased activity, coupled with the potential decline of prey fish species in the absence of CWH, may decrease largemouth bass growth potential regardless of the prey type consumed. Our results suggest that lakeshore residential development and associated removals of CWH from lakes may influence fish behavior, while CWH augmentation may reverse some of those changes.

**Keywords** Centrarchidae · Coarse woody habitat · Largemouth bass · Radio telemetry · Structural complexity · Whole-lake experiment

**Introduction**

Structural attributes of aquatic ecosystems may play a large role in determining the distributions, movement patterns, and feeding ecology of fish populations (Scheuerell & Schindler, 2004). Past research has examined the role of aquatic macrophytes in determining home range size and spatial distributions of largemouth bass (*Micropterus salmoides* Lacepede) (e.g., Essington & Kitchell, 1999). Largemouth bass generally maintain relatively small home ranges (0.2–5.2 ha) in lakes with abundant littoral vegetation (Fish & Savitz, 1983; Mesing & Wicker, 1986; Wildhaber & Neill, 1992) and vegetation tends to
focus largemouth bass distributions in near-shore areas (94–97% of locations less than 3 m deep) (Bain & Boltz, 1992; Essington & Kitchell, 1999; Sass et al., 2006a). While vegetation may play a key role in determining largemouth bass home ranges and distributions, no studies to our knowledge have examined largemouth bass movements in lakes with little vegetation and varying amounts of coarse woody habitat (i.e., logs, branches, trees in the water; CWH) (Newbrey et al., 2005; Sass et al., 2006a).

The relationship between structural habitats and fish movement patterns is ecologically important because a predator’s resource use is dictated by home range sizes and spatial distributions, which can ultimately affect aquatic ecosystems through top-down trophic cascading interactions (Carpenter & Kitchell, 1993; Hodgson et al., 1998). Understanding the influences of within-lake structural complexity on fish distributions and movement patterns is also of applied concern as humans continue to alter the riparian and littoral zones of aquatic ecosystems (Newbrey et al., 2005; Sass et al., 2006a, 2006b). For example, the abundance of CWH in lakes is negatively correlated with lakeshore residential development in Upper Michigan, Northern Wisconsin, and Washington State lakes (Christensen et al., 1996; Jennings et al., 2003; Francis & Schindler, 2006; Marburg et al., 2006). Other structural attributes of lakes, such as aquatic macrophytes, show a similar negative correlation with lakeshore residential development (Radomski & Goeman, 2001; Jennings et al., 2003).

The abundance of CWH in lakes may have important consequences for largemouth bass feeding behaviors. Optimal foraging theory states that a predator will maximize energy intake and growth by selecting high energy prey items that minimize energetic losses through foraging and handling costs, while avoiding predation risk (Werner & Hall, 1974; Mittelbach, 1981; Werner & Hall, 1988). Since largemouth bass are keystone species and the apex predator in many systems (Carpenter & Kitchell, 1993), largemouth bass, as well as most fish species, should select a feeding behavior that reflects optimal foraging tenets unless the structural complexity of the system or the forage base dictates otherwise (Hodgson & Kitchell, 1987). Empirical diet information from largemouth bass may provide insight into mechanisms leading to variation in feeding behaviors in lakes with a gradient of habitat complexities and differences in forage bases.

The structural complexity provided by aquatic vegetation and CWH may serve to decrease predator foraging success, provide a focal point for predator–prey interactions in lakes, and cause a shift in largemouth bass foraging behavior (Savino & Stein, 1982; Sass et al., 2006a). For example, largemouth bass forego actively searching for prey and use a sit-and-wait foraging strategy at a threshold level of simulated aquatic vegetation in laboratory studies (Savino & Stein, 1982). The goal of our study was to evaluate largemouth bass movement patterns and feeding habits in the context of two whole-lake experiments that resulted in a gradient of four lake basins (i.e., two separate bodies of water in each lake) varying in natural and manipulated CWH abundances. More specifically, we tested for differences in largemouth bass home range size, minimum activity rate, percentage of time spent in the littoral zone, consumption rate, and dietary breadth among high- and low-CWH treatments in each of the two lakes. Due to the known effects of structure on predator–prey movements and optimal foraging tenets, we hypothesized that largemouth bass in basins with more CWH would move less (i.e., smaller home range) and be less selective predators. With increasing levels of littoral structure, largemouth bass tend to become ambush predators (Savino & Stein, 1982; Sass et al., 2006a). Therefore, this foraging strategy would suggest a smaller home range size and potentially less prey selectivity because prey availability is restricted to the home range of the fish. In this context, we also hypothesized that largemouth bass would adhere to optimal foraging tenets, with respect to maximizing growth potential, given variable feeding behaviors that may result from differences in structural attributes among lakes. With different activity levels (i.e., home range size) of largemouth bass, prey availability and the ability to select energetically profitable prey are dependent upon the size of the individual’s foraging arena (Walters & Juanes, 1993). Because largemouth bass are generalist predators and typically consume the most energetically profitable prey item when available within the foraging arena, we predict optimal foraging despite potential changes in feeding behavior caused by the presence or absence of littoral structure (Hodgson & Kitchell, 1987).
Materials and methods

Study lakes

We examined largemouth bass movement patterns in two Vilas County, Wisconsin lakes (four basins) with no lakeshore residential development in the summer of 2005. Camp (45°59′58.29″ N 89°43′48.53″ W) and Little Rock lakes (45°59′44.69″ N 89°42′12.76″ W) are separated into two basins (i.e., two separate bodies of water in one lake), creating a treatment and reference basin (Fig. 1). Camp and Little Rock are oligotrophic, seepage lakes with average Secchi disk transparencies exceeding 5 m. Both lakes have maximum depths of 10 m.

Little Rock Lake was separated into two basins in 1984 by two poly-vinyl chloride (PVC) curtains, which disallows any movement of fishes or water among basins. Since 1984, Little Rock Lake has been closed to public access and fishing. Little Rock Lake has minimal amounts of aquatic vegetation and about 25% of the surface area is less than 2 m in depth (Fig. 1a). The treatment basin was experimentally acidified throughout the late 1980s and then allowed to recover during the 1990s. The aquatic communities were similar in both basins prior to the CWH removal experiment (Sampson, 1999; Hrabik & Watras, 2002). In 2002, about 75% of the littoral zone CWH was removed from the treatment basin of Little Rock Lake (10.5 ha), reducing CWH (logs > 10 cm in diameter) abundances from 475 logs km⁻¹ to 128 logs km⁻¹ of shoreline (Fig. 1a) (Sass, 2004; Sass et al., 2006b). The reference basin of Little Rock Lake (8.6 ha) remained unchanged (344 logs km⁻¹ of shoreline) throughout the study. The fish community of Little Rock Lake is dominated by largemouth bass and yellow perch (Perca flavescens Mitchill). However, yellow perch abundances have declined to very low levels following the CWH removal in the treatment basin (Sass et al., 2006b). Black crappie (Pomoxis nigromaculatus Lesueur), rock bass (Ambloplites rupestris Rafinesque), and central mudminnow (Umbra limi Kirtland) are also present at low abundances. Largemouth bass densities were not significantly different among basins prior to the CWH removal (Sass, 2004).

Camp Lake is naturally separated into individual basins by a narrow, shallow channel. Little movement of largemouth bass (<1%, 6 of 820 tagged fish) has been observed among the basins of Camp Lake in previous tagging studies and the current study (G.G. Sass, unpublished data). Camp Lake is a trolling-motor only lake, has a primitive boat launch, and receives minimal fishing pressure. Similar to Little Rock Lake, Camp Lake has sparse aquatic vegetation and about 25% of its surface area is less than 2 m in depth (Fig. 1b). In the spring of 2004, we added over 300 trees (1 for every 10 m of shoreline) to the littoral zone of the treatment basin of Camp Lake (17.6 ha), thus increasing CWH abundances from 41 logs km⁻¹ to 141 logs km⁻¹ of shoreline (Fig. 1b). Coarse woody habitat (>10 cm in diameter) from various deciduous and coniferous trees was added. We qualitatively scored added CWH for branching complexity on a 0–3 scale with 0 indicating

![Fig. 1](https://example.com/fig1.png)

**Fig. 1** Coarse woody habitat (CWH) (logs km⁻¹ of shoreline > 10 cm diameter) (white dots) in a) the treatment (LRT) and reference (LRR) basins of Little Rock Lake after the CWH reduction in LRT in the summer of 2002 and b) in the treatment (CT) and reference (CR) basins of Camp Lake after the CWH addition in CR in the spring of 2004. The thin black line denotes the 2 m depth contour in each basin. The thick black line in Little Rock Lake represents the double curtain separating LRT and LRR.
CWH with no branches and 3 indicating a full crown with attached canopy. Of the added CWH, 8.6% of the CWH scored 0, 20.4% scored 1, 28.4% scored 2, and 42.6% scored 3. The reference basin of Camp Lake (8.5 ha) remained unchanged (40 logs km\(^{-1}\) of shoreline) throughout the study. Largemouth bass and bluegill (*Lepomis macrochirus* Rafinesque) are the dominant fish species in Camp Lake. Yellow perch, johnny darter (*Etheostoma nigrum* Rafinesque), and Iowa darter (*Etheostoma exile* Girard) comprise the rest of the fish community. Largemouth bass densities were similar in all four basins in 2005 as determined by Chapman-modified continuous Schnabel mark-recapture population estimates (Ricker, 1975) (Table 1). For the purpose of this study, the four basins provided a gradient of CWH abundances listed here from highest to lowest; Little Rock Lake reference (LRR), Camp Lake treatment (CT), Little Rock Lake treatment (LRT), and Camp Lake reference (CR).

**Radio telemetry**

We surgically implanted radio transmitters (advanced telemetry systems, 3.6 g, 2.4 cm long, 0.7 cm in diameter, 25.5 cm exterior trailing antennae, 55 pulses min\(^{-1}\), 18 ms pulse width, ca. 100-day life span), with unique frequencies, into five largemouth bass in each of the four basins (*n* = 20) in June 2005 to allow tracking of positions. Prior to surgery, we held all largemouth bass for 24 h to decrease stress following capture (Cooke et al., 2003; Suski et al., 2003; Suski et al., 2007). Radio transmitters were inserted into the gut cavity on the mid-line of the ventral side of the fish’s abdomen, just posterior to the pelvic girdle. All largemouth bass survived the surgical procedure and recovered. After surgery and a 24-h holding period, we released the largemouth bass into their separate basins and radio tracking began 7-days later to allow sufficient time for healing and for largemouth bass distributions to be established. We conducted all surgical procedures using aseptic techniques. During the study, we were unable to track two largemouth bass in LRR and one largemouth bass in CR due to transmitter failure, transmitter expulsion, mortality due to unknown causes, or harvest by anglers in Camp Lake. One largemouth bass in LRR either lost its transmitter or died of unknown causes as we were able to track the stationary signal over time, yet never observed the fish in the shallow, clear water and were unable to recover the transmitter from the sediment. Data from these three fish were not used in our analyses. All 17 largemouth bass used in our analyses were captured by hook-and-line angling and ranged in size from 300 to 395 mm (0.32–0.73 kg). The mean size of the largemouth bass tracked in Little Rock Lake did not significantly differ among basins (LRT = 369 mm, LRR = 368 mm). In addition, there was no significant difference in the mean size of the largemouth bass tracked among basins in Camp Lake (CT = 333 mm, CR = 327 mm).

We used hand-held loop antennae and a Fieldmaster receiver (advanced telemetry systems) to locate radio-tagged largemouth bass. For each largemouth bass, we located its transmitter signal and then approached the signal until the fish was visually observed or the signal sharply changed direction (Fuller et al., 2005). We selected this method because the low conductivity of the study lakes (Little Rock Lake = 13 µmhos; Camp Lake = 16 µmhos) made the range of the radio signals too short for accurate triangulation. We recorded latitude and longitude for each located largemouth bass using a Garmin model 12XL GPS (~5 m accuracy). We surveyed each basin in a john boat with an electric trolling motor.

**Table 1** Experimental and biological attributes of Little Rock and Camp lakes, Vilas County, Wisconsin, USA, with the number of adult largemouth bass (*Micropterus salmoides* Lacepede) tracked, diet breadth, consumption, and population estimates for each basin

<table>
<thead>
<tr>
<th>Lake</th>
<th>Basin (treatment)</th>
<th>Surface area (ha)</th>
<th>Logs km(^{-1}) of shoreline</th>
<th>No. of LMB tracked</th>
<th>Diet breadth</th>
<th>Consumption (g diet(^{-1}))</th>
<th>LMB density with 95% CI (no. ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>LRT (− wood)</td>
<td>10.5</td>
<td>128</td>
<td>5</td>
<td>3.9</td>
<td>0.091</td>
<td>98 (82–121)</td>
</tr>
<tr>
<td></td>
<td>LRR (Control)</td>
<td>8.6</td>
<td>344</td>
<td>3</td>
<td>2.9</td>
<td>0.154</td>
<td>106 (85–134)</td>
</tr>
<tr>
<td>Camp</td>
<td>CT (+ wood)</td>
<td>17.6</td>
<td>141</td>
<td>5</td>
<td>2.2</td>
<td>0.144</td>
<td>64 (47–95)</td>
</tr>
<tr>
<td></td>
<td>CR (Control)</td>
<td>8.5</td>
<td>40</td>
<td>4</td>
<td>1.95</td>
<td>0.066</td>
<td>86 (49–229)</td>
</tr>
</tbody>
</table>

LRT = Little Rock Lake treatment, LRR = Little Rock Lake reference, CT = Camp Lake treatment, CR = Camp Lake reference, CI = Confidence interval, and LMB = Largemouth bass
from 7 July 2005 to 25 August 2005 using the cyclic sampling design described below. Because largemouth bass home range sizes may change seasonally, our tracking was limited to a 7-week summer period to reduce any bias associated with spawning and overwintering movements.

We located largemouth bass according to a cyclic sampling schedule based on a 3/7 cycle (Clinger & Van Ness, 1976; Burrows et al., 2002). This design allowed us to efficiently measure both fine-scale and broad-scale patterns of largemouth bass movements. Each week, for 7 weeks, we located the largemouth bass midmorning on Monday, Tuesday, and Thursday (i.e., three sampling days per 7 days = 3/7 cycle). In addition, on Tuesdays, we located each largemouth bass 12-h later than when located midmorning. On Thursdays, we located each largemouth bass at 4, 6, or 8 h time intervals for 24-h. This sampling design resulted in about 50 marked locations per largemouth bass at a variety of temporal lags.

Telemetry data analyses

We used an adaptive kernel-based estimation procedure to calculate the home range size of each largemouth bass. We chose this method because it is non-parametric and not affected by auto-correlated data (Kernohan et al., 2001). The input into the kernel estimator is the measured locations for each individual largemouth bass. The estimated value of the utilization distribution (UD) at an observed location is calculated by:

\[
\hat{f}(x) = \frac{1}{nh^2} \sum_{i=1}^{n} K \left[ \frac{x - X_i}{h} \right]
\]

where \( \hat{f}(x) \) is the estimated probability density function, or UD, \( n \) the number of locations, \( h \) the smoothing parameter or bandwidth, \( X \) contains the \( x \) and \( y \) coordinates for the \( n \) observed locations, \( x \) the point at which the kernel estimate is calculated, and \( K \) the kernel function (Worton, 1989). The estimated home range area can be thought of as the sum of \( n \) separate kernel functions, each centered at a marked location (Silverman, 1986). The bandwidth (\( h \) value) controls the width of the individual kernels, and therefore, the amount of smoothing applied to the home range estimation. Large bandwidth values result in greater smoothing of the data, while a small bandwidth value creates less smoothing and smaller kernels. A different \( h \) value, depending upon the distribution of the fish’s locations, is used to calculate each individual home range. A common method to calculate the bandwidth value for each fish is to use least squares cross validation (LSCV), which minimizes error between the estimated and true density (Kernohan et al., 2001). We used the LSCV method to calculate the \( h \) value (using the statistical software package R) for individual largemouth bass (Kernohan et al., 2001). We then calculated each fish’s home range size, using the \( h \) value and the marked locations of that largemouth bass, in the statistical software package Biotas 1.03. The home range size of all the largemouth bass in each basin were then averaged to give a mean home range size per basin. For the purpose of this study, the largest possible home range size corresponded to the surface area of the basin. No home range was defined as a fish that was observed in the same location throughout the 7-week study period.

We conducted separate two-tailed \( t \)-tests for each lake to test for the effects of high-and low-CWH treatments on average largemouth bass home range sizes with the null hypothesis of no difference in average home range size among basins (\( \alpha = 0.05 \)). We also used simple linear regression to test for a relationship between mean home range size and CWH abundance with the null hypothesis of no change in slope with increasing CWH abundances among the basins of Camp and Little Rock lakes (ANOVA; \( \alpha = 0.05 \)) due to the similarity of the study systems. CWH abundance was reciprocally transformed to satisfy the assumptions of ANOVA (Draper & Smith, 1998). While our observations among basins were not independent, this regression analysis was statistically valid because we did not use the fitted regression model to make inferences to lakes not in our study (Hurlbert, 1984). Our regression analysis was thus only used to describe relationships between largemouth bass behavior and CWH in our study lakes, and should not be used to make predictions as to the home range size of largemouth bass in other lakes that vary in CWH abundance.

We also calculated the average minimum activity rate (m h\(^{-1}\)) for largemouth bass in each basin. Because we located each bass at a minimum of every 4 h, we defined this metric as a minimum activity rate
to account for longer movements that may have occurred within the 4-h untracked period. For individual largemouth bass, we calculated the minimum movement in every 4-h time interval and standardized this rate among fish as the minimum movement per hour. The movement per hour observed for each bass was then averaged to provide the mean minimum distance moved per hour by largemouth bass in each basin. A separate two-tailed \( t \)-test for each lake was used to test for the effects of differing CWH densities on largemouth bass minimum activity rates with the null hypothesis of no difference in minimum activity rate among basins (\( \alpha = 0.05 \)).

Lastly, we used the radio telemetry data to examine bathymetric spatial distributions of largemouth bass throughout the basins. Largemouth bass locations were described as either being located in \( \leq 2 \) m of water or in water \( > 2 \) m. The 2 m depth contour generally corresponded to the edge of the littoral refuge in each basin. Coarse woody habitat in water \( > 2 \) m in depth was rare in both study lakes (G.G. Sass, personal observation). We recorded the total depth of the water column for every relocated largemouth bass in each tracking period and reported the mean percent of time all largemouth bass in each basin spent in shallow water. We used separate two-tailed \( t \)-tests for each lake to test for differences in the percent of observations where largemouth bass were located in water \( \leq 2 \) m deep among basins with the null hypothesis of no difference in the percent of locations observed \( \leq 2 \) m deep among basins (\( \alpha = 0.05 \)).

Diet analyses

We collected diet information from largemouth bass at biweekly intervals during May–September, 2004–2005 in each basin of Camp and Little Rock lakes. Although our telemetry study was conducted in 2005, we combined post-CWH manipulation diet data to provide a broader picture of largemouth bass diet composition in each basin (LRR, \( n = 163 \); LRT, \( n = 167 \); CR, \( n = 108 \); CT, \( n = 119 \)). All largemouth bass were collected by hook-and-line angling because the low conductivity of the water precluded effective electrofishing. We determined diet composition by performing gastric lavage on at least 10 largemouth bass (range: 10–20) on each sampling occasion in each basin (Seaburg, 1957; Hodgson & Kitchell, 1987). Largemouth bass sizes ranged from 182 to 455 mm and 162 to 411 mm in Camp and Little Rock lakes, respectively. Although our radio-tagged largemouth bass were larger individuals (300–395 mm), ontogenetic diet shifts to piscivory in largemouth bass may occur in the first summer and are generally complete by the second summer of life in north temperate lakes (Post, 2003). The minimum size of the largemouth bass used in our diet analyses were 2–3-year-old individuals; therefore, our radio-tagged largemouth bass should be representative of the fish population sampled for diets (Sass, 2004). Diet items were separated into major taxonomic categories (e.g., Amphipoda, Coleoptera, Diptera, fish, Odonata, terrestrial invertebrate, terrestrial vertebrate, and Trichoptera), enumerated, and dried to determine the dry mass proportion of each prey item in the diet.

An index of absolute importance (IAI) was calculated for each prey category as follows:

\[
IAI_a = \frac{N_a + W_a + FO_a}{2}
\]

where \( N \) was the percentage of the total number of food items represented by food type \( a \), \( W \) the percentage weight (grams of dry biomass) of each food item \( a \) of the total weight of foods eaten, and \( FO \) the frequency of occurrence of each food type \( a \) (the percentage of fish that eat that food type) (George & Hadley, 1979). We then used IAI values to calculate an index of relative importance (IRI) for each prey item:

\[
IRI_a = 100 \frac{IAI_a}{\sum IAI_a}
\]

where \( a \) is the specific food item and the summation in the denominator is taken over all food items. The range of IRI values for any diet was 0–100 (Hodgson & Kitchell, 1987). We calculated diet breadth (\( B \)) for largemouth bass in each basin following Levins (1968):

\[
B = \frac{1}{\sum p_i^2}
\]

where \( p_i \) is the fraction of total diet mass represented by item \( i \) and the summation is over 1. This index is minimized at 1.0 when only one prey type is found in the diet and is maximized at \( n \), where \( n \) is the total number of prey types, each representing an equal proportion of the diet (Schindler et al., 1997).
breadth was calculated to test whether prey proportions and diversity were correlated with CWH abundances and largemouth bass home range sizes among basins. We used separate two-tailed t-tests for each lake to test for differences in largemouth bass consumption rates among basins with the null hypothesis of no difference in consumption rates among the high- and low-CWH treatments in each lake ($\alpha = 0.05$). Consumption rate was log$_e$ transformed to satisfy the assumption of normality for t-tests.

**Results**

Average home range sizes for largemouth bass decreased significantly with increasing levels of CWH among basins (home range size (ha) = $0.443 + 108.57 \cdot \text{CWH abundance}^{-1}$; $n = 4$; $df = 1.2; F = 57.85; P = 0.017; R^2 = 0.97$) (Fig. 2). The home range size of largemouth bass in LRT ($n = 5$) averaged 1.57 ha, while largemouth bass in LRR ($n = 3$) averaged 0.69 ha (Fig. 3). The home range size of largemouth bass in CT ($n = 5$) and CR ($n = 4$) averaged 1.03 and 3.13 ha, respectively (Fig. 3). Average largemouth bass home range size did not significantly differ among treatments in each lake. Overlap of individual home ranges with land was due to home ranges being estimates of probability, not physical space.

Largemouth bass average minimum activity rates were significantly lower in the high-CWH treatments compared to the low-CWH treatments in each lake (LRR vs. LRT, $n = 78$, $df = 76$, $t = 2.26$, $P = 0.03$; CR vs. CT, $n = 90$, $df = 88$, $t = 2.21$, $P = 0.03$). Average minimum activity rates for largemouth bass were LRR ($8.09 \pm 1.86 \text{ m h}^{-1}$), LRT ($13.98 \pm 1.65 \text{ m h}^{-1}$), CR ($18.00 \pm 1.76 \text{ m h}^{-1}$), and CT ($12.05 \pm 1.96 \text{ m h}^{-1}$).

Greater amounts of CWH in a basin resulted in more observations of largemouth bass located in the littoral zone of each lake (LRR vs. LRT, $n = 8$, $df = 6$, $t = 2.91$, $P = 0.03$; CR vs. CT, $n = 9$, $df = 7$, $t = 3.23$, $P = 0.01$). Largemouth bass in
LRT were located in ≤2 m of water during 58% of the recorded locations, while largemouth bass in LRR were found in shallow water 69% of the time. Largemouth bass in CT and CR were found in shallow water 94% and 46% of the time, respectively.

Diet breadth and consumption rates increased in largemouth bass populations across the gradient of lakes from low to high amounts of CWH. Largemouth bass were more selective predators in CR (largest home range size, least CWH) compared to largemouth bass in CT and LRR (smallest home range size, most CWH) (Table 1). In contrast to this pattern, diet breadth was greatest for largemouth bass in LRT. Largemouth bass consumption rates were significantly greater in the high-CWH treatments compared to the low-CWH treatments in each lake (loge LRR vs. loge LRT, n = 330, df = 328, t = 2.16, P = 0.03; loge CR vs. loge CT, n = 227, df = 225, t = 1.92, P = 0.05). Prey biomass per largemouth bass diet (a proxy for consumption rate) increased from 0.066 g diet$^{-1}$ in CR largemouth bass to 0.154 g diet$^{-1}$ in LRR largemouth bass. Intermediate consumption rates were observed in largemouth bass from LRT (0.091 g diet$^{-1}$) and CT (0.144 g diet$^{-1}$) (Table 1).

Fish and odonate nymphs dominated the diets of largemouth bass in all basins, but differed in importance among lakes. Index of relative importance values for fish prey approached 60% for largemouth bass in CR (fish IRI = 58%) and CT (fish IRI = 59%). Largemouth bass diets were more dominated by odonate larvae than fish in LRR (Odonata IRI = 38%) and LRT (Odonata IRI = 25%) (LRR fish IRI = 33%, LRT fish IRI = 23%). Largemouth bass diets in LRT were also supplemented by terrestrial invertebrate and vertebrate prey (terrestrial IRI = 23%).

Discussion

Our study suggests that variability in largemouth bass home range sizes, spatial distributions, and feeding behaviors among lakes may be influenced by CWH. Largemouth bass home range sizes decreased significantly with increasing CWH abundances and average minimum activity rates were lower in basins with greater densities of CWH. Our inability to detect significant differences in largemouth bass home range sizes among basins in each lake may have been a result of low statistical power (Carpenter et al., 1995). We were only able to track up to five largemouth bass in each basin and lost several individuals, which further decreased our statistical power to detect effects. Previous studies of largemouth bass home range sizes and spatial distributions suggest that movements are often influenced by aquatic vegetation (Bain & Boltz, 1992; Demers et al., 1996; Essington & Kitchell, 1999). Our results show similar patterns in largemouth bass movements in lakes with varying levels of CWH. According to Savino & Stein (1982), largemouth bass use a sit-and-wait foraging strategy at high densities of simulated aquatic vegetation and a cruising strategy with decreased levels of structure. Although population density and size–structure may also influence fish movement behaviors, largemouth bass densities and size–structure were not significantly different among treatments suggesting that these factors were not important drivers of differences in movement behaviors among basins. Therefore, the amount of littoral zone structure present in an aquatic ecosystem may be a major factor dictating which foraging strategy a predator uses.

Greater densities of CWH were associated with more observations of largemouth bass in shallow water. The predominant usage of shallow water by largemouth bass in CT (94% of locations ≤2 m) is likely attributable to the amount of complex CWH available (Newbrey et al., 2005). Because 100 logs km$^{-1}$ of shoreline were added to this basin in 2004, greater amounts of structurally complex CWH was available that had not been degraded or buried in sediment compared to LRR. Therefore, our results also suggest that largemouth bass distributions are affected by CWH abundances. The distributions of largemouth bass may be a result of the tradeoff observed between foraging strategies and available littoral zone structure. In concert, perturbations to littoral structure may alter fish behaviors from what would normally be observed in lakes rich with CWH and aquatic macrophytes.

Similar to other studies, the distributions of largemouth bass among basins in our study were variable and likely dependent upon prey distributions. For example, Mesing & Wicker (1986) reported that largemouth bass were consistently observed in both the littoral and pelagic zone, while other studies found that largemouth bass spent nearly all of their time in the littoral zone or directly adjacent to it (Winter, 1977; Essington & Kitchell, 1999). The
study that reports largemouth bass movements in shallow and deep water was from a lake in Florida, which contained both littoral and pelagic prey species. The other studies were in Minnesota and Michigan lakes, which contained prey species generally associated with the littoral zone. Differences in the distributions of largemouth bass among studies may be caused by different prey availabilities and distributions, which can be linked to the presence of littoral structure. With less CWH, prey species may distribute more variably throughout the water column, while high CWH abundances may focus prey in shallow, refuge areas (Sass et al., 2006a; Lewin et al., 2004). For example, Sass et al. (2006a) showed that predation by largemouth bass was focused on the edge of littoral refuge habitats in lakes with high structural complexity and was more diffuse in less structurally complex lakes. In addition, the Sass et al. (2006a) study used tethering of prey to infer largemouth bass distributions in two different lakes than those presented here and found similar results.

Assuming that our radio-tagged fish were indicative of the overall largemouth bass population, largemouth bass with the largest home range sizes were the most selective predators in our study. However, diet breadth in LRT was unusually high compared to the other basins. The treatment basin of Little Rock Lake was subjected to a whole-lake reduction of CWH in 2002, which caused the collapse of the dominant forage fish, yellow perch (Sass, 2004; Sass et al., 2006b). The loss of CWH in LRT likely resulted in a switch in largemouth bass foraging behavior to actively searching, but also caused a decrease in prey selectivity with the loss of the dominant forage fish population. The collapse of the yellow perch population in LRT resulted in a shift in largemouth bass diets from primarily fish to terrestrial sources of prey (Sass et al., 2006b). Given equivalent water temperatures among systems, fish growth is bioenergetically determined by consumption rates, the energy density of prey consumed, and activity costs (Hanson et al., 1997). Therefore, fishes using different optimal foraging strategies may still grow at equivalent rates. For example, a fish that expends little energy foraging and non-selectively feeds on low energy prey at high rates may still grow equivalently to a predator that is actively searching (i.e., high activity costs) and selectively consuming lower amounts of energy-rich prey. Largemouth bass consumption rates were negatively correlated with home range size among basins. Larger home range size and increased prey selectivity resulted in lower consumption rates by largemouth bass in CR and LRT. In contrast, largemouth bass in CT and LRR were less selective, but had higher consumption rates. The lower consumption rates observed in the largemouth bass of CR and LRT do not appear to be strongly correlated with a reduction in prey densities. Bluegill populations remain robust in both basins of Camp Lake, and macroinvertebrate densities did not change and largemouth bass switched to a more terrestrial diet in LRT following the CWH removal (Sass et al., 2006b; Helmus and Sass, 2008). Combinations of lower activity and higher consumption rates may increase growth potential for largemouth bass in the presence of CWH and an energy-rich forage base (Schindler et al., 2000; Sass et al., 2006b). For example, Schindler et al. (2000) reported higher size-specific growth rates in bluegill and largemouth bass from lakes with greater amounts of CWH, while Sass et al. (2006b) observed declines in largemouth bass growth rates following the whole-lake removal of CWH described in the present study.

Our findings supported the prediction that largemouth bass in CWH-rich basins would have smaller home range sizes and be less selective predators. The presence of CWH, similar to simulated aquatic macrophytes, appears to create ambush points for largemouth bass (sit-and-wait foraging strategy) (Savino & Stein, 1982; Sass et al., 2006a). Although this strategy may negatively influence selectivity (i.e., selectivity of prey items is restricted to availability within the home range), increased consumption rates of marginal prey may still provide for optimal growth due to the lack of energy loss associated with actively searching for prey (Hanson et al., 1997). Our observations also supported the prediction of optimal foraging by largemouth bass given differences in movement behaviors associated with various levels of littoral CWH. Despite the foraging strategy used, our empirical diet studies suggest optimal foraging in terms of growth by largemouth bass either having a: (1) small home range and minimum activity rate (i.e., little energy loss due to activity), being a less selective predator, and maintaining higher consumption rates; or (2) large home range and minimum activity rate (i.e., high-energy loss due to activity), being a more selective predator, and maintaining
lower consumption rates. According to bioenergetics principles, these two foraging strategies would maximize growth potential given that littoral structure appears to alter the type of feeding behavior used.

The results of our study provide further support that CWH is a critical feature of lakes (Schindler et al., 2000; Newbrey et al., 2005; Sass et al., 2006b). Removal of CWH, which is commonly observed as a consequence of the lakeshore residential development process, may alter home ranges, distributions, and feeding habits of largemouth bass. In addition to effects on largemouth bass, these changes in home range size and movement patterns may also have negative consequences for small fishes and macroinvertebrates (Sass et al., 2006b). Our results further suggest that CWH augmentation may reverse some of the negative effects of anthropogenic CWH removal on fish behavior. Future research should be aimed to track a greater number of largemouth bass in a larger number of systems over a gradient of fish sizes to determine intra-population, size-specific, and threshold effects of CWH on fish home ranges, distributions, and feeding habits.

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References


Direct Observations of Largemouth and Smallmouth Bass in Response to Various Brush Structure Designs in Ruth Reservoir, California

by Gregory J. Bryant

Abstract

The purpose of this study was to evaluate the effectiveness of three brush structure designs as spawning cover and rearing habitat for largemouth and smallmouth basses, and to observe the interaction of all species around the structures compared to natural habitat locations. Comparisons of habitat utilization by young-of-year, juvenile, and adult largemouth and smallmouth basses were made between control sites, structures, and between sampling dates within and between each cove. The use of the brush structures and control sites were evaluated by two divers using SCUBA. Adult basses were occasionally observed in habitats located towards the back of coves; however, after spawning, adult basses utilized rocky point habitats and brush structures located near the entrances of coves adjacent to deep water channels, through the summer and fall in 1989 and 1990. As water temperatures increased and water levels remained constant through the spring and fall, juvenile basses were found to utilize backwater areas and structures located towards the back of coves. When water temperatures and levels decreased rapidly, juvenile basses migrated out of shoreline habitats to brush structures and control sites located toward the entrances of coves in deeper water. Young-of-year basses were found to utilize backwater area habitats and brush structures located towards the back of coves. As the number of juvenile basses increased in backwater areas, young-of-year basses migrated towards brush structures located near the entrances of coves. The discrete open center structure was the most utilized of the three designs by young-of-year, juvenile, and adult largemouth and smallmouth basses in 1989 and 1990. However, both the continuous open center and dense design structures were utilized by largemouth and smallmouth basses more than shoreline areas with no aquatic vegetation or woody debris. Water temperature, water level, brush structure location, and brush structure design were found to be the most important physical factors influencing habitat utilization by both largemouth and smallmouth basses in Ruth Reservoir.
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**Purpose**

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Introduction

Largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*) are two of the principle warm water predators in lakes and reservoirs. They are often found in open water areas, but are usually associated with shoreline cover or deep water structures (Vogele and Rainwater 1975; Warden and Lario 1975; Savitz et al. 1983). Largemouth bass, the most common black bass species in California, are native to the eastern part of the United States. It is primarily a fish of lakes, ponds, oxbows, and the quieter portions of flowing water (Robbins and MacCrimmon 1974). They grow best in clear water with aquatic vegetation; the adults prefer areas with abundant macrocover such as stumps, dead trees, tree roots, or large rocks (Aggus and Elliot 1975; Morgenson 1983). Smallmouth bass also are native to the eastern United States. Smallmouth bass prefer clear-water lakes and cool streams with moderate current, and rock and gravel substrate (Robbins and MacCrimmon 1974). In lakes and reservoirs, smallmouth bass live in rocky-rubble sites and areas with stumps and vegetation (Forney 1972; Pflug and Pauley 1984; Kraai and Munger 1991).

The magnitude of water level fluctuations in reservoirs resulting from irrigation, hydroelectric generation, industrial, and municipal needs often precludes the establishment of a suitable and stable littoral zone in the form of rooted aquatic vegetation (Brouha and Von Geldern 1979). In addition, several other physical conditions such as turbidity, shoreline erosion, poor soils, and steep sideslopes further inhibit rooted aquatic growth. As a reservoir ages, terrestrial vegetation in newly flooded basins which help stabilize the shoreline and provide spawning and nursery habitat for warm water fish, is gradually lost. The loss of these materials is believed to be responsible, in part, for the observed declines in production of certain littorally-oriented species such as largemouth and smallmouth basses which are heavily dependent on stable and sheltered shorelines (Von Geldern 1971; Forney 1972; Aggus and Elliot 1975; Wege and Anderson 1979; Stuber et al. 1982; Ploskey 1982; Morgenson 1983; Anderson 1984; Durocher et al. 1984).

In an effort to provide adequate spawning, rearing, and cover habitat in littoral zones, habitat enhancement structures have been used extensively in the eastern and southern portions of the United States (Rodeheffer 1939, 1940, 1945; Sheridan 1957; Thomas et al. 1968; Crumpton and Wilbur 1973; Prince and Brouha 1973; Brouha 1974; Prince et al. 1975; Majure 1977; Prince and Maughan 1977; Reeves et al. 1977; Pierce and Hooper 1979; Smith et al. 1980; Hasse 1986; Hoff 1991) and now have become an important fishery management tool in the west (Bartholomew 1972; Pollard 1974; Vogel and Rainwater 1975; Brouha and Von Geldern 1979; Fitch 1982; Larson et al. 1986; Warnecke and McMahon 1988; Cross 1989; Lee and Gleason 1989; Christenson 1990; Cofer 1991; Mabbot 1991; Uberuaga and Bizios 1991). However, there has been very little information presented on the seasonal utilization and intraspecific behavior of bass associated with brush structures versus natural habitats within fluctuating reservoirs and lakes.

The purpose of this study was to evaluate the effectiveness of three specific brush structure designs as spawning cover and as rearing habitat for largemouth and smallmouth basses compared to natural habitat locations. In addition, the interaction of all species around the structures compared to natural habitat locations were observed.
Study Site

Ruth Reservoir is impounded behind R. W. Matthews Dam (completed in 1961), at the headwaters of the Mad River in Trinity County, California. This water supply reservoir, about 127 river kilometers (79 river miles) from the Pacific Ocean, provides municipal and industrial water for the Humboldt Bay area. The reservoir is 11 kilometers (7 miles) long, has a mean width of 0.6 kilometers (0.4 miles), a maximum surface area of 445 hectares (1100 acres), a maximum storage capacity of 64 million meters$^3$ (2.2 billion feet$^3$), and a mean depth of 14.4 meters (47 feet) at maximum pool. Water level fluctuates about 10 meters (33 feet) annually and is lowest in fall and highest in winter and spring.

Methods

Eight manzanita (*Arctostaphylos manzanita*) brush structures of three designs (dense, discrete open center, and continuous open center (Figure 1) were placed in selected areas in the reservoir during low water in fall of 1988. Each structure was 35 meters (115 feet) long, 3 meters (10 feet) high, and 4 meters (13 feet) wide. Structures were cabled together with 0.32 centimeters (0.12 inches) diameter wire, and weighted with cement blocks every 2 meters (7 feet). Single structures of each design was placed in two coves and two discrete open center structures were placed in a third cove (figure 2).

Nine control sites were established in spring 1989 and were representative of three basic habitat types: rocky points (substrate consisting of large rocks or boulders located adjacent to deep water), backwater areas (substrate consisting of silt, sand and/or gravel located towards the back of coves), or shorelines with aquatic vegetation (substrate consisting of silt, sand, and/or gravel located throughout the reservoir). Five control sites were in coves with brush structures, one in a fourth cove and three in the open reservoir (one at north end, middle, and south end). Each control site was 35 meters (115 feet) long and 4 meters (13 feet) wide.

![Figure 1. Brush structure designs for Ruth Reservoir, Trinity County, California](image-url)
Transects were established at the eight brush structures and nine control sites. All transects were perpendicular to the shoreline. Two wire baskets 25.4 centimeters (10 inches) x 12.7 centimeters (5 inches) x 7.6 centimeters (3 inches) filled with gravel were placed at the deep-water corners of all transects to mark deep water transect boundaries.

Physical descriptions of transects were observed and recorded using the following criteria: structure type or control site habitat type, percent slope (gradual 0-10 percent, moderate 11-40 percent, steep >40 percent), general abundance of vegetation and naturally occurring woody debris (absent 0 percent, spotty 1-10 percent, moderate 11-40 percent, heavy >40 percent) (Table 1). Percent slope was measured with a clinometer at low water level in the fall of 1989.
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*aSee Figure 2 for transect locations*

Table 1. Description of transects for direct observations in Ruth Reservoir, Trinity County, California.
The use of the brush structures and control sites were evaluated by two divers using SCUBA (Bryant, in press). The sites were sampled every other week from July through September in 1989 and 1990. Comparisons of habitat utilization by young-of-year <5.0 centimeters (<2 inches), juvenile 5.0-20.5 centimeters (2-8 inches) and adult >20.5 centimeters (>8 inches) largemouth and smallmouth basses were made between control sites, structures, and between sampling dates within each cove and between the coves for each size group of bass.

Data were analyzed separately each year using Friedman’s test (Zar 1984). If Friedman’s test indicated a significant difference (P ≤ 5 percent), then it was followed with a non-parametric multiple comparisons test (Wilcoxon and Wilcox 1964). To eliminate repetition, the term “bass” or “basses” as used in this paper will include both species unless otherwise stated.

**Results and Discussion**

**Young-of-Year Basses:**

Total number of observed young-of-year basses increased across all transects from 1989 to 1990 (figure 3). This increase of young-of-year basses

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**Figure 3.** Total number of young-of-year largemouth and smallmouth basses observed by habitat type in Ruth Reservoir, Trinity County, CA 1989 and 1990.
was possibly due to a more successful spawning season in 1990 as was indicated by spawning surveys (Reck, in preparation).

Previous studies have reported that large numbers of young-of-year centrarchid basses utilized artificial structures for shelter (La Roche 1972; Prince and Brouha 1973; and Pollard 1974). The structures in Ruth Reservoir did serve as shelters for both young-of-year bass species in the summer of 1989 and 1990. In 1989 young-of-year bass were more frequently observed utilizing the discrete open center structures located towards the back of coves; however, in 1990 both the discrete open center and dense design structures were equally utilized. As the water level in Ruth Reservoir was drawn down and the numbers of juvenile fish increased in backwater locations, young-of-year basses were found to utilize shoreline areas of the dense design structures located towards the entrances of coves. The majority of the aquatic macrophyte beds located in backwater areas had been dewatered by September, and the dense design structures offered the most cover and an abundant source of invertebrate prey for young-of-year basses.

Backwater area control sites consistently had higher numbers of young-of-year basses than all other transect locations. These areas typically were shallower in slope, warmer, the most protected from the wind, and usually had a dense to moderate growth of aquatic macrophytes. There were also tremendous numbers of aquatic invertebrates in the backwater areas, and the aquatic macrophytes (primarily *Potamogeton pusillus*; *P. nodosus*; and *P. amplifolius*) supplied the thickest cover for young-of-year bass. Okeyo and Hassler (1985) found that aquatic invertebrates made up the largest part of the diet of young bass in Clair Engle Lake, California.

Young-of-year basses seemed to have been migratory from the time they left the nest through dispersion into the available shoreline habitats in Ruth Reservoir in both years. Several schools of mixed young-of-year largemouth and smallmouth basses, with either an adult largemouth or smallmouth bass in attendance, were observed moving into brush structured transects each year. After only one day on the structures, the schools of integrated young-of-year basses dispersed along the shoreline edge into mats of aquatic vegetation, and the adult departed. Exchange of fish schools between adjacent coves and migration into shallow waters occurred frequently in Ruth Reservoir. Allan and Romero (1975) found similar results in their study which reported that inventories of bass fingerling populations were severely complicated in defined study areas as a result of lateral and vertical dispersion which progressed through the summer months. In Ruth Reservoir, when young-of-year bass were found, they were in mixed schools of largemouth and smallmouth bass, black crappie (*Pomoxis nigromaculatus*), golden shiner (*Notemigonus crysoleucas*), bluegill (*Lepomis macrochirrus*), and green sunfish (*Lepomis cyanellus*).

**Juvenile Basses:**

Juveniles represented the majority of total bass observed throughout all transect locations in 1989 and 1990 (figure 4). However, their numbers decreased from 1989 to 1990 across all transect types. A decrease in juvenile bass numbers in 1990 surveys could have been due to larger juvenile bass in 1989 surveys growing to the adult size classification in 1990 surveys and low recruitment of young-of-year bass from 1989 surveys.

Juvenile bass more frequently utilized the discrete open center design structures than the
continuous open center and dense design structures. Higher numbers of juvenile smallmouth bass were observed on the structures in 1989 than largemouth bass juveniles, but each were equally represented in 1990.

Backwater control sites were the most frequently utilized control site type for both species of juvenile bass in both years. In 1989 and 1990, rocky points and shoreline areas with spotty to moderate amounts of aquatic macrophytes were equally utilized habitats by both species of juvenile bass.

Juvenile bass numbers increased in backwater control sites and structure sites as the season progressed and water temperatures exceeded 22 C (71 F), peaking in late July for largemouth bass, and August and September for smallmouth bass. Juvenile bass numbers remained fairly constant in these locations through most of the season as long as water levels and temperatures remained steady. Juvenile bass were predominantly found within 1.0 meter (3 feet) of the waters surface in backwater channels and structures during mid-summer, and then were
found 3-8 meters (10-26 feet) deep as they migrated vertically from shoreline habitats when water temperatures dropped more than 2°C (3.5°F) in August and September of 1989 and 1990. Rodeheffer (1945), who compared fish utilization of brush structures located at depths of 1.5, 3.0, and 4.6 meters (5, 10, and 15 feet), found that during July and August, juvenile bass preferred structures in shallow water at the 1.5 meters (5 feet) level. Prince and Brouha (1973) reported that immature bass were found in greatest numbers on structures located in shallow water during summer months in Smith Mountain Lake, Virginia. In Ruth Reservoir, shallow water habitats that were warmer, protected from the wind, had higher concentrations of potential prey species, and offered cover in the form of brush structures or aquatic macrophytes adjacent to deeper water were the most selected locations by both species of juvenile bass.

**Adult Basses:**

Total number of adult basses observed increased from 1989 to 1990 across all transect

![Figure 5. Total number of adult largemouth and smallmouth basses observed by habitat type in Ruth Reservoir, Trinity County, CA 1989 and 1990.](image)
types (Figure 5). This increased number of adult bass could be attributed to the recruitment of 1989's larger juveniles into the adult size category for 1990 surveys which was mentioned previously.

The discrete open center structure was the most utilized structure design for both species of adult bass throughout the study. Largemouth bass adults primarily concentrated on the structures April through May in 1989 and 1990. Smallmouth bass adults utilized all structures more than the adult largemouth bass throughout the study each year. This could have been an artifact of natural segregation of largemouth and smallmouth bass within Ruth Reservoir. The south end of the reservoir was typically shallower and had the majority of aquatic macrophyte beds; whereas, the north end was typically steeper and had very limited areas of aquatic macrophyte beds.

Rocky points were the most inhabited control site type throughout the reservoir by both adult bass species in Ruth Reservoir. Rocky points offered adult basses deep water escape routes and excellent feeding areas among the rocks. As the seasons progressed from spring to fall and the water level dropped, greater numbers of adult bass species were found to utilize rocky points.

The structures in Ruth Reservoir attracted pre-spawning adult basses in 1989 and 1990 as water temperatures exceeded 13 C (55 F). Largemouth bass grouped together at the shallow end of structures, in less than 1.6 meters (5 feet) of water, and smallmouth bass were spread throughout the structures from 1.0-4.5 meters (3-15 feet) of water. In Ruth Reservoir the structures seemed to be a grouping area for adult bass to gather and begin their courtship behavior; however, only two largemouth bass nests were found near brush structures each year. La Roche (1972) found that large-mouth bass and pumpkinseed sunfish (Lepomis gibbosus) spawned in the vicinity of brush structures in Sand Pond, Maine. Vogele and Rainwater (1975) reported that spotted bass (Micropterus punctulatus) and largemouth bass in Bull Shoals Reservoir selected areas adjacent to brush shelters as spawning sites, but that smallmouth bass did not. As water temperatures approached 20 C (68 F) in Ruth Reservoir, there was an increase in numbers of golden shiners, green sunfish, and juvenile basses in shallow water transects in less than 3 meters (10 feet) of water. Because of the increased numbers of fish species in transect locations, adult bass may have been forced to select nesting locations in areas less disturbed by potential predators.

As the water warmed to 20 C (68 F) in Ruth Reservoir, most adult bass began to move away from the structures and were observed roaming the shoreline within all coves, possibly looking for spawning companions. Once spawning behavior began, the numbers of adult largemouth bass remained low on the structures and backwater areas throughout the season for both years. Adult bass were occasionally observed in habitats located towards the back of coves. However, after spawning, adult basses utilized rocky point habitats and brush structures located near the entrances of coves, adjacent to deep water channels, through the summer and fall in 1989 and 1990. The few adult bass observed on the structures after spawning were usually located in the middle and deeper ends of the structures, preferring 3 meters (10 feet) of water depth and deeper. They normally were solitary and were located within the inside and outside edges of the structures. Shoreline areas devoid of structures, backwater areas, and structures located towards the back of coves were generally not utilized by the adult basses after spawning.
Other Benefits of Brush Structures:

In other studies, biologists have reported increased production in plant and animal populations associated with artificial structures. Tarzwell (1936) reported that algae, crayfish, and aquatic insects were more abundant in brush shelter areas than in non-shelter areas of Douglas Lake, Michigan. Thomas and Bromley (1968), who evaluated the same brush shelters 30 years later, found that those structures contributed to the establishment of rooted aquatic vegetation and algae. Chaflin (1968) observed large numbers of aquatic invertebrates, mostly midge larvae, associated with periphyton on submerged trees in two Missouri River reservoirs.

The structures in Ruth Reservoir were colonized by periphyton within the first year, and by 1990 long filamentous green algae covered all of the structures. Increased numbers of aquatic invertebrates associated with the structures were seen as well as increased sediment at the base of all the structures. The increase of sediment load around each structure was beneficial in many ways: it was an excellent base for aquatic macrophytes to root, decreased shoreline erosion, and the structures decreased the wave energy impacting the shoreline. Consequently, aquatic macrophytes became well established within the boundaries and adjacent to the leeward side of the structures.

Although artificial structures are not a panacea for every bass management problem, the results show that such structures can indeed benefit the bass fishery in shelter-deficient lakes and reservoirs. With a better understanding of habitat utilization by specific age classes of fish, and the seasonal variations associated with habitat use, fishery managers will have greater success with the proper design, placement, and monitoring of structures. Furthermore, by understanding lateral and vertical migration patterns of fishes in reservoirs and lakes as it relates to fluctuating water levels and water temperatures, fishery managers can develop a more comprehensive habitat enhancement program directed towards specific age classes of fish under varying conditions.

Acknowledgments

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Conclusions

Behavior of basses associated with artificial structures has not been well studied or documented. Direct observations at Ruth Reservoir are far from conclusive, but generally support the thesis of seasonally localized bass stocks associated with structured areas.

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Impact of Predation by Smallmouth Bass on Sockeye Salmon in Lake Washington, Washington

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Abstract.—In the Lake Washington basin, run sizes of sockeye salmon Oncorhynchus nerka and other anadromous salmon species declined during the 1980s. Reduced survival of juvenile sockeye salmon in the lake suggested that increased predation may have contributed to the decreased run size. Introduced smallmouth bass Micropterus dolomieu were considered to be a potential cause of increased predation on juvenile salmonid populations. Ultrasonic tracking showed limited spatial and temporal overlap between smallmouth bass and juvenile sockeye salmon. Substantial overlap occurred only in the littoral zone during the migration of the sockeye salmon fry from the Cedar River into the lake and during the out-migration of smolts from the lake through the Lake Washington Ship Canal into Puget Sound. Salmonids occurred in smallmouth bass stomachs only during the out-migration of smolts from Lake Washington to Puget Sound. For smallmouth bass larger than 150 mm total length, juvenile salmonids constituted 28% of the diet in the lake and 38% in the Lake Washington Ship Canal area during the out-migration. A bioenergetics model was used to estimate an annual consumption of 76.7 g of juvenile salmonids by each smallmouth bass in the lake and 105.9 g of juvenile salmonids in the Ship Canal area. These data were used to estimate total consumption of juvenile salmonids by the smallmouth bass population. However, there is little evidence that predation by smallmouth bass has increased over the past two decades.

During the early to mid 1980s, both the number of returning adult sockeye salmon Oncorhynchus nerka and the estimated freshwater survival of juveniles declined markedly in the Lake Washington population. One potential explanation was increased predation by introduced smallmouth bass Micropterus dolomieu or other piscivorous species. The predominant piscivores present in Lake Washington are cutthroat trout O. clarki, northern pikeminnow (formerly called northern squawfish) Ptychocheilus oregonensis, rainbow trout O. mykiss, yellow perch Perca flavescens, largemouth bass M. salmoides, and smallmouth bass. Of these, the northern pikeminnow, cutthroat trout, and rainbow trout are native; the other three species were introduced to the lake over the last century (Ajwani 1956). Rainbow trout abundance has been increased substantially through stocking efforts. Many of these piscivores feed extensively in the littoral zone. Juvenile sockeye salmon also occupy the littoral zone during late February–April when fry (approximately 25 mm total length, TL) migrate from spawning streams before moving offshore to the limnetic zone and again from April to June when smolts (approximately 125 mm TL) migrate to the ocean (Woody 1972; Pflug 1981; Curet 1993; Martz et al. 1996). Juvenile sockeye salmon may be particularly susceptible to predation during these time periods. All species of anadromous salmonids must pass through the littoral zone and are susceptible to predation during their out-migration to the ocean.

Smallmouth bass can have a wide range of effects on juvenile salmonid populations. Specific effects depend on factors such as timing of salmonid out-migration, salmonid species, and residence of the juvenile salmonids in lentic or lotic environments (Warner 1972; Pflug and Pauley 1983; Gray et al. 1984; Poe et al. 1991; Shively et al. 1991; Tabor et al. 1993). Given the potentially large impact of piscivorous smallmouth bass on juvenile salmonid populations, effects could become more severe if smallmouth bass abundance increased over time or if diet and distribution shifted to increase the contribution of juvenile salmonids in the diet through increased spatial overlap or duration of predation.

Very little information exists regarding the population size or ecological role of smallmouth bass in Lake Washington. Smallmouth bass data from studies that targeted other species (Nishimoto 1973; Beauchamp 1993) were collected using different methodologies and at varying times of year and are difficult to compare. Catch-per-unit-effort

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(CPUE) data from multiple bass tournaments held on Lake Washington each year suggest that the smallmouth bass population has not increased (Fayram 1996), but the extent to which this population impacts juvenile salmonids is unclear. Both sockeye salmon and smallmouth bass are popular game fish in Lake Washington. Given the potentially large detrimental impact of smallmouth bass on sockeye salmon and the importance of efficiently managing the fisheries for both species, we investigated interactions between these two species.

Although sockeye salmon may have been native to Lake Washington and kokanee, the freshwater nonmigratory form, was apparently abundant in the 1890s (Scale 1895), sockeye salmon were introduced into Lake Washington primarily from Baker Lake, Washington, and Cultus Lake, British Columbia, between 1917 and 1954 (Ajwani 1956). By the mid 1960s, the population had increased sufficiently to support a fishery that has been managed by state and tribal agencies since 1967 (Fresh 1994). The recreational fishery has historically been opened when the run size exceeds the escapement goal of 350,000. This has occurred 13 times since 1967, including the most recent opening in 1996.

Previous studies of diet composition of piscivores in Lake Washington (Beauchamp 1990, 1994; Beauchamp et al. 1992) suggest that juvenile sockeye salmon are consumed in relatively large numbers by rainbow and cutthroat trout. It is unclear, however, if these species were responsible for the downward trend in sockeye salmon freshwater survival during the 1980s. Northern pikeminnow also eat large numbers of juvenile sockeye salmon. It has been estimated that they consume up to 30% of the available presmolts in Lake Washington (Eggers et al. 1978). Brocksmith (1999) showed that the composition of the northern pikeminnow diet has changed substantially since the 1970s. However, the role of northern pikeminnow in the reduced freshwater survival of sockeye salmon remains unclear (Brocksmith 1999). It is unlikely that yellow perch have had a substantial impact on juvenile salmonids because juvenile salmonids make up a very small portion of their diet (Costa 1979).

Lake Washington historically contained relatively few largemouth bass (Stein 1970), and our sampling suggested that largemouth bass abundance has probably declined compared with historic levels. We believe the largemouth bass population is currently too small to have a large impact on the juvenile sockeye salmon population (Fayram 1996).

The principle objective of this project was to determine to what extent predation by smallmouth bass affects the populations of juvenile sockeye salmon and other salmonids in Lake Washington. Smallmouth bass are generally restricted to the littoral zone (Coble 1975; Pflug and Pauley 1983; Daney and Ringer 1991; Kraai et al. 1991), which would limit their interactions with limnetic sockeye salmon. A second objective was to evaluate the potential for predation resulting from spatial and temporal overlap of smallmouth bass and juvenile salmonids. Ultrasonic tracking of individual smallmouth bass was used to examine their expected littoral distribution and seasonal movement patterns.

Methods

Study site.—Lake Washington is a large monomictic lake adjacent to Seattle, Washington (Figure 1). It is approximately 30 km long, 4 km wide, and reaches a depth of approximately 70 m. Temperatures in the lake range from about 7°C during the winter to about 22°C in the summer. The lake is generally thermally stratified from April through November. Variations in the species composition, nutrient loading regimes, and physical alterations to the lake have dramatically altered food web interactions (Ajwani 1956; Edmondson 1991). Changes in the species composition in the lake as a result of natural fluctuations in population sizes, legal and illegal stocking of exotic and native fish species, and changing levels of commercial and recreational fishing have created a complex and dynamic ecosystem.

Fish collection.—Smallmouth bass were collected for diet analysis and ultrasonic tracking primarily from four widely distributed areas in Lake Washington by electrofishing, gillnetting, and angling (Figure 1). An electrofishing survey by the Washington Department of Fish and Wildlife in the early 1980s showed that these areas contained relatively high concentrations of smallmouth bass compared with other littoral regions of the lake (R. Pfeifer, Washington Department of Fish and Wildlife, personal communication). Each station was sampled one night per month with a sinking horizontal gill net (50 m × 2 m, 14-cm stretch mesh monofilament) during March–September 1995. Nets were set overnight for approximately 12 h. Mortality of the fish in gill nets was low because of the relatively short set time. Each station was also sampled one night each month from May 1995
to July 1995 with electrofishing equipment, generally using a pulsed DC of about 350 V. Several hundred meters of shoreline between prominent landmarks near these stations were sampled. Shocking times ranged from approximately 10 min to 25 min, depending on the size of the sampling area. Electrofishing equipment was not available for sampling after July. Angling was used as often as possible throughout the project because this was the most successful capture method in terms of CPUE and was the only successful method for collecting fish before May. Fish were also obtained from bass fishing tournaments held on Lake Washington in May and September 1995. Generally, the smallmouth bass were tagged with an individually marked "spaghetti tag" before release. Fish with a low probability of survival were not tagged.

**Ultrasonic tracking.**—Ultrasonic transmitters were surgically implanted in seven smallmouth bass collected from various locations. Only fish larger than 0.4 kg received ultrasonic tags because transmitters larger than 2% of fish body weight may negatively affect behavior (Ross and McCormick 1981). Fish were anesthetized with tricaine methanesulfonate (MS-222, 10 mg/L) and then placed in a basin containing aerated water, MS-222 (5 mg/L), and NaCl (1% solution). The ultrasonic transmitters, previously sterilized in ethyl alcohol, were inserted into the abdominal cavity through a 5-cm incision along the ventral line posterior to the pelvic fins, and the incision was stitched closed with suitable thread (Colle et al. 1989). Fish were held for recovery and observation for a minimum of 1 d before release in open water at the mouth of Union Bay (Figure 2).

Ultrasonic tracking was conducted on a monthly basis throughout the year. The transmitters (Sonotronics model CHP-87-S) operated on a frequency of 75 kHz with projected battery life of 6 months. Tagged fish were located with a Sonotronics USR-5 receiver and directional hydrophone. Individual fish were located by first using these instruments at their last known location. If the fish was not immediately located, the boat was moved approximately 200 m along the shoreline and the procedure was repeated. This continued until the fish was located or until we had traveled the entire perimeter of the lake. The instantaneous position of individual fish was specified with a hand-held global positioning system (GPS) with an accuracy of approximately ±100 m.

Each ultrasonically tagged fish was located at least once a month at dusk, dawn, day, and night. The precise times varied depending on the time of sunrise and sunset on the day of sampling; dawn and dusk were defined as 45 min before until 45 min after sunrise or sunset, respectively. Monthly tracking efforts continued until all of the fish were located during each time interval. Individual fish were tagged and released at different times of year to characterize movements over an entire year. Tracking occurred during July–December 1995 and March–June 1996 (Table 1), providing a general characterization of smallmouth bass movement during all seasons of the year.

**Stomach content analysis.**—Fish for diet analysis were collected from March to September. This period is that of the highest activity and feeding for smallmouth bass. Activity and feeding is greatly reduced in water temperatures below 10°C (Scott and Crossman 1973; Pflug 1981; Curet 1993), and the entire water column in Lake Washington is generally at or below 10°C from November through late April. We were unable to collect

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**Figure 1.**—Sampling locations in Lake Washington. Electrofishing and gill-net sampling was conducted monthly at the designated stations. Fish from unspecified locations were also obtained from anglers during bass tournaments.
samples during the months of April and October due to the inactivity of smallmouth bass.

We examined stomach contents of smallmouth bass larger than 150 mm TL, the smallest size at which smallmouth bass were expected to consume substantial numbers of salmonid smolts (Poe et al. 1991; Tabor et al. 1993). Stomach contents were extracted and examined from 82 smallmouth bass ranging in size from 189 to 470 mm TL. The stomach contents were collected primarily with a stomach-flushing technique (Seaburg 1957). This method is very effective and results in a high recovery of prey (98%) and a high survival rate (approximately 90%) in bass species (Foster 1977). Stomach contents were frozen immediately upon return to the laboratory. The fish were then retained for ultrasonic tagging or released.

The stomach contents were thawed on a number 60 sieve (250-μm mesh) and examined under a dissecting microscope. The contents were identified to the lowest practical taxonomic classification. Fish prey in advanced states of digestion were identified through the use of diagnostic bones such as the cleithrum, opercle, dentary, and vertebrae (Hansel et al. 1988). Occasionally a section of vertebrae or, in some cases, a single vertebra was the only remaining fish material. In this situation, it was extremely difficult to determine the species of the prey. However, it was relatively easy to determine if the prey item was a salmonid or a nonsalmonid based on the shape of the vertebrae. Other prey items were lumped into larger groups based on forage type: (1) other fish, (2) the crayfish Pacifastacus leniusculus, (3) zooplankton, and (4) other invertebrates. "Other invertebrates" were all invertebrate prey items not considered zooplankton. The number of organisms in each group of prey items was counted, and each group of prey items was blotted dry on a paper towel and weighed.

Diet composition was stratified temporally and

**Figure 2.**—Observed locations of ultrasonically tagged smallmouth bass following their release. All fish were released at the mouth of Union Bay. Initial capture location is known for three fish; other fish were obtained from anglers during bass tournaments.

**Table 1.**—Information for tagged smallmouth bass. Number of marks refers to the total times a fish was relocated after release. Fish with unknown capture locations were obtained from fishermen during bass tournaments.

<table>
<thead>
<tr>
<th>Tag number</th>
<th>Release date</th>
<th>Length (mm)</th>
<th>Weight (g)</th>
<th>Number of marks</th>
<th>Capture location</th>
</tr>
</thead>
<tbody>
<tr>
<td>348</td>
<td>17 Jul 1995</td>
<td>400</td>
<td>900</td>
<td>30</td>
<td>Ship Canal</td>
</tr>
<tr>
<td>339</td>
<td>17 Jul 1995</td>
<td>350</td>
<td>650</td>
<td>6</td>
<td>Ship Canal</td>
</tr>
<tr>
<td>249</td>
<td>28 Aug 1995</td>
<td>410</td>
<td>1,400</td>
<td>26</td>
<td>Union Bay</td>
</tr>
<tr>
<td>258</td>
<td>19 Sep 1995</td>
<td>365</td>
<td>950</td>
<td>6</td>
<td>Unknown</td>
</tr>
<tr>
<td>447</td>
<td>19 Sep 1995</td>
<td>325</td>
<td>550</td>
<td>1</td>
<td>Unknown</td>
</tr>
<tr>
<td>384</td>
<td>15 Mar 1996</td>
<td>301</td>
<td>450</td>
<td>2</td>
<td>Unknown</td>
</tr>
<tr>
<td>366</td>
<td>9 May 1996</td>
<td>394</td>
<td>1,300</td>
<td>5</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Table 2.—Growth data for smallmouth bass in Lake Washington. Age was determined from scales. Weight is the arithmetic average for individuals in each age-class.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Number</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>223</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>367</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>470</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>680</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>1,038</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>1,260</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1,250</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>1,950</td>
</tr>
</tbody>
</table>

Spatially. The two time periods were out-migration (April–June) and the remainder of the year when juvenile salmonids were located primarily in the limnetic zone. The two areas were the Lake Washington Ship Canal, Union Bay, Lake Union area (hereafter referred to as the Ship Canal) and the main body of Lake Washington (Figure 1).

Salmonid consumption estimates.—We used a bioenergetics model (Hewett and Johnson 1992) to estimate the annual smallmouth bass consumption of juvenile salmonids. We calculated the relative contribution (percentage by weight) of each prey type to the diet of smallmouth bass in each time period. Ages from a subsample of smallmouth bass were determined using scale analysis (DeVries and Frie 1996). The average weights (Table 2) were plotted against ages for age-classes larger than 150 mm (age 2 and older). The slope of the line obtained from regression analysis was used as the average growth (weight, $g = 216$ age, years $- 483$; $N = 9$, $r^2 = 0.94$).

To calculate consumption, we assumed that the entire smallmouth bass population consisted of fish that weighed 586 g (average weight of the smallmouth bass captured in this study) and gained 216 g/year (average growth rate of the population). The growth curve constructed for smallmouth bass in Lake Washington from scale analysis was essentially linear with age. Therefore, we used average growth because all age-classes experienced essentially the same growth. Average weight of smallmouth bass was used because there is very limited information on smallmouth bass population size structure in Lake Washington.

Temperatures for this model were collected in Lake Washington at 5-m depth throughout 1995 and ranged from a low of 7.1°C in February to a high of 22.2°C in July (data provided by the University of Washington Department of Zoology).

Given the variety of prey items in each prey category, energy densities were approximated from Cummins and Wuycheck (1971) and Hewett and Johnson (1992) to represent each general category. “Salmonids” and “other fish” were assigned a value of 5,000 J/g, “zooplankton” and crayfish were assigned a value of 2,800 J/g, and “other invertebrates” was assigned a value of 3,000 J/g. The model estimated the total grams of juvenile salmonids consumed annually by individual smallmouth bass in each area.

Results

Ultrasonic Tracking

Tracking confirmed that smallmouth bass generally remained in the littoral zone throughout the year (Figure 2), primarily around the mouth of Union Bay. The number of times each tagged fish was successfully located ranged from 1 to 30 (Table 1). Of 76 locations of tagged smallmouth bass, only one was far enough from shore to be considered in the limnetic zone (Figure 2).

Ultrasonically tagged smallmouth bass generally remained alive during the 6-month life expectancy of the tags. If any of the fish had died during the tracking period, they would have been located in the exact same location on successive tracking efforts. Of the five fish that were relocated multiple times, all appeared to establish permanent areas of residence that were restricted to approximately 400 m of shoreline and depths of less than 10 m. Our tracking data did not demonstrate any clear diel movement patterns.

Little information was collected from two of the seven ultrasonically tagged smallmouth bass because they were “lost” almost immediately. These fish may have used an area of the lake where it would be impossible to locate them with the ultrasonic tracking gear. Several littoral areas of the lake are structurally very complex, making ultrasonic tracking difficult. Other possibilities include capture by anglers or malfunctioning tags. An angler on the west side of Lake Washington captured a tagged smallmouth bass (number 258) approximately 3.2 km south of Union Bay 2 months after release.

Diet

Salmonids were only present in stomachs during the smolt out-migration. “Other fish” and crayfish were the other primary food items; invertebrates and zooplankton only represented a small percentage of the total diet at any time of the year. During the smolt out-migration, salmonids repre-
TABLE 3.—Diet composition for smallmouth bass in Lake Washington. Results are stratified spatially and temporally and presented as percent of diet by weight. The major impact of bass predation on salmonids occurs in the Ship Canal during salmonid out-migration (April–June).

<table>
<thead>
<tr>
<th>Diet item</th>
<th>Apr-Jun</th>
<th>Jul-Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ship Canal area (N = 13)</td>
<td>Lake Washington area (N = 28)</td>
</tr>
<tr>
<td>Salmonids</td>
<td>38.0</td>
<td>28.2</td>
</tr>
<tr>
<td>Other fish</td>
<td>3.4</td>
<td>51.1</td>
</tr>
<tr>
<td>Crayfish</td>
<td>58.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Zooplankton</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Other invertebrates</td>
<td>0.0</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Presented 38% of the diet of the smallmouth bass located in the Ship Canal area, “other fish” represented 3%, and crayfish represented 59%. At other times of the year salmonids were absent from the diet, “other fish” represented 67%, and crayfish represented 31%. In the main body of the lake, during salmon smolt out-migration, salmonids made up 28% of the diet, “other fish” represented 51%, and crayfish represented 13%. During the remainder of the year, “other fish” constituted 70%, and crayfish represented 30% of the diet (Table 3). All of the salmonids consumed by captured smallmouth bass were of smolt size (>80 mm).

Salmon Consumption Estimate

The bioenergetics model estimated an annual consumption of 76.7 g of juvenile salmonids per smallmouth bass in the main body of the lake and 105.9 g of juvenile salmonids per smallmouth bass in the Ship Canal area. This translates to approximately 6.4 juvenile salmonids per smallmouth bass in the lake and 8.8 juvenile salmonids per smallmouth bass in the Ship Canal area, assuming an average juvenile salmonid weight of 12 g.

Discussion

Previous studies of smallmouth bass–salmonid interactions have generally shown minimal predation on juvenile salmonid populations (Warner 1972; Gray et al. 1984; Poe et al. 1991; Shively et al. 1991). Substantial predation may occur, however, when smallmouth bass and concentrations of juvenile salmonids overlap significantly in time and space (Pflug and Pauley 1983; Tabor et al. 1993). Although we did not follow the movements of the tagged smallmouth bass continuously, the tracking information confirms the expected littoral distribution throughout the year in Lake Washington.

Other projects have described diel movement patterns of smallmouth bass (Gerber and Haynes 1988; Savitz et al. 1993). However, Lake Washington has a relatively small littoral zone as a result of the steep shoreline gradient. Because smallmouth bass primarily reside in the littoral zone, any onshore–offshore movement patterns would, therefore, take place over short distances. The scale of the tracking data did not allow us to distinguish these patterns, if they occur. The tagged smallmouth bass probably remained near the mouth of Union Bay (Figure 2) because smallmouth bass generally exhibit relatively strong home range tendencies (Hubert and Lackey 1980; Pflug and Pauley 1983; Gerber and Haynes 1988) and several of the tagged fish were initially captured from this area.

Smallmouth bass have physiologically limited consumption during the period when sockeye salmon fry enter the lake (February–April); low water temperature during this time severely limits feeding (Scott and Crossman 1973; Pflug 1981; Curet 1993). In effect, the juvenile sockeye salmon have a thermal refuge from bass predation during their migration to the lake.

The primary impact of smallmouth bass on the populations of juvenile salmonids occurred during out-migration of the smolts from Lake Washington to Puget Sound during late April, May, and June, when the smolts were concentrated in the littoral zone and smallmouth bass were actively feeding. This spatial overlap provides an opportunity for smallmouth bass to consume juvenile salmonids. However, the relatively coarse temporal resolution for diet during this period could overestimate total juvenile salmonid consumption. Data were pooled over the entire period of out-migration (April–June). Because most of the smallmouth bass diet data were collected during the peak of juvenile salmonid out-migration (May and June), we may have overestimated the proportion of juvenile
salmonids in the diet during April and thus overestimated the total consumption of juvenile salmonids during out-migration.

It is difficult to assess the role of smallmouth bass in the decline in juvenile salmonid survival without knowing past population sizes. Based on CPUE data from bass tournaments, there is no evidence that the smallmouth bass population has increased dramatically over the past decade (Fayram 1996). An accurate population estimate for the smallmouth bass in Lake Washington was difficult to obtain because of the large size of the lake and the relatively small number of smallmouth bass sampled.

To obtain a maximum abundance estimate, and thus a worst-case predation loss estimate for salmonids, we calculated a Schnabel estimate (Schnabel 1938) for the sampled area with the highest density of smallmouth bass (station 4) and extrapolated this density to the entire area of the lake that is less than 10 m in depth. At station 4, we tagged 18 fish and recovered 2 tags in a total of 26 captures. The Schnabel point estimate was 141 fish (80% confidence interval, 74–1,496) in an area of approximately 72,000 m². The 80% confidence interval was necessary because of the low number of recaptures. The area less than 10 m in depth was calculated to be approximately 14,023,500 m² in the lake and approximately 4,779,700 m² in the Ship Canal. Extrapolating the point estimate density of smallmouth bass at station 4 to the lake and the Ship Canal area produced an estimated smallmouth bass population of 27,463 in the lake and 9,360 in the Ship Canal area. With these population estimates, the bioenergetics model calculates a yearly consumption of 3,097,667 g of salmonids or approximately 258,139 individual salmonid smolts, each with an average weight of 12 g. This corresponds to approximately 28,395 returning sockeye salmon adults, based on average marine survival of 11%. This population estimate is an extreme upper bound on the maximum abundance and potential predation impact of smallmouth bass on juvenile salmonids because density of smallmouth bass in the entire littoral zone obviously lower than in our sampling areas. The actual impact is certainly much smaller.

Between 1970 and 1990, the estimated out-migration of sockeye salmon smolts ranged from 0.25 to 6.8 million, with an average of 2.73 ± 0.69 million. During this study the estimated out-migration was 2.18 million. Consumption calculated by the bioenergetics model is less than 10% of the average out-migration and is an extreme value that overestimates actual consumption of sockeye salmon smolts for several reasons. In the model, all juvenile salmonids consumed by smallmouth bass were considered to be juvenile sockeye salmon. However, smolts of coho salmon *O. kisutch*, chinook salmon *O. tshawytshca*, and steelhead *O. mykiss* also migrate through the lake during April–June and are expected to occur in the smallmouth bass diet. Including those species in the model would reduce the estimate of predation on juvenile sockeye salmon. More importantly, the four sampling locations for smallmouth bass were chosen precisely because they had high densities of smallmouth bass (Pfeifer, personal communication). We then used the highest density obtained at those sites and extrapolated to the entire lake. This would significantly overestimate population size of smallmouth bass and thus their consumption of prey.

Based on CPUE calculations for electrofishing during the months of May and June (Fayram 1996), smallmouth bass density is 34 times higher in the Ship Canal area than in the lake. If the population estimate is adjusted to reflect the difference in CPUE values, the population estimate for the lake becomes 807 and the population estimate for the Ship Canal area remains 9,360. The total yearly consumption estimate using the revised predator abundance was 1,053,506 g of salmonids or approximately 87,792 smolts. This estimate represents approximately 3.5% of the average estimated number of out-migrating sockeye salmon smolts.

We believe the population estimates based on CPUE values underestimate the lake population and overestimate the Ship Canal population. The lack of quantitative data for smallmouth bass population sizes in Lake Washington makes it difficult to assign a more accurate population size. Despite this uncertainty, both the worst-case and revised estimates of smallmouth bass abundance suggest that this predator represents a minor source of mortality on juvenile sockeye salmon.

The most compelling evidence that smallmouth bass have a small impact on the freshwater survival of juvenile sockeye salmon populations in Lake Washington is based on the timing of the yearly presmolt estimate. Presmolt abundance is estimated by a hydroacoustic survey conducted by the Washington Department of Fish and Wildlife in late March or early April while the juvenile sockeye salmon are still in the limnetic zone. Freshwater survival is estimated from the presmolt: spawner ratio. Therefore, for the calculation
of stage-specific survival rates, freshwater survival ends and marine survival begins at the time of the presmolt survey. Because the primary impact of smallmouth bass occurs during the smolt out-migration, any significant impact by smallmouth bass would be noted as a decrease in the marine survival. However, there has been no obvious downward trend in the marine survival of sockeye salmon during the period of sockeye salmon decline. This suggests that smallmouth bass predation on juvenile salmonids in Lake Washington has had little impact on the observed decrease in sockeye salmon abundance.

Acknowledgments

This project was made possible through the funding from H. Mason Keefer Endowment for Excellence and the Washington Bass Angler Sportsmen's Society. We acknowledge the assistance in data collection and analysis by Gilbert Pauley, Steven Mathews, Scott Bonar, Roger Tabor, Jim Owens, Paul Schlenger, Richard Brocksmith, David Hand, Bob Pfeifer, Barry Thom, and Peggy Barnes. Bob Pfeifer provided equipment and extremely helpful comments on this manuscript. We also thank Doug Fletcher and three anonymous reviewers for providing insightful comments. Finally, we thank David Beauchamp for his extensive discussions and extremely valuable comments through multiple revisions.

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Impact of Predation by Smallmouth Bass on Sockeye Salmon in Lake Washington, Washington

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Abstract.—In the Lake Washington basin, run sizes of sockeye salmon Oncorhynchus nerka and other anadromous salmon species declined during the 1980s. Reduced survival of juvenile sockeye salmon in the lake suggested that increased predation may have contributed to the decreased run size. Introduced smallmouth bass Micropterus dolomieu were considered to be a potential cause of increased predation on juvenile salmonid populations. Ultrasonic tracking showed limited spatial and temporal overlap between smallmouth bass and juvenile sockeye salmon. Substantial overlap occurred only in the littoral zone during the migration of the sockeye salmon fry from the Cedar River into the lake and during the out-migration of smolts from the lake through the Lake Washington Ship Canal into Puget Sound. Salmonids occurred in smallmouth bass stomachs only during the out-migration of smolts from Lake Washington to Puget Sound. For smallmouth bass larger than 150 mm total length, juvenile salmonids constituted 28% of the diet in the lake and 38% in the Lake Washington Ship Canal area during the out-migration. A bioenergetics model was used to estimate an annual consumption of 76.7 g of juvenile salmonids by each smallmouth bass in the lake and 105.9 g of juvenile salmonids in the Ship Canal area. These data were used to estimate total consumption of juvenile salmonids by the smallmouth bass population. However, there is little evidence that predation by smallmouth bass has increased over the past two decades.

During the early to mid 1980s, both the number of returning adult sockeye salmon Oncorhynchus nerka and the estimated freshwater survival of juveniles declined markedly in the Lake Washington population. One potential explanation was increased predation by introduced smallmouth bass Micropterus dolomieu or other piscivorous species. The predominant piscivores present in Lake Washington are cutthroat trout O. clarki, northern pikeminnow (formerly called northern squawfish) Ptychocheilus oreognensis, rainbow trout O. mykiss, yellow perch Perca flavesca, largemouth bass M. salmoides, and smallmouth bass. Of these, the northern pikeminnow, cutthroat trout, and rainbow trout are native; the other three species were introduced to the lake over the last century (Ajwani 1956). Rainbow trout abundance has been increased substantially through stocking efforts. Many of these piscivores feed extensively in the littoral zone. Juvenile sockeye salmon also occupy the littoral zone during late February–April when fry (approximately 25 mm total length, TL) migrate from spawning streams before moving offshore to the limnetic zone and again from April to June when smolts (approximately 125 mm TL) migrate to the ocean (Woody 1972; Pflug 1981; Curet 1993; Martz et al. 1996). Juvenile sockeye salmon may be particularly susceptible to predation during these time periods. All species of anadromous salmonids must pass through the littoral zone and are susceptible to predation during their out-migration to the ocean.

Smallmouth bass can have a wide range of effects on juvenile salmonid populations. Specific effects depend on factors such as timing of salmonid out-migration, salmonid species, and residence of the juvenile salmonids in lentic or lotic environments (Warner 1972; Pflug and Pauley 1983; Gray et al. 1984; Poe et al. 1991; Shively et al. 1991; Tabor et al. 1993). Given the potentially large impact of piscivorous smallmouth bass on juvenile salmonid populations, effects could become more severe if smallmouth bass abundance increased over time or if diet and distribution shifted to increase the contribution of juvenile salmonids in the diet through increased spatial overlap or duration of predation.

Very little information exists regarding the population size or ecological role of smallmouth bass in Lake Washington. Smallmouth bass data from studies that targeted other species (Nishimoto 1973; Beauchamp 1993) were collected using different methodologies and at varying times of year and are difficult to compare. Catch-per-unit-effort

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(CPUE) data from multiple bass tournaments held on Lake Washington each year suggest that the smallmouth bass population has not increased (Fayram 1996), but the extent to which this population impacts juvenile salmonids is unclear. Both sockeye salmon and smallmouth bass are popular game fish in Lake Washington. Given the potentially large detrimental impact of smallmouth bass on sockeye salmon and the importance of efficiently managing the fisheries for both species, we investigated interactions between these two species.

Although sockeye salmon may have been native to Lake Washington and kokanee, the freshwater nonmigratory form, was apparently abundant in the 1890s (Scale 1895), sockeye salmon were introduced into Lake Washington primarily from Baker Lake, Washington, and Cultus Lake, British Columbia, between 1917 and 1954 (Ajwani 1956). By the mid 1960s, the population had increased sufficiently to support a fishery that has been managed by state and tribal agencies since 1967 (Fresh 1994). The recreational fishery has historically been opened when the run size exceeds the escapement goal of 350,000. This has occurred 13 times since 1967, including the most recent opening in 1996.

Previous studies of diet composition of piscivores in Lake Washington (Beauchamp 1990, 1994; Beauchamp et al. 1992) suggest that juvenile sockeye salmon are consumed in relatively large numbers by rainbow and cutthroat trout. It is unclear, however, if these species were responsible for the downward trend in sockeye salmon freshwater survival during the 1980s. Northern pikeminnow also eat large numbers of juvenile sockeye salmon. It has been estimated that they consume up to 30% of the available precocious in Lake Washington (Eggers et al. 1978). Brocksmith (1999) showed that the composition of the northern pikeminnow diet has changed substantially since the 1970s. However, the role of northern pikeminnow in the reduced freshwater survival of sockeye salmon remains unclear (Brocksmith 1999). It is unlikely that yellow perch have had a substantial impact on juvenile salmonids because juvenile salmonids make up a very small portion of their diet (Costa 1979).

Lake Washington historically contained relatively few largemouth bass (Stein 1970), and our sampling suggested that largemouth bass abundance has probably declined compared with historic levels. We believe the largemouth bass population is currently too small to have a large impact on the juvenile sockeye salmon population (Fayram 1996).

The principle objective of this project was to determine to what extent predation by smallmouth bass affects the populations of juvenile sockeye salmon and other salmonids in Lake Washington. Smallmouth bass are generally restricted to the littoral zone (Coble 1975; Pflug and Pauley 1983; Daney and Ringer 1991; Kraai et al. 1991), which would limit their interactions with limnetic sockeye salmon. A second objective was to evaluate the potential for predation resulting from spatial and temporal overlap of smallmouth bass and juvenile salmonids. Ultrasonic tracking of individual smallmouth bass was used to examine their expected littoral distribution and seasonal movement patterns.

Methods

Study site.—Lake Washington is a large monomictic lake adjacent to Seattle, Washington (Figure 1). It is approximately 30 km long, 4 km wide, and reaches a depth of approximately 70 m. Temperatures in the lake range from about 7°C during the winter to about 22°C in the summer. The lake is generally thermally stratified from April through November. Variations in the species composition, nutrient loading regimes, and physical alterations to the lake have dramatically altered food web interactions (Ajwani 1956; Edmondson 1991). Changes in the species composition in the lake as a result of natural fluctuations in population sizes, legal and illegal stocking of exotic and native fish species, and changing levels of commercial and recreational fishing have created a complex and dynamic ecosystem.

Fish collection.—Smallmouth bass were collected for diet analysis and ultrasonic tracking primarily from four widely distributed areas in Lake Washington by electrofishing, gillnetting, and angling (Figure 1). An electrofishing survey by the Washington Department of Fish and Wildlife in the early 1980s showed that these areas contained relatively high concentrations of smallmouth bass compared with other littoral regions of the lake (R. Pfeifer, Washington Department of Fish and Wildlife, personal communication). Each station was sampled one night per month with a sinking horizontal gill net (50 m × 2 m, 14-cm stretch mesh monofilament) during March–September 1995. Nets were set overnight for approximately 12 h. Mortality of the fish in gill nets was low because of the relatively short set time. Each station was also sampled one night each month from May 1995
transmitters larger than 2% of fish body weight may negatively affect behavior (Ross and McCormick 1981). Fish were anesthetized with tricaine methanesulfonate (MS-222, 10 mg/L) and then placed in a basin containing aerated water, MS-222 (5 mg/L), and NaCl (1% solution). The ultrasonic transmitters, previously sterilized in ethyl alcohol, were inserted into the abdominal cavity through a 5-cm incision along the ventral line posterior to the pelvic fins, and the incision was stitched closed with suitable thread (Colle et al. 1989). Fish were held for recovery and observation for a minimum of 1 d before release in open water at the mouth of Union Bay (Figure 2).

Ultrasonic tracking was conducted on a monthly basis throughout the year. The transmitters (Sonotronics model CHP-87-S) operated on a frequency of 75 kHz with projected battery life of 6 months. Tagged fish were located with a Sonotronics USR-5 receiver and directional hydrophone. Individual fish were located by first using these instruments at their last known location. If the fish was not immediately located, the boat was moved approximately 200 m along the shoreline and the procedure was repeated. This continued until the fish was located or until we had traveled the entire perimeter of the lake. The instantaneous position of individual fish was specified with a hand-held global positioning system (GPS) with an accuracy of approximately ±100 m.

Each ultrasonically tagged fish was located at least once a month at dusk, dawn, day, and night. The precise times varied depending on the time of sunrise and sunset on the day of sampling; dawn and dusk were defined as 45 min before until 45 min after sunrise or sunset, respectively. Monthly tracking efforts continued until all of the fish were located during each time interval. Individual fish were tagged and released at different times of year to characterize movements over an entire year. Tracking occurred during July–December 1995 and March–June 1996 (Table 1), providing a general characterization of smallmouth bass movement during all seasons of the year.

Stomach content analysis.—Fish for diet analysis were collected from March to September. This period is that of the highest activity and feeding for smallmouth bass. Activity and feeding is greatly reduced in water temperatures below 10°C (Scott and Crossman 1973; Pflug 1981; Curet 1993), and the entire water column in Lake Washington is generally at or below 10°C from November through late April. We were unable to collect

Figure 1.—Sampling locations in Lake Washington. Electrofishing and gill-net sampling was conducted monthly at the designated stations. Fish from unspecified locations were also obtained from anglers during bass tournaments.
samples during the months of April and October due to the inactivity of smallmouth bass.

We examined stomach contents of smallmouth bass larger than 150 mm TL, the smallest size at which smallmouth bass were expected to consume substantial numbers of salmonid smolts (Poe et al. 1991; Tabor et al. 1993). Stomach contents were extracted and examined from 82 smallmouth bass ranging in size from 189 to 470 mm TL. The stomach contents were collected primarily with a stomach-flushing technique (Seaburg 1957). This method is very effective and results in a high recovery of prey (98%) and a high survival rate (approximately 90%) in bass species (Foster 1977). Stomach contents were frozen immediately upon return to the laboratory. The fish were then retained for ultrasonic tagging or released.

The stomach contents were thawed on a number 60 sieve (250-µm mesh) and examined under a dissecting microscope. The contents were identified to the lowest practical taxonomic classification. Fish prey in advanced states of digestion were identified through the use of diagnostic bones such as the cleithrum, opercle, dentary, and vertebrae (Hansel et al. 1988). Occasionally a section of vertebrae or, in some cases, a single vertebra was the only remaining fish material. In this situation, it was extremely difficult to determine the species of the prey. However, it was relatively easy to determine if the prey item was a salmonid or a non-salmonid based on the shape of the vertebrae. Other prey items were lumped into larger groups based on forage type: (1) other fish, (2) the crayfish *Pacifastacus leniusculus*, (3) zooplankton, and (4) other invertebrates. “Other invertebrates” were all invertebrate prey items not considered zooplankton. The number of organisms in each group of prey items was counted, and each group of prey items was blotted dry on a paper towel and weighed.

Diet composition was stratified temporally and

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**Table 1.** Information for tagged smallmouth bass. Number of marks refers to the total times a fish was relocated after release. Fish with unknown capture locations were obtained from fishermen during bass tournaments.

<table>
<thead>
<tr>
<th>Tag number</th>
<th>Release date</th>
<th>Length (mm)</th>
<th>Weight (g)</th>
<th>Number of marks</th>
<th>Capture location</th>
</tr>
</thead>
<tbody>
<tr>
<td>348</td>
<td>17 Jul 1995</td>
<td>400</td>
<td>900</td>
<td>30</td>
<td>Ship Canal</td>
</tr>
<tr>
<td>339</td>
<td>17 Jul 1995</td>
<td>350</td>
<td>650</td>
<td>6</td>
<td>Ship Canal</td>
</tr>
<tr>
<td>249</td>
<td>28 Aug 1995</td>
<td>410</td>
<td>1,400</td>
<td>26</td>
<td>Union Bay</td>
</tr>
<tr>
<td>258</td>
<td>19 Sep 1995</td>
<td>365</td>
<td>950</td>
<td>6</td>
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</tr>
<tr>
<td>447</td>
<td>19 Sep 1995</td>
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<td>550</td>
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<td>Unknown</td>
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<tr>
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<td>301</td>
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<tr>
<td>366</td>
<td>9 May 1996</td>
<td>394</td>
<td>1,300</td>
<td>5</td>
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</table>
Table 2.—Growth data for smallmouth bass in Lake Washington. Age was determined from scales. Weight is the arithmetic average for individuals in each age-class.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Number</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>12</td>
<td>367</td>
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<td>5</td>
<td>10</td>
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<td>6</td>
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<tr>
<td>7</td>
<td>5</td>
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<td>8</td>
<td>4</td>
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<td>9</td>
<td>1</td>
<td>1,250</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>1,950</td>
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</table>

spatially. The two time periods were out-migration (April–June) and the remainder of the year when juvenile salmonids were located primarily in the limnetic zone. The two areas were the Lake Washington Ship Canal, Union Bay, Lake Union area (hereafter referred to as the Ship Canal) and the main body of Lake Washington (Figure 1).

Salmonid consumption estimates.—We used a bioenergetics model (Hewett and Johnson 1992) to estimate the annual smallmouth bass consumption of juvenile salmonids. We calculated the relative contribution (percentage by weight) of each prey type to the diet of smallmouth bass in each time period. Ages from a subsample of smallmouth bass were determined using scale analysis (Devries and Frie 1996). The average weights (Table 2) were plotted against ages for age-classes larger than 150 mm (age 2 and older). The slope of the line obtained from regression analysis was used as the average growth (weight, g = 216 age, years - 483; N = 9, r² = 0.94).

To calculate consumption, we assumed that the entire smallmouth bass population consisted of fish that weighed 586 g (average weight of the smallmouth bass captured in this study) and gained 216 g/year (average growth rate of the population). The growth curve constructed for smallmouth bass in Lake Washington from scale analysis was essentially linear with age. Therefore, we used average growth because all age-classes experienced essentially the same growth. Average weight of smallmouth bass was used because there is very limited information on smallmouth bass population size structure in Lake Washington.

Temperatures for this model were collected in Lake Washington at 5-m depth throughout 1995 and ranged from a low of 7.1°C in February to a high of 22.2°C in July (data provided by the University of Washington Department of Zoology).

Given the variety of prey items in each prey category, energy densities were approximated from Cummins and Wuycheck (1971) and Hewett and Johnson (1992) to represent each general category. “Salmonids” and “other fish” were assigned a value of 5,000 J/g, “zooplankton” and crayfish were assigned a value of 2,800 J/g, and “other invertebrates” was assigned a value of 3,000 J/g. The model estimated the total grams of juvenile salmonids consumed annually by individual smallmouth bass in each area.

Results

Ultrasonic Tracking

Tracking confirmed that smallmouth bass generally remained in the littoral zone throughout the year (Figure 2), primarily around the mouth of Union Bay. The number of times each tagged fish was successfully located ranged from 1 to 30 (Table 1). Of 76 locations of tagged smallmouth bass, only one was far enough from shore to be considered in the limnetic zone (Figure 2).

Ultrasonically tagged smallmouth bass generally remained alive during the 6-month life expectancy of the tags. If any of the fish had died during the tracking period, they would have been located in the exact same location on successive tracking efforts. Of the five fish that were relocated multiple times, all appeared to establish permanent areas of residence that were restricted to approximately 400 m of shoreline and depths of less than 10 m. Our tracking data did not demonstrate any clear diel movement patterns.

Little information was collected from two of the seven ultrasonically tagged smallmouth bass because they were “lost” almost immediately. These fish may have used an area of the lake where it would be impossible to locate them with the ultrasonic tracking gear. Several littoral areas of the lake are structurally very complex, making ultrasonic tracking difficult. Other possibilities include capture by anglers or malfunctioning tags. An angler on the west side of Lake Washington captured a tagged smallmouth bass (number 258) approximately 3.2 km south of Union Bay 2 months after release.

Diet

Salmonids were only present in stomachs during the smolt out-migration. “Other fish” and crayfish were the other primary food items; invertebrates and zooplankton only represented a small percentage of the total diet at any time of the year. During the smolt out-migration, salmonids repre-
sent 38% of the diet of the smallmouth bass located in the Ship Canal area, “other fish” represented 3%, and crayfish represented 59%. At other times of the year salmonids were absent from the diet, “other fish” represented 67%, and crayfish represented 31%. In the main body of the lake, during salmon smolt out-migration, salmonids made up 28% of the diet, “other fish” represented 51%, and crayfish represented 13%. During the remainder of the year, “other fish” constituted 70%, and crayfish represented 30% of the diet (Table 3). All of the salmonids consumed by captured smallmouth bass were of smolt size (>80 mm).

Salmon Consumption Estimate

The bioenergetics model estimated an annual consumption of 76.7 g of juvenile salmonids per smallmouth bass in the main body of the lake and 105.9 g of juvenile salmonids per smallmouth bass in the Ship Canal area. This translates to approximately 6.4 juvenile salmonids per smallmouth bass in the lake and 8.8 juvenile salmonids per smallmouth bass in the Ship Canal area, assuming an average juvenile salmonid weight of 12 g.

Discussion

Previous studies of smallmouth bass–salmonid interactions have generally shown minimal predation on juvenile salmonid populations (Warner 1972; Gray et al. 1984; Poe et al. 1991; Shively et al. 1991). Substantial predation may occur, however, when smallmouth bass and concentrations of juvenile salmonids overlap significantly in time and space (Pflug and Pauley 1983; Tabor et al. 1993). Although we did not follow the movements of the tagged smallmouth bass continuously, the tracking information confirms the expected littoral distribution throughout the year in Lake Washington.

Other projects have described diel movement patterns of smallmouth bass (Gerber and Haynes 1988; Savitz et al. 1993). However, Lake Washington has a relatively small littoral zone as a result of the steep shoreline gradient. Because smallmouth bass primarily reside in the littoral zone, any onshore–offshore movement patterns would, therefore, take place over short distances. The scale of the tracking data did not allow us to distinguish these patterns, if they occur. The tagged smallmouth bass probably remained near the mouth of Union Bay (Figure 2) because smallmouth bass generally exhibit relatively strong home range tendencies (Hubert and Lackey 1980; Pflug and Pauley 1983; Gerber and Haynes 1988) and several of the tagged fish were initially captured from this area.

Smallmouth bass have physiologically limited consumption during the period when sockeye salmon fry enter the lake (February–April); low water temperature during this time severely limits feeding (Scott and Crossman 1973; Pflug 1981; Curet 1993). In effect, the juvenile sockeye salmon have a thermal refuge from bass predation during their migration to the lake.

The primary impact of smallmouth bass on the populations of juvenile salmonids occurred during out-migration of the smolts from Lake Washington to Puget Sound during late April, May, and June, when the smolts were concentrated in the littoral zone and smallmouth bass were actively feeding. This spatial overlap provides an opportunity for smallmouth bass to consume juvenile salmonids. However, the relatively coarse temporal resolution for diet during this period could overestimate total juvenile salmonid consumption. Data were pooled over the entire period of out-migration (April–June). Because most of the smallmouth bass diet data were collected during the peak of juvenile salmonid out-migration (May and June), we may have overestimated the proportion of juvenile
salmonids in the diet during April and thus overestimated the total consumption of juvenile salmonids during out-migration.

It is difficult to assess the role of smallmouth bass in the decline in juvenile salmonid survival without knowing past population sizes. Based on CPUE data from bass tournaments, there is no evidence that the smallmouth bass population has increased dramatically over the past decade (Fayram 1996). An accurate population estimate for the smallmouth bass in Lake Washington was difficult to obtain because of the large size of the lake and the relatively small number of smallmouth bass sampled.

To obtain a maximum abundance estimate, and thus a worst-case predation loss estimate for salmonids, we calculated a Schnabel estimate (Schnabel 1938) for the sampled area with the highest density of smallmouth bass (station 4) and extrapolated this density to the entire area of the lake that is less than 10 m in depth. At station 4, we tagged 18 fish and recovered 2 tags in a total of 26 captures. The Schnabel point estimate was 141 fish (80% confidence interval, 74–1,496) in an area of approximately 72,000 m². The 80% confidence interval was necessary because of the low number of recaptures. The area less than 10 m in depth was calculated to be approximately 14,023,500 m² in the lake and approximately 4,779,700 m² in the Ship Canal. Extrapolating the point estimate density of smallmouth bass at station 4 to the lake and the Ship Canal area produced an estimated smallmouth bass population of 27,463 in the lake and 9,360 in the Ship Canal area. With these population estimates, the bioenergetics model calculates a yearly consumption of 3,097,667 g of salmonids or approximately 258,139 individual salmonid smolts, each with an average weight of 12 g. This corresponds to approximately 28,395 returning sockeye salmon adults, based on average marine survival of 11%. This population estimate is an extreme upper bound on the maximum abundance and potential predation impact of smallmouth bass on juvenile salmonids because density of smallmouth bass in the entire littoral zone obviously lower than in our sampling areas. The actual impact is certainly much smaller.

Between 1970 and 1990, the estimated out-migration of sockeye salmon smolts ranged from 0.25 to 6.8 million, with an average of 2.73 ± 0.69 million. During this study the estimated out-migration was 2.18 million. Consumption calculated by the bioenergetics model is less than 10% of the average out-migration and is an extreme value that overestimates actual consumption of sockeye salmon smolts for several reasons. In the model, all juvenile salmonids consumed by smallmouth bass were considered to be juvenile sockeye salmon. However, smolts of coho salmon *O. kisutch*, chinook salmon *O. tshawytscha*, and steelhead *O. mykiss* also migrate through the lake during April-June and are expected to occur in the smallmouth bass diet. Including those species in the model would reduce the estimate of predation on juvenile sockeye salmon. More importantly, the four sampling locations for smallmouth bass were chosen precisely because they had high densities of smallmouth bass (Pfeifer, personal communication). We then used the highest density obtained at those sites and extrapolated to the entire lake. This would significantly overestimate population size of smallmouth bass and thus their consumption of prey.

Based on CPUE calculations for electrofishing during the months of May and June (Fayram 1996), smallmouth bass density is 34 times higher in the Ship Canal area than in the lake. If the population estimate is adjusted to reflect the difference in CPUE values, the population estimate for the lake becomes 807 and the population estimate for the Ship Canal area remains 9,360. The total yearly consumption estimate using the revised predator abundance was 1,053,506 g of salmonids or approximately 87,792 smolts. This estimate represents approximately 3.5% of the average estimated number of out-migrating sockeye salmon smolts.

We believe the population estimates based on CPUE values underestimate the lake population and overestimate the Ship Canal population. The lack of quantitative data for smallmouth bass population sizes in Lake Washington makes it difficult to assign a more accurate population size. Despite this uncertainty, both the worst-case and revised estimates of smallmouth bass abundance suggest that this predator represents a minor source of mortality on juvenile sockeye salmon.

The most compelling evidence that smallmouth bass have a small impact on the freshwater survival of juvenile sockeye salmon populations in Lake Washington is based on the timing of the yearly presmolt estimate. Presmolt abundance is estimated by a hydroacoustic survey conducted by the Washington Department of Fish and Wildlife in late March or early April while the juvenile sockeye salmon are still in the limnetic zone. Freshwater survival is estimated from the presmolt: spawner ratio. Therefore, for the calculation
of stage-specific survival rates, freshwater survival ends and marine survival begins at the time of the presmolt survey. Because the primary impact of smallmouth bass occurs during the smolt out-migration, any significant impact by smallmouth bass would be noted as a decrease in the marine survival. However, there has been no obvious downward trend in the marine survival of sockeye salmon during the period of sockeye salmon decline. This suggests that smallmouth bass predation on juvenile salmonids in Lake Washington has had little impact on the observed decrease in sockeye salmon abundance.

Acknowledgments

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Smallmouth Bass and Largemouth Bass Predation on Juvenile Chinook Salmon and Other Salmonids in the Lake Washington Basin

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Abstract.—We assessed the impact of predation by smallmouth bass Micropterus dolomieu and largemouth bass M. salmoides on juveniles of federally listed Chinook salmon Oncorhynchus tshawytscha and other anadromous salmonid populations in the Lake Washington system. Bass were collected with boat electrofishing equipment in the south end of Lake Washington (February–June) and the Lake Washington Ship Canal (LWSC; April–July), a narrow waterway that smolts must migrate through to reach the marine environment. Genetic analysis was used to identify ingested salmonids to obtain a more precise species-specific consumption estimate. Overall, we examined the stomachs of 783 smallmouth bass and 310 largemouth bass greater than 100 mm fork length (FL). Rates of predation on salmonids in the south end of Lake Washington were generally low for both black bass species. In the LWSC, juvenile salmonids made up a substantial part of bass diets; consumption of salmonids was lower for largemouth bass than for smallmouth bass. Smallmouth bass predation on juvenile salmonids was greatest in June, when salmonids made up approximately 50% of their diet. In the LWSC, overall black bass consumption of salmonids was approximately 36,000 (bioenergetics model) to 46,000 (meal turnover consumption model) juveniles, of which about one-third was juvenile Chinook salmon, one-third was coho salmon O. kisutch, and one-third was sockeye salmon O. nerka. We estimated that about 2,460,000 juvenile Chinook salmon (hatchery and wild sources combined) were produced in the Lake Washington basin in 1999; thus, the mortality estimates in the LWSC range from 0.5% (bioenergetics) to 0.6% (meal turnover). Black bass prey mostly on subyearlings of each salmonid species. The vulnerability of subyearlings to predation can be attributed to their relatively small size; their tendency to migrate when water temperatures exceed 15°C, coinciding with greater black bass activity; and their use of nearshore areas, where overlap with black bass is greatest. We conclude that under current conditions, predation by smallmouth bass and largemouth bass has a minor impact on Chinook salmon and other salmonid populations in the Lake Washington system.

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Throughout the Pacific Northwest, numerous stocks of anadromous salmonids Oncorhynchus spp. have declined to historically low levels (Nehlsen et al. 1991). Several of them are now federally protected under the U.S. Endangered Species Act. Developing recovery plans for these salmonids depends upon knowledge of life-stage-specific mortality rates and factors responsible for mortality at each stage.
Predation by introduced fish species is one possible factor in salmonid declines (Ruckelshaus et al. 2002). Much attention has focused on effects of smallmouth bass Micropterus dolomieu and largemouth bass M. salmoides because they are known piscivores throughout their range, are widely distributed in both lotic and lentic habitats, and often co-occur with anadromous salmonids (Li et al. 1987; Bennett et al. 1991; Bonar et al. 2005).

Predation by black basses Micropterus spp. on juvenile salmonids has been documented in both lotic and lentic habitats of the Pacific Northwest (Pflug 1981; Bennett et al. 1991; Poe et al. 1991; Tabor et al. 1993; Fayram 1996; Bonar et al. 2005). For example, in large, low-gradient riverine areas of the Columbia River system, smallmouth bass are an important predator of subyearling Chinook salmon O. tshawytscha (Bennett et al. 1991; Tabor et al. 1993; Poe et al. 1994; Zimmerman 1999; Fritts and Pearsons 2004). Fritts and Pearsons (2004) concluded that smallmouth bass predation affected productivity of wild ocean-type Chinook salmon in the lower Yakima River, Washington, a major tributary of the Columbia River. Reimers (1989) suggested that predation by introduced largemouth bass in the Tenmile Lakes system, Oregon, caused the population of coho salmon O. kisutch to decline substantially.

In lentic habitats of Lake Washington, Washington, juveniles of sockeye salmon O. nerka, coho salmon, Chinook salmon, and steelhead O. mykiss (anadromous rainbow trout) all spatially overlap with both smallmouth bass and largemouth bass. Two populations of naturally reproducing Chinook salmon spawning in the Lake Washington basin are listed as threatened under the U.S. Endangered Species Act (Ruckelshaus et al. 2006; USFWS 1999). Within the Lake Washington basin, Pflug (1981) reported the proportion of salmonids in smallmouth bass stomachs in Lake Sammamish but did not distinguish the species present. Fayram (1996) reported that the importance of salmonids in the diet was greater for largemouth bass than for smallmouth bass in Lake Washington, but the salmonid species were not separately identified.

To assess the importance of black bass predation in the decline of anadromous salmonids, estimates of consumption must be species specific. However, because ingested juvenile salmonids can be difficult to identify to species, separate consumption estimates for each prey species are usually not possible (Rieman et al. 1991; Fayram and Sibley 2000; Naughton et al. 2004). Some researchers have used diagnostic bones (Hansel et al. 1988) to reduce the numbers of unidentifiable prey. However, diagnostic bones are not always present; even when the bones are present, species identification is often difficult. Another potential technique is genetic analysis, which has recently been used to identify salmonid prey of Pacific harbor seals Phoca vitulina richardsi to species (Parcell et al. 2004); this method is advantageous because it only requires a small amount of tissue or bone.

Our objective was to evaluate smallmouth bass and largemouth bass consumption of juvenile ocean-type Chinook salmon and other juvenile salmonids in Lake Washington. To estimate black bass consumption of salmonids, we evaluated diet and estimated black bass population sizes in two areas of the Lake Washington basin where black bass distribution strongly overlapped with the distribution of juvenile Chinook salmon. One area was Lake Washington’s south end, which is an important rearing area for juvenile Chinook salmon. From February to May, most naturally produced juvenile Chinook salmon enter Lake Washington at the south end and use shallow nearshore habitats (Tabor et al. 2004). The second area was the Lake Washington Ship Canal (LWSC), which is a narrow waterway that smolts must migrate through to reach the marine environment. We used a bioenergetics model and a meal turnover consumption model to quantify consumption of juvenile Chinook salmon. To obtain a more precise species-specific estimate, we used genetic analysis to identify well-digested salmonid prey found in black bass stomachs.

Study Area

Lake Washington is a large monomictic lake with a total surface area of 87.6 km². The lake has an average depth of 33 m and a maximum depth of 67 m. The lake typically stratifies during June–October. Surface water temperature ranges from 4–6°C in winter to over 20°C in summer and may exceed 23°C in some years. The Cedar River, the largest tributary to Lake Washington, enters the lake’s south end (Figure 1).

Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered. Historically, the Cedar River flowed into the Black River near the old outlet of Lake Washington at the south end. The Cedar River was diverted into Lake Washington, the lake level was lowered by 2.4 m, and the outlet of the lake was rerouted through the LWSC. The Hiram Chittenden Locks, located at the downstream end of the LWSC, now controls the lake level.

Over 78% of the lake’s shoreline is comprised of residential land use (Fresh and Lucchetti 2000). Much of the shoreline is armored with numerous small, private piers. We sampled predators along a 4.6-km-long shoreline section in the south end of the lake (Figure 1).
The LWSC is an 8.9-km-long waterway that allows navigation between Lake Washington and Puget Sound (Figure 1). The largest part of the LWSC is Lake Union, which is 2.4 km² in size and has a mean depth of 9.8 m. Most shorelines of the LWSC are highly developed and contain numerous marinas, commercial shipyards, and house-boat communities. Two sections of the LWSC are narrow channels with steep armored banks. Smallmouth bass and largemouth bass were sampled along the entire length of the LWSC.

Compared with other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species, including 25 native species (primarily salmonids, sculpins Cottus spp., and cyprinids) and at least 15 introduced species. Largemouth bass were initially planted in the system in 1890. The history of smallmouth bass planting in Lake Washington is less clear, but records suggest that smallmouth bass have been present since at least 1930 (Lampman 1946).

Anadromous salmonids in the Lake Washington basin include hatchery-origin and naturally produced sockeye salmon, Chinook salmon, coho salmon, and steelhead. Sockeye salmon are by far the most abundant anadromous salmonid in the basin; adult returns of sockeye salmon exceed 350,000 fish in some years (Fresh and Lucchetti 2000). The major source of natural production is the Cedar River, and additional production is contributed by smaller tributaries in the north end of the basin. Hatchery-produced juvenile Chinook salmon and coho salmon are released from the Washington Department of Fish and Wildlife's (WDFW) Issaquah Creek Hatchery and from the University of Washington (UW) Hatchery on Portage Bay of the LWSC.

**Methods**

*Predator sampling.*—All black bass were collected with a 6-m Smith–Root electrofishing boat. At the south end of Lake Washington, black bass were sampled along a 4.6-km stretch of shoreline once every 3 weeks from February to June of 1995–1997. We established 15 transects of various lengths (200–460 m long). The start and end points were chosen based on changes in habitat types and easily recognizable landmarks. On most dates, we were able to sample the entire shoreline of the study area; however, due to large catches in late May and June, sampling was limited to nine transects (64% of total length), which were representative of the other transects. We made one pass along each transect except in large, shallow areas, where we made two to four passes.

The LWSC was sampled once every 7–14 d from late April to late July 1999 using a stratified sampling design. The LWSC was divided into four general areas, and the shoreline for each area was divided into several transects of approximately 500 m in length. For each sampling date, two randomly selected transects were selected from each area. Other randomly chosen transects were sampled as time permitted.

Sampling in both areas was conducted at night because black bass catch rates obtained by electrofishing are substantially greater at night than during the day (Paragamian 1989). Stunned fish were collected with dip nets, kept in a live well, and then processed after each transect was sampled. Black bass greater than 100 mm were anesthetized, measured to fork length (FL nearest mm), and weighed (g); scales were also removed from selected individuals.

*Diet analysis.*—Stomach contents were removed by gastric lavage as described by Foster (1977), saved on ice, and kept frozen for later laboratory analysis. In the laboratory, each stomach sample was thawed and placed under a dissecting microscope. Stomach contents were separated into major prey taxa. Insects and crustaceans were identified to order; other
invertebrate prey items were identified to a convenient, major taxonomic group. Each prey group was blotted for 10 s on a paper towel and weighed to the nearest 0.001 g.

Prey fish that were slightly digested were identified to species. Fishes in more advanced stages of digestion were identified to family, genus, or species from diagnostic bones, gill raker counts, pyloric caeca counts, or vertebral columns. The FL of prey fish was measured to the nearest millimeter. When direct FL measurements were not possible, prey lengths were estimated from measurements of standard or nape-total length or from diagnostic bones (Hansel et al. 1988; Vigg et al. 1991). Prey fish were individually weighed to the nearest 0.001 g.

Unidentified salmonid samples were sent to the Conservation Biology Molecular Genetics Laboratory (National Oceanic and Atmospheric Administration [NOAA] Fisheries, Northwest Fisheries Science Center) and molecular genetic (DNA) analysis was conducted. Methodologies were similar to those used by Purcell et al. (2004) except that muscle tissue, when available, was analyzed instead of bones. Identifications were made with the restriction fragment length polymorphism analysis, and positive identifications were only made when unambiguous restriction patterns were obtained for all six enzymes described by Purcell et al. (2004).

Three size-classes of black bass were chosen (100–199, 200–299, and ≥300 mm FL) for diet comparisons. Prey items for each size-class and month were expressed as percent of the total weight of food eaten. The frequency of salmonids in the diet was also compared between black bass species by use of contingency tables (Zar 1999).

Population estimates.—To estimate population sizes, smallmouth bass and largemouth bass greater than 150 mm FL were tagged just behind the dorsal fin with individually numbered Floy anchor or thread tags (smaller individuals were not marked due to the large tag size in relation to the fish size). A small hole was also punched in the opercle as a backup in case the Floy tag was lost. After fish recovered, they were released into the middle of the capture transect. A modified Schnabel multiple-census technique (Ricker 1975) was used to estimate population sizes:

\[ \hat{N} = \sum \frac{C_t M_t}{R + 1} \]

where \( N \) = population size; \( C_t \) = total sample taken on day \( t \); \( M_t \) = total marked fish at large at the start of the \( t \)th day (the number previously marked minus any fish accidentally killed at previous recaptures); and \( R = \) total number of recaptures. Confidence intervals (95% CIs) were obtained by considering \( R \) as a Poisson variable, and values were obtained from a Poisson frequency distribution table (Ricker 1975). The population size of smallmouth bass in the south end of Lake Washington was estimated from 1995 data. Because few largemouth bass were collected in the south end, we estimated their population size by comparing catch-per-unit-effort (CPUE) data in the south end to that of smallmouth bass. In the LWSC, separate population estimates were made for each stratum and then summed together. Population estimates from LWSC were expanded to incorporate shoreline areas (i.e., large houseboat communities, shipyards) that could not be adequately sampled. We assumed that these areas had the same densities (number per shoreline length) of black bass as the areas surveyed. The entire LWSC is extremely developed, and we believed that habitat conditions and black bass population densities would be similar between sampled and unsampled areas. Population estimates were also adjusted (based on CPUE) for 135–149-mm black bass, which could also consume juvenile salmonids but were unmarked due to their small size.

Consumption estimates.—Black bass consumption of juvenile salmonids was calculated with the bioenergetics model of Hanson et al. (1997) and a simple meal turnover method (Adams et al. 1982; Naughton et al. 2004). The bioenergetics model is an energy mass balance equation in which energy consumed by a fish is balanced by total metabolism, waste losses, and growth. Bioenergetics models have been widely used to quantify consumption rates of piscivorous fishes and compare favorably with field-generated consumption estimates (Ruggerone and Rogers 1992). An advantage of the meal turnover method is that predation rates are based on digestion of salmonids and are not significantly influenced by differential digestion rates among prey types (Naughton et al. 2004). Other models that incorporate all prey types, including hard-bodied prey (such as crayfish), which take longer to digest (Bromley 1994), can have large errors if hard-bodied prey make up a large portion of the diet and if the digestion equations were developed for salmonid prey (Rogers and Burley 1991). For each method, separate consumption estimates (based on separate diet and population estimates) were made for the four areas of the LWSC and then summed together.

We used the smallmouth bass bioenergetics model of Roell and Orth (1993) and the largemouth bass model of Rice et al. (1983). Major inputs into the bioenergetics model include growth, diet, water temperature, and caloric density of the predator and prey. Scales of
smallmouth bass and largemouth bass from LWSC were analyzed to determine their age and growth. The data were fitted with a von Bertalanffy growth equation (Dickie 1971) to estimate fish size at age. Age and growth data were not collected in the south end of Lake Washington; we therefore used data collected in the LWSC. Diet information (percent of the diet by weight of each salmonid species and seven other prey categories) and predator abundances were obtained directly from field data. Water temperatures were taken from measurements by King County personnel at 1-m depths in the lake’s south end and in the LWSC. Prey energy densities were obtained from literature values (Table 1). Output from the model included the number of grams consumed of each salmonid species, which was converted into number of fish based on the monthly average size of salmonids consumed by each black bass species and size-class.

The basic formula for the simple meal turnover method was:

\[
C = \frac{n}{N},
\]

where \(C\) = rate of black bass consumption of Chinook salmon (fish/d), \(n\) = number of Chinook salmon consumed within 24 h of capture, and \(N\) = number of predators sampled, including those with empty stomachs. Based on the observed water temperatures and sizes of the predators and prey, more than 5\% of each salmonid consumed would still be present in the stomach 24 h after predator capture. We compared the observed weight of each partially digested Chinook salmon with the weight it would have had if consumed 24 h before collection (i.e., predicted weight). If the observed weight was larger than the predicted weight, then the salmonid prey was considered to have been consumed within 24 h of sampling. Chinook salmon in more advanced stages of digestion were not used to calculate the daily consumption rate. The original salmonid prey weights were calculated from the length-weight regressions of Vigg et al. (1991) or from regressions developed from salmonids collected n the Lake Washington basin. We used the following equation from Rogers and Burley (1991) to determine the grams evacuated after 24 h of digestion:

\[
E = S[1 - \exp(-0.0125S^{-0.29} e^{-0.15T} W^{-0.23})]^{1.95},
\]

where \(E\) = grams evacuated in 24 h; \(S\) = meal weight (g); \(T\) = temperature (°C); and \(W\) = predator weight (g). Meal weight was the estimated weight of the Chinook salmon plus the digested weight of all other food items in the stomach (Vigg et al. 1991). This assumes that the observed weight of all other food items is the average amount of prey in the stomach while the Chinook salmon was being digested. The predicted weight of each salmonid after 24 h of digestion was then calculated with the following equation:

\[
D = (S - E) \frac{p}{S},
\]

where \(D\) = digested salmonid weight after 24 h; \(P\) = original salmonid prey weight; \(E\) = grams evacuated from meal after 24 h; and \(S\) = meal weight (g).

### Results

**Predator Diets**

Overall, 310 largemouth bass and 783 smallmouth bass were caught in the study areas from 1995 to 1999; of these, 30 largemouth bass and 253 smallmouth bass were caught in the south end of Lake Washington. Seventy-four percent of the smallmouth bass and 90\% of the largemouth bass in the LWSC were less than 250 mm FL. (Figure 2). This trend was also apparent for smallmouth bass caught in the south end, but not for largemouth bass.

**South Lake Washington.**—Of the 28 smallmouth bass collected in February and March in the south end of Lake Washington, only four (14\%) contained food, which included longfin smelt *Spirinchus thaleichthys*, three-spined sticklebacks *Gasterosteus aculeatus*, and fish eggs. The diet of smallmouth bass during April-June (\(N = 225\)) consisted primarily of sculpins, crayfish, salmonids, and other prey fish (primarily perch and pumymouths *Mylocheilus caurinus*). (Figure 3). Salmonids were consumed primarily in May and represented an average of 21\% of the diet for the three size-classes. Twenty-three salmonids were observed, which included Chinook salmon, coho salmon, sockeye salmon, and rainbow trout. Ingested rainbow trout were probably newly released hatchery fish, as

<table>
<thead>
<tr>
<th>Table 1.—Caloric densities (J/g) of major prey items consumed by smallmouth and largemouth bass in the lower Lake Washington basin. The caloric density values are used in bioenergetics models.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prey type</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td><em>Salmo salar</em></td>
</tr>
<tr>
<td><em>Salmo sciota</em></td>
</tr>
<tr>
<td><em>Salmo gairdnerii</em></td>
</tr>
<tr>
<td><em>Carassius auratus</em></td>
</tr>
<tr>
<td><em>Percidae</em></td>
</tr>
<tr>
<td><em>Perca flavescens</em></td>
</tr>
<tr>
<td><em>Esox lucius</em></td>
</tr>
<tr>
<td><em>Procambarus clarkii</em></td>
</tr>
<tr>
<td><em>Brachyura</em></td>
</tr>
<tr>
<td><em>Chilopoda</em></td>
</tr>
</tbody>
</table>
lengths were similar to the size of hatchery rainbow trout released. Also, newly released rainbow trout were the most abundant salmonid along shoreline transects during electrofishing. In June, the only salmonid species consumed was Chinook salmon (8% of the overall diet).

Few largemouth bass (\(N = 30\)) were caught in the south end of Lake Washington. Largemouth bass of the 100–199-mm FL class ate primarily sculpins (36%), amphipods (33%), and larval fish (22%). Over 99% of the diet of 300-mm and larger largemouth bass (\(N = 9\)) consisted of fish (Chinook salmon, sculpins, brown bullhead \(Ameiurus nebulosus\), and threespine sticklebacks). Few crayfish were observed in the diet of largemouth bass (Figure 3). Overall, only two salmonids were observed in largemouth bass stomachs (one sockeye salmon fry and one juvenile Chinook salmon).

**LWSC.**—Approximately half of the overall diet of smallmouth bass in the LWSC consisted of salmonid smolts. Within the 508 stomachs examined, 159 smolts were found. Salmonids were a major diet item of all size-classes of smallmouth bass, including predators as small as 139 mm FL (Figure 4). Smallmouth bass of the 200–299-mm FL class contained the highest diet percentage (54% by weight) made up of salmonids; for this size-class, the diet also consisted of crayfish (19%), sculpins (16%), and yellow perch (9%). Sculpins were consumed by all size-classes of smallmouth bass but rarely so for 300-mm and larger predators.

Largemouth bass predation on salmonids was only observed in 159–264-mm fish. Within the 280 stomachs examined, only 31 smolts were found. Largemouth bass also consumed more prey fish of other species than smallmouth bass: over 75% of the diet of largemouth bass consisted of nonsalmonid fish (Figure 4). Largemouth bass consumed 68 sculpins (40% of the diet by weight), 35 threespine sticklebacks (2%), 5 sunfish \(Lepomis\) spp. (7%), 3 yellow perch (6%), 2 oriental weatherfish \(Misgurnus anguillicaudatus\) (3%), 7 black bass (1%), and 1 peamouth (1%).

Overall, the frequency of occurrence of salmonids in LWSC black bass stomachs was higher for smallmouth bass than for largemouth bass. In April–May, predation on smolts was only observed in smallmouth bass. In June, 100–199- and 200–299-mm smallmouth bass had a significantly higher occurrence of salmonids than did largemouth bass of the same size categories (contingency tables: \(P < 0.05\)); however, in July the occurrence of salmonids was similar between the two species (contingency tables: \(P > 0.05\)). No salmonids were observed in 300-mm or larger largemouth bass (\(N = 14\)); however, 40% of 300-mm and larger smallmouth bass (\(N = 83\); all months combined) consumed salmonids.

We observed 190 salmonids in LWSC samples from both black bass species. We were able to directly
identify 39 salmonids (21%), and an additional 135 salmonids (71%) were identified through genetic analysis. In May, all ingested salmonids (N = 5) were sockeye salmon. In June, Chinook salmon were found in 20% of the smallmouth bass but only 6% of the largemouth bass (Table 2). In July, Chinook salmon made up 44% of the salmonids consumed by smallmouth bass and only 13% of salmonids consumed by largemouth bass. Sockeye salmon consumed by smallmouth bass in May (mean FL = 125 mm) were significantly larger than those consumed in June (mean FL = 87 mm) or July (mean FL = 99 mm; analysis of variance: F = 11.9, df = 2, 10, P = 0.002; Tukey’s honestly significant difference test: P < 0.05). The sizes of Chinook salmon and coho salmon consumed by smallmouth bass did not differ between June and July (t-tests: P > 0.05). Also, sizes of ingested coho salmon did not differ between smallmouth bass and largemouth bass (t-test: P = 0.23); 65% of coho salmon in the diet were less than 90 mm FL (Figure 5).

Population Estimates

Two important assumptions of capture-recapture methods are that the population is closed and mortality is minimal between mark-recapture events. We believe there was little immigration or emigration of black bass (i.e., the populations were closed), as movement of both species in Lake Washington and the LWSC appeared to be minimal; 86% of all recaptured smallmouth bass were caught either in the same transect (60%) or an adjoining transect (26%). Similarly, 88% of recaptured largemouth bass were from the same transect (41%) or an adjoining transect (47%). Mortality also appeared to be minimal during this time period, since black bass angling pressure was generally low in these areas and bass anglers usually released their catch.

In south Lake Washington in 1995, the estimated population size of 150-mm and larger smallmouth bass was 190 fish (Table 3), while that of largemouth bass was 12 fish. The estimated population sizes in sampled areas of the LWSC in 1999 were 1,655 smallmouth bass and 902 largemouth bass (Table 3). Population estimates in LWSC were also adjusted to account for the shoreline areas we were unable to sample (i.e., houseboat communities) and to include 135-149-mm black bass. After making these adjustments, we estimated that 3,388 smallmouth bass and 2,500 largemouth bass could consume salmonid smolts in the LWSC (Table 3).

Table 2.—Number (N) and frequency of occurrence (FO) of salmonids observed in stomachs of largemouth bass and smallmouth bass collected from the Lake Washington Ship Canal, 1999. The number of bass stomachs examined is given in parentheses.

<table>
<thead>
<tr>
<th>Species</th>
<th>Largemouth bass</th>
<th>Smallmouth bass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Apr-May (42)</td>
<td>Jun (64)</td>
</tr>
<tr>
<td></td>
<td>N  FO</td>
<td>N  FO</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0  0</td>
<td>5  6.3</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0  0</td>
<td>15 18.8</td>
</tr>
<tr>
<td>Sockeye salmon</td>
<td>0  0</td>
<td>1  1.6</td>
</tr>
<tr>
<td>Unidentified salmonids</td>
<td>0  0</td>
<td>1  1.6</td>
</tr>
<tr>
<td>All salmonids</td>
<td>0  0</td>
<td>22 26.6</td>
</tr>
<tr>
<td></td>
<td>N  FO</td>
<td>N  FO</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0  0</td>
<td>55 20.0</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0  0</td>
<td>42 13.9</td>
</tr>
<tr>
<td>Sockeye salmon</td>
<td>5  10.0</td>
<td>7  3.0</td>
</tr>
<tr>
<td>Unidentified salmonids</td>
<td>0  0</td>
<td>13 4.8</td>
</tr>
<tr>
<td>All salmonids</td>
<td>5  10.0</td>
<td>117 38.3</td>
</tr>
</tbody>
</table>
TABLE 3.—Schnabel multiple-census population parameters for largemouth bass (LMB) and smallmouth bass (SMB) (>150 mm FL) from two locations in the lower Lake Washington basin. South Lake Washington was sampled during February–June 1995 and, the Lake Washington Ship Canal (LWSC) sampled during April–July 1999. The LWSC results represent the summation of four areas (strata). Few LMB were collected in south Lake Washington. Adjusted population estimate incorporates shoreline areas (i.e., large houseboat communities and shipyards) that could not be adequately sampled and small bass that could consume salmonids but were not marked.

<table>
<thead>
<tr>
<th>Variable or statistic</th>
<th>South Lake</th>
<th>LWSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Washington</td>
<td>SMB</td>
</tr>
<tr>
<td>Number of survey dates</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Total number caught (C)</td>
<td>102</td>
<td>372</td>
</tr>
<tr>
<td>Number marked (M)</td>
<td>54</td>
<td>258</td>
</tr>
<tr>
<td>Number of recaptures (R)</td>
<td>10</td>
<td>41</td>
</tr>
<tr>
<td>Population estimate (N)</td>
<td>190</td>
<td>1,655</td>
</tr>
<tr>
<td>Lower 95% CI</td>
<td>114</td>
<td>892</td>
</tr>
<tr>
<td>Upper 95% CI</td>
<td>445</td>
<td>3,641</td>
</tr>
<tr>
<td>Adjusted population estimate</td>
<td>—</td>
<td>3,388</td>
</tr>
</tbody>
</table>

Discussion

Our primary objective was to evaluate the significance of black bass predation on juvenile salmonids in the Lake Washington system, especially on naturally produced, federally protected Chinook salmon. Our results suggest that black bass predation on all salmonids was low under the conditions studied. In the south end of Lake Washington, where large numbers of naturally produced Chinook salmon rear from February to June, total losses of juvenile salmonids were 600 fish in the 4.6-km-long study section; of these, 319 fish were juvenile Chinook salmon (meal turnover model). Because habitat conditions in the south end are representative of other areas of the lake and because juvenile salmonids and black bass are found throughout the littoral zone of Lake Washington in May and June (K.L.F., unpublished), it is reasonable to assume that our consumption estimates from the south end were representative of lakewide consumption during that time period. If we extrapolate our estimates of juvenile salmon consumed per kilometer of shoreline in the south end to the whole lake (140 km of shoreline), the number of juvenile salmonids eaten by black bass lakewide (exclusive of Lake Sammamish, Sammamish River, and LWSC) would be 18,300 fish, of which about 50%, or 9,000, would be juvenile Chinook salmon.

In the LWSC, juvenile salmon become concentrated and confined as they migrate from Lake Washington to Puget Sound, potentially increasing losses of juvenile salmonids to black bass predation in this area. For example, predation could increase if black bass...
aggregate in the LWSC in response to the increased abundance of prey. Our worst-case estimate (the greatest loss was with the meal turnover model) for the LWSC was 46,000 total juvenile salmonids eaten, of which 15,000 were Chinook salmon. Although we did not have estimates of the population size of juvenile Chinook salmon encountered by the black bass populations in either area, the abundance of juvenile Chinook salmon emigrating from spawning areas can be calculated. This value was computed by summing the number of hatchery fish released from the Issaquah Creek and UW hatcheries and the number of naturally produced juvenile Chinook salmon passing smolt traps on Bear Creek and the Cedar River (Seiler et al. 2003). Bear Creek and the Cedar River are the major sources of naturally produced Chinook salmon in the basin (Seiler et al. 2003). We determined that approximately 2,460,000 hatchery- and naturally produced juvenile Chinook salmon entered the Lake Washington system from all sources in 1999; of these, about 2,360,000 fish were of hatchery origin.

Estimates of 9,000 juvenile Chinook salmon eaten in Lake Washington and 15,000 eaten in the LWSC translate to mortality estimates of 0.4% in the lake and 0.6% in the LWSC. Because an unknown number of juvenile Chinook salmon will be eaten (e.g., by birds) during their migration from spawning streams or hatcheries to the LWSC, mortality due to black bass predation will be greater than indicated by these values. For example, if we assume that 50% of the smolts from spawning areas and hatchery release locations survived to reach the LWSC, then approximately 1,230,000 juvenile Chinook salmon would have been available to predators in the LWSC. This would result in a total predation mortality estimate of about 1.2% for hatchery- and naturally produced Chinook salmon.

The use of genetic analyses was a key element of this study and made it possible for us to identify the species of most salmonid carcasses present in the black bass stomachs (69% carcasses were identified by genetic analysis and 21% by direct observation; 10% were unidentified). This approach was more powerful than the use of diagnostic bones and was a significant improvement from previous work that did not differentiate among salmonid species consumed by black bass in the system (Pflug 1981; Fayram 1996). However, although we were able to identify most salmon prey to species, we were unable to distinguish
hatchery from wild fish or determine the population of origin.

Without knowledge of populations of origin, we were unable to determine the number of naturally produced Chinook salmon consumed by black bass. If we assume that predation mortality of hatchery and wild fish was proportional to their relative abundance, then the worst-case loss of naturally produced juvenile Chinook salmon in Lake Washington and the LWSC combined would be about 975 fish. However, predation losses of hatchery and wild fish are often not proportional to abundance. Under laboratory (Berejikian 1995) and field (Fresh et al. 2003) conditions, hatchery salmonids exhibit higher predation mortality than wild salmonids. Differences in behavior, condition, timing of movements, and fish size between hatchery- and naturally produced fish can result in differential predation losses, meaning that predation is not proportional to abundance (Fritts and Pearsons 2004). Sizes of hatchery- and naturally produced Chinook salmon in the lake and LWSC are often similar (DeVries et al. 2004; Koehler et al. 2006), as is timing of passage through the LWSC (DeVries et al. 2004); these results suggest that predation is proportional to the relative abundance of hatchery and wild fish. However, we do not know whether behavior (e.g., habitat use) or condition was similar between hatchery and wild fish.

Our results suggest that black bass predation on salmonids is not considerable relative to the numbers of juvenile salmonids migrating from the system. However, our incomplete understanding of variability associated with our estimates prevented us from developing 95% CIs for the predation estimates. If 95% CIs on the estimated predation mortality are large enough, then the uncertainty associated with conclusions about the importance of black bass predation on salmonids in the basin increases. The size of the 95% CIs on our predation estimates will be a function of a number of factors, such as black bass diet data and juvenile salmonid abundance. We did, however, have 95% CIs for estimated black bass population sizes. Even if the population size of smallmouth bass (the primary predator of salmonids) was at the upper end of the CI, predation mortality would only double to 1.2% in the LWSC.

Further, we also recognize that our LWSC predation estimates were only for 1 year and that annual variability in a number of factors (e.g., predator and prey abundance levels, relative proportion of different prey species, and environmental conditions) could increase predation mortality beyond this level. Thus, additional years of data would have helped frame the importance of black bass predation on Chinook salmon recovery in the Lake Washington system. We would be concerned if the conditions in 1999 were for some reason considerably different than those in other years, resulting in an estimate of predation mortality that was substantially lower (e.g., by an order of magnitude) than estimates for other years. To the best of our knowledge, 1999 conditions (e.g., black bass abundance, water temperature, and smolt abundance) were not unusual and were within the range of conditions in other recent years. This suggests that our estimates of predation mortality characterize what currently occurs in the Lake Washington watershed. For example, independent estimates of smallmouth bass population size in Lake Washington from 2000 to 2002 varied between 12,000 and 18,000 fish (K.L.F., unpublished). From 1998 to 2001, releases of juvenile Chinook salmon from the Issaquah Creek Hatchery, which produces most of the Chinook salmon migrants, ranged from 1.6 to 2.2 million fish.

Most of the salmonids eaten, regardless of species, were subyearling-sized fish, which is consistent with black bass predation on juvenile salmonids in other systems such as the Columbia River (Bennett et al. 1991; Tabor et al. 1993; Fritts and Pearsons 2004). The occurrence of juvenile Chinook salmon in black bass stomachs was not surprising because nearly all Chinook salmon produced by this basin are subyearlings. However, the presence of subyearling sockeye salmon and coho salmon in LWSC black bass stomachs was unexpected, since these two species typically migrate to sea as yearlings (Thorne and Ames 1987; Seiler et al. 2003). Our work and other studies in the basin (DeVries et al. 2004) suggest that subyearling coho salmon and sockeye salmon are more abundant than previously thought.

The smaller size of the subyearlings and differences in migration timing between subyearlings and yearlings contribute to the higher predation levels on subyearlings in the Lake Washington system. Most yearling salmonids in the Lake Washington system are coho salmon and sockeye salmon (i.e., yearling Chinook salmon rarely occur). Although yearlings are abundant (e.g., >2 million sockeye salmon smolts leave the system in some years; Thorne and Ames 1987), black bass can capture and swallow subyearlings more easily than yearlings.

Yearlings migrate through the LWSC in May and early June (DeVries 2002; DeVries et al. 2004), whereas subyearlings are more abundant there in June and July, when nearly all losses due to black bass predation occurred. DeVries et al. (2004) found that a subyearling size-class of sockeye salmon migrated through the LWSC in June and July after the yearling
migration. The subyearling group of sockeye salmon was that primarily consumed by black bass.

The size and date of ingestion of coho salmon prey suggest that most were probably newly released fish from the UW Hatchery. The UW Hatchery releases age-0 coho salmon that are smaller than naturally produced or Issaquah Creek Hatchery yearlings. The mean length of coho salmon was 89.3 mm FL for those released from UW Hatchery in 1999, over 105 mm for smolts collected at the mouth of the Cedar River (Seiler et al. 2003), and over 130 mm for those collected in 2001 in Lake Union (DeVries 2002; size data for 1999 were not available). Because 65% of the coho salmon eaten by black bass were smaller than 90 mm FL, it seems likely that many of these fish were from the UW Hatchery. Additionally, UW Hatchery coho salmon are released directly into the LWSC. Hatchery fish often experience higher predation rates near release locations because they are abundant close to the stocking site (Collis et al. 1995) and may be stressed and somewhat disoriented for a period of time after being released.

The higher losses of subyearling fish migrating through in the LWSC in June and July may be due to differences in water temperature. It is possible that yearlings migrating in May and early June avoid predation because water temperatures are usually below 15°C. Black bass at temperatures less than 15°C are less active and exhibit lower metabolic rates than those at warmer temperatures (Wydoski and Whitney 2003). For example, water temperatures at a depth of 1 m in the LWSC were 10–14.5°C in May, 14.5–18.5°C in June, and 17.5–21°C in July. The higher water temperatures in June and July also may be a source of stress to the subyearling salmonids migrating through the LWSC and may increase their vulnerability to predators (Mesa et al. 1994).

Water temperatures also probably have an important influence on predation in Lake Washington. Although Chinook salmon and sockeye salmon juveniles are present in the littoral zone of Lake Washington’s south end from February to May, little predation by black bass was observed until mid-June. We speculate that low predation levels before June occurred because water temperatures are generally below 10°C; as a result of the low water temperatures, black bass are found in deeper waters and are not actively feeding. By June, when water temperatures exceed 15°C, black bass become more active. Predation in the lake probably declines in July because most salmonids have left littoral areas and either moved offshore or emigrated from the lake (Koehler et al. 2006). In July, water temperatures in littoral areas typically are above 17°C, which is stressful to juvenile salmonids (K.L.F., unpublished).

In addition to water temperature, predation in the LWSC appeared to be related to salmonid abundance. Although we do not have monthly estimates of abundance, work by DeVries et al. (2004) suggests that salmonid abundance in the LWSC peaks in June and declines in July. We found that black bass consumption of subyearling Chinook salmon and coho salmon was highest in June, when juveniles are abundant. Through July, predation rates gradually decreased as the abundance of salmonids passing through the LWSC decreased. By the last week of July, little predation was detected. Because the temporal abundance and availability of salmonids and other prey (i.e., sculpins and crayfish) were unknown, we were unable to describe the mechanisms influencing prey selection and prey switching by black bass. Further research is needed to understand the various factors that influence black bass consumption of salmonids in the LWSC.

Of the two black bass species, smallmouth bass were responsible for most of the salmonid predation mortality. Smallmouth bass had a higher occurrence of salmonids in stomachs than did largemouth bass, and salmonids made up a substantially higher percent of the diet for smallmouth bass than for largemouth bass. Previous research in the Lake Washington basin (Pflug 1981; Fayram 1996) found that largemouth bass had a higher occurrence of salmonids in stomachs than did smallmouth bass. Fayram’s (1996) results from Lake Washington may be due to small sample size (31 largemouth bass) and the areas sampled, while Pflug’s (1981) results from Lake Sammamish may be explained by the fact that largemouth bass were caught in areas where hatchery salmonids were concentrated. In other studies of sympatric black basses, largemouth bass were generally more piscivorous than smallmouth bass, which often had a higher occurrence of crayfish in their diet (Hubert 1977; Hodgson et al. 1997; Long and Fisher 2000; Liao et al. 2002; Olson and Young 2003). In the Lake Washington basin, we found the same high occurrence of crayfish in the diet of smallmouth bass.

We believe that the higher predation mortality caused by smallmouth bass was due to several factors. First, in both environments, smallmouth bass were more abundant than largemouth bass. Anecdotal evidence suggests that largemouth bass were historically the more abundant of the two species (Eggers et al. 1978). However, over the past 30 years, the shoreline has become more developed and some habitat features (e.g., overhanging vegetation and large woody debris) that are preferred by largemouth bass (Wydoski and Whitney 2003) have become rare. Much of the habitat preferred by largemouth bass that
remains in Lake Washington is primarily associated with the extreme north end of the lake and entrance to the LWSC. The types of habitat preferred by smallmouth bass (unvegetated, steep slopes and large substrates such as cobble and riprap; Coble 1975; Keast 1978; Hubert and Lackey 1980; Weaver et al. 1997) have become more prevalent with increasing development. We believe it is probable the population size of largemouth bass has concomitantly decreased with the change in habitat characteristics of the Lake Washington shoreline. In contrast, the LWSC consists of a mosaic of different habitat types that can vary dramatically over small areas in aspects of slope, vegetation, structure, and substrate type; this high variability may allow both smallmouth bass and largemouth bass to be abundant in the same general area.

The greater consumption of salmonids by smallmouth bass than largemouth bass may also be explained by the greater spatial and temporal overlap between smallmouth bass and salmonid prey, particularly Chinook salmon. Results of a tracking study of juvenile Chinook salmon in the LWSC indicated that they migrate through the LWSC in waters that are 4–10 m deep (M.T.C., unpublished). Largemouth bass are usually found in shallow water (Wydoski and Whitney 2003) and thus may not overlap with Chinook salmon. Smallmouth bass typically inhabit deeper waters than do largemouth bass and may therefore have a greater opportunity to prey upon Chinook salmon.

Our results support the hypothesis that black bass predation on salmonids under current conditions is not a major factor limiting recovery of naturally produced Chinook salmon populations associated with the Lake Washington system. Smallmouth bass were responsible for most of the observed predation, and the primary impacts were on subyearling-sized coho salmon, Chinook salmon, and sockeye salmon. Subyearlings are probably more vulnerable to black bass predation because they (1) migrate later, when water temperatures are warmer and when black bass are more active, (2) are abundant in littoral areas, and (3) are of smaller size than yearlings.

We recommend that actions addressing recovery of Chinook salmon or other salmonid populations in this basin focus on other potential limiting factors, such as other predators (e.g., cutthroat trout O. clarkii, Nowak et al. 2004) or the condition of major riverine rearing and spawning areas. It seems prudent for managers to revisit the issue of black bass predation if system changes occur that can significantly affect predator–prey interactions. Changes in the numbers, species, or types of salmon juveniles leaving the system could indicate that predator–prey interactions have been altered. For example, if hatchery Chinook salmon buffer naturally produced fish from predation and if hatchery releases decline substantially, the relative abundance and predation vulnerability of naturally produced Chinook salmon could increase. Substantial reductions in numbers of other salmonids leaving the system could have similar effects.

In addition, the Lake Washington ecosystem has a history of significant changes that have altered predator–prey interactions (Edmondson 1994). Of concern would be significant increases in water temperatures in Lake Washington due to climate change (Arhonitis et al. 2004; Romare et al. 2005); water temperature increases will raise the metabolic rate of black bass and hence their consumption of salmonids and other prey. Warmer littoral water temperatures could also increase overlap between predators and prey by allowing black bass to enter littoral areas earlier.

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