WHITE PAPER

Marinas and Shipping/Ferry Terminals

Prepared for
Washington Department of Fish and Wildlife

December 2007 Working Draft

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Executive Summary

The Revised Code of Washington (RCW) directs the Washington Department of Fish and Wildlife (WDFW) to "preserve, protect, perpetuate, and manage" the fish and wildlife species of the state as its paramount responsibility (RCW 77.04.012). Under RCW 77.55, any construction or work that uses, diverts, obstructs, or changes the natural bed or flow of state waters requires a Hydraulic Project Approval (HPA) issued by WDFW. The purpose of the HPA program is to ensure that hydraulic projects are completed in a manner that prevents damage to public fish and shellfish resources and their habitats. To ensure that the HPA program complies with the Endangered Species Act (ESA), WDFW is developing a programmatic multispecies Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit from the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (also known as NOAA Fisheries), in accordance with Section 10 of the ESA. For WDFW, the objective is to avoid and/or minimize the incidental take of those aquatic species considered for coverage under the HCP (referred to as "HCP species") resulting from activities conducted under an HPA.

The HCP will address the impacts, potential for take, and mitigation measures for effects on HCP species from hydraulic projects that require HPAs. WDFW's intent is to build the scientific foundation for the effort to prepare an HCP for hydraulic projects that receive HPAs. To accomplish this, WDFW is compiling the best available scientific information related to the impacts, potential for incidental "take" of species that may be covered in the HCP (as defined in the ESA; see Section 9 [*Potential Risk of Take*] of this report for a definition of "take"), adequacy of existing rules (Washington Administrative Code [WAC] 220-110), and possible management directives and mitigation measures to avoid and/or minimize potential take to the maximum extent practicable. As the HPA authority covers all waters of the state, this white paper considers hydraulic project impacts in both freshwater and marine environments.

This white paper is one of a suite of white papers prepared to establish the scientific basis for the HCP and assist WDFW decision-making on what specific HPA activities should be covered by the HCP. This particular white paper compiles and synthesizes existing scientific information on marinas and shipping and ferry terminals. This white paper was prepared as a supplement to a white paper prepared in 2006 that covered all other overwater structures (i.e., docks, piers, floats, ramps, and wharfs) (Jones and Stokes 2006).

The objectives of this white paper are to:

- Compile and synthesize the best available scientific information related to the potential human impacts on HCP species, their habitats, and associated ecological processes resulting from the construction, maintenance, repair, replacement, modification, operation, and removal (hereafter collectively referred to as construction, operation, and repair) of marinas and shipping/ferry terminals (hereafter referred to as marinas/terminals)

- Use this scientific information to estimate the circumstances, mechanisms, and risks of incidental take potentially or likely to result from the construction, operation, and repair of marinas and ferry or shipping terminals

- Identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), to avoid and/or minimize the risk of incidental take of HCP species.

The literature review conducted for this white paper identified six impact mechanisms associated with marinas/terminals that could potentially affect HCP species. These mechanisms of impact are both direct and indirect and can have temporary, short-term effects or permanent, long-term effects. The impact mechanisms analyzed in this white paper are:

- Construction and maintenance activities
- Facility operation and vessel activity
- Water quality modifications
- Riparian vegetation modifications
- Aquatic vegetation modifications
- Hydraulics and geomorphic modifications.

This white paper presents an overview of what is known about the potential impact mechanisms in relation to the 52 species considered for HCP coverage (i.e., the HCP species). Based on a separate analysis conducted using exposure-response matrices for each species, the risks of direct and indirect impacts on these species and their habitats are identified and described. This white paper also reviews data gaps and, where there is insufficient information, estimates the risk of take. In addition, habitat protection, conservation, mitigation, and management strategies that could avoid, minimize, or mitigate the identified potential impacts are presented. Key elements of the white paper are to:

- Identify the distribution of HCP species (i.e., whether they use fresh water, marine water, or both) and the habitat requirements of those species.

- Identify the risk of "take" associated with each of these impacts mechanisms based on the distribution information.

- Identify cumulative impacts.

- Identify data gaps.

- Identify habitat protection, conservation, and mitigation strategies.

1.0 Introduction

The Revised Code of Washington (RCW) directs the Washington Department of Fish and Wildlife (WDFW) to "preserve, protect, perpetuate, and manage" the fish and wildlife species of the state as its paramount responsibility (RCW 77.04.012). Under RCW 77.55, any construction or work that uses, diverts, obstructs, or changes the natural bed or flow of state waters requires a Hydraulic Project Approval (HPA) issued by WDFW. The purpose of the HPA program is to ensure that these activities are completed in a manner that prevents damage to public fish and shellfish resources and their habitats. To ensure that the HPA program complies with the Endangered Species Act (ESA), WDFW is developing a programmatic multispecies Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit (ITP), in accordance with Section 10 of the ESA, from the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (also known as NOAA Fisheries). For WDFW, the benefits of an HCP are to contribute to the long-term conservation of both listed and unlisted species through the minimization and mitigation of impacts on those species and their habitats, while ensuring that WDFW can legally proceed with the issuance of HPAs that could otherwise result in the incidental "take" of ESA-listed species (as defined in the ESA; see Section 9 [*Potential Risk of Take*] of this report for a definition of "take").

The HCP will identify the impacts on those aquatic species considered for coverage under the HCP (referred to as "HCP species"), the potential for take, and mitigation measures for hydraulic projects that require HPAs. This white paper is part of the effort to compile the best available scientific information to protect these species during the creation, construction, maintenance, repair, replacement, modification, operation, and removal (hereafter referred to as construction, operation, and repair) of hydraulic projects. To accomplish this, WDFW is analyzing the adequacy of existing rules (Washington Administrative Code [WAC] 220-110), as well as possible management directives and mitigation measures, to avoid and/or minimize potential take to the maximum extent practicable. As the HPA authority covers all waters of the state, this white paper considers hydraulic project impacts in both freshwater and marine environments. This white paper is one of a suite of white papers prepared to establish the scientific basis for the HCP and assist WDFW decision-making with regard to what specific HPA activities should be covered by the HCP and what minimization and mitigation measures can be taken to address the potential effects of hydraulic projects. This white paper addresses impacts and mitigation/minimization measures to be applied to marinas and shipping/ferry terminals (hereafter referred to as marinas/terminals). Species covered under the HCP are listed in Table 1-1. For the purpose of this white paper, some of the HCP species have been grouped when applicable (each group is separated by a gray-colored line in Table 1-1). This white paper only addresses the effects of construction, operation, and repair of marinas/terminals, including discharges and effects associated with the facility and vessels using the facility. Marinas typically include considerable shoreline modification structures in the form of breakwaters, bulkheads, and nearshore buildings; the effects of these shoreline modifications are covered in a separate white paper (Shoreline Modifications, Herrera 2007a).

Table 1-1. HCP species addressed in this white paper [a]

Common Name	Scientific Name	Status	Habitat
Chinook salmon	*Oncorhynchus tshawytscha*	FE/FT/SC	Freshwater, Estuarine, Marine
Coho salmon	*Oncorhynchus kisutch*	FT/FSC	Freshwater, Estuarine, Marine
Chum salmon	*Oncorhynchus keta*	FT/SC	Freshwater, Estuarine, Marine
Pink salmon	*Oncorhynchus gorbuscha*	SPHS	Freshwater, Estuarine, Marine
Sockeye salmon	*Oncorhynchus nerka*	FE/FT/SC	Freshwater, Estuarine, Marine
Steelhead	*Oncorhynchus mykiss*	FE/FT/SC	Freshwater, Estuarine, Marine
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	FSC	Freshwater, Estuarine, Marine
Westslope cutthroat trout	*Oncorhynchus clarki lewisii*	FSC	Freshwater
Redband trout	*Oncorhynchus mykiss*	FSC	Freshwater
Bull trout	*Salvelinus confluentus*	FT/SC	Freshwater, Estuarine
Dolly Varden	*Salvelinus malma*	FP	Freshwater, Estuarine
Pygmy whitefish	*Prosopiim coulteri*	FSC/SS	Freshwater
Olympic mudminnow	*Novumbra hubbsi*	SS	Freshwater
Lake chub	*Couesius plumbeus*	SC	Freshwater
Leopard dace	*Rhinichthys falcatus*	SC	Freshwater
Margined sculpin	*Cottus marginatus*	FSC/SS	Freshwater
Mountain sucker	*Catostomus platyrynchus*	SC	Freshwater
Umatilla dace	*Rhinichthys umatilla*	SC	Freshwater
Pacific lamprey	*Lampetra tridentata*	FSC	Freshwater, Estuarine, Marine
River lamprey	*Lampetra ayresi*	FSC/SC	Freshwater, Estuarine, Marine
Western brook lamprey	*Lampetra richardsoni*	FSC	Freshwater
Green sturgeon	*Acipenser medirostris*	FSC/FT/SPHS	Freshwater, Estuarine, Marine
White sturgeon	*Acipenser transmontanus*	SPHS	Freshwater, Estuarine, Marine
Eulachon	*Thaleichthys pacificus*	FC/SC	Freshwater, Estuarine, Marine
Longfin smelt	*Spirinchus thaleichthys*	SPHS	Freshwater, Estuarine, Marine
Pacific sand lance	*Ammodytes hexapterus*	SPHS	Marine & Estuarine
Surf smelt	*Hypomesus pretiosus*	SPHS	Marine & Estuarine
Pacific herring	*Clupea harengus pallasi*	FC/SC	Marine & Estuarine
Lingcod	*Ophiodon elongatus*	SPHS	Marine & Estuarine
Pacific cod	*Gadus macrocephalus*	FSC/SC	Marine (occ. Estuarine)
Pacific hake	*Merluccius productus*	FSC/SC	Marine & Estuarine
Walleye pollock	*Theragra chalcogramma*	FSC/SC	Marine (occ. Estuarine)

Table 1-1 (continued). HCP species addressed in this white paper [a]

Common Name	Scientific Name	Status	Habitat
Black rockfish	*Sebastes melanops*	SC	Marine & Estuarine
Bocaccio rockfish	*Sebastes paucispinis*	SC	Marine & Estuarine
Brown rockfish	*Sebastes auriculatus*	SC	Marine & Estuarine
Canary rockfish	*Sebastes pinniger*	SC	Marine & Estuarine
China rockfish	*Sebastes nebulosis*	SC	Marine & Estuarine
Copper rockfish	*Sebastes caurinus*	FSC/SC	Marine & Estuarine
Greenstriped rockfish	*Sebastes elongates*	SC	Marine & Estuarine
Quillback rockfish	*Sebastes maliger*	FSC/SC	Marine & Estuarine
Redstripe rockfish	*Sebastes proriger*	SC	Marine & Estuarine
Tiger rockfish	*Sebastes nigrocinctus*	SC	Marine & Estuarine
Widow rockfish	*Sebastes entomelas*	SC	Marine & Estuarine
Yelloweye rockfish	*Sebastes ruberrimus*	SC	Marine & Estuarine
Yellowtail rockfish	*Sebastes flavidus*	SC	Marine & Estuarine
Olympia oyster	*Ostrea lurida*	SPHS	Marine & Estuarine
Northern abalone	*Haliotis kamtschatkana*	FSC/SC	Marine
Newcomb's littorine snail	*Algamorda subrotundata*	FSC/SC	Marine
Giant Columbia River limpet	*Fisherola nuttalli*	SC	Freshwater
Great Columbia River spire snail	*Fluminicola columbiana*	FSC/SC	Freshwater
California floater (mussel)	*Anodonta californiensis*	FSC/SC	Freshwater
Western ridged mussel	*Gonidea angulata*	None	Freshwater

Notes:
[a] For the purpose of this white paper, some of the HCP species have been grouped when applicable (each group is separated by a gray-colored line).

FE=Federal Endangered
FP=Federal Proposed
FT = Federal Threatened
FC = Federal Candidate
FSC = Federal Species of Concern
SC = State Candidate
SS = State Sensitive
SPHS = State Priority Habitat Species

2.0 Objectives

The objectives of this white paper are to:

- Compile and synthesize best available scientific information related to the potential human impacts on HCP species, their habitats, and associated ecological processes resulting from the creation, construction, maintenance, repair, replacement, modification, operation, and removal (hereafter collectively referred to as construction, operation, and repair) of marinas/terminals.

- Use this scientific information to estimate the circumstances, mechanisms, and risks of incidental take potentially or likely resulting from the construction, operation, and repair of marinas/terminals.

- Identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), to avoid and/or minimize the risks of incidental take of HCP species.

3.0 Methods

Information presented in this white paper is primarily based on the compilation and synthesis of the best available scientific information related to human impacts on HCP species, their habitats, and associated ecological processes. The methods used here included the acquisition of existing literature, followed by an analysis of impacts based on a review of the literature. In addition, where specific information is lacking, best professional judgment was used to draw inferences from other pertinent, similar, or related studies and data sources. The conceptual framework for assessing potential impacts is described in detail in Section 6; below is a discussion of the literature acquisition and review process.

To acquire literature supporting the best available scientific information, an extensive search of the available literature was conducted using the following electronic databases: NOAA Regional Library, the Northwest Fishery Science Center (NWFSC), Aquatic Sciences and Fisheries Abstracts (ASFA), University of Washington (UW) Fisheries Research Institute Reports, the National Technical Information Service (NTIS), the UW Urban Water Resource Management database, the Seattle Aquarium Salmon Information Center database, the library catalog of the University of Washington, and the U.S. Department of Energy, Energy Citation Database.

The UW Fisheries Research Institute Reports, UW Water Resource Management, Salmon Information Center, UW library, the U.S. Department of Energy, Energy Citation Database, and the NTIS electronic databases have unlimited internet access. The UW library catalog is available at http://catalog.lib.washington.edu/search~/. The University of Washington School of Aquatic and Fisheries Sciences, Fisheries Research Institute Reports (UW-FRI) database includes more than 500 reports pertaining to research conducted by Fisheries Research Institute (FRI) personnel from 1973 to the present. These are available on the internet at http://www.fish.washington.edu/Publications/frireps.html. The UW Urban Water Resource Management and Salmon Information Center database is accessible at http://depts.washington.edu/cuwrm/. The U.S. Department of Energy, Energy Citation Database is available at http://www.osti.gov/energycitations/.

The ASFA database has limited online membership but was accessed through the UW library system. The ASFA database includes literature dating back to 1982 covering the science, technology, and management of marine and freshwater environments. It includes 5,000 international sources in the form of primary journals, source documents, books, monographic series, conference proceedings, and technical research reports.

Finally, because this white paper was prepared by a diverse group of scientists from a wide range of backgrounds, many other primary resources (e.g., consultant reports and textbooks) were found in the personal collection of the staff of Herrera Environmental Consultants, Inc. (the consulting firm working with WDFW to prepare this white paper).

To identify knowledge gaps and evaluate the state of scientific knowledge applicable to the potential impacts of marinas/terminals on the HCP species and their habitats, the acquired literature was examined to assess the broader issue of how these species use aquatic habitats and how marinas/terminals and their associated uses can alter habitat functions.

Existing literature reviews, peer-reviewed journal articles, books, theses/dissertations, and technical reports were reviewed for information specific to aquatic species and their interaction with marinas/terminals. Through this process, a collection of information was assembled on the life history, habitat uses, and the potential impacts that marinas/terminals pose to HCP species.

Reference material from each of the above databases was compiled in an Endnote personal reference database (Endnote version X). Reference types collected and entered into the database included journal articles, reports, web pages, conference proceedings, theses, statutes, books, and book sections. Each entry in the database included descriptive information, including author(s), year, title, volume, pages, publisher, and other relevant information. Whenever an electronic copy of the reference material was available, a link between the reference entry and a .pdf copy of the reference material was included in the database. If an electronic (.pdf) copy of a reference was not available, a hardcopy of the material was kept on file. All reference material cited in the literature review was either linked to the reference database or kept in an associated file as a hardcopy.

Endnote X is the industry standard software for organizing bibliographic information. It features a fully searchable and field sortable database that can contain an unlimited number of references. Reference information is entered into the database either by direct import from online databases or by manually entering the reference information into reference type templates. Once all the references were entered, the database was used for organizational and archival purposes. The final database is included as an electronic appendix to this report (Appendix B).

4.0 Hydraulic Project Description

RCW 77.55.011(7) defines a hydraulic project as "the construction or performance of work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or freshwaters of the state." Construction, operation, and repair of marinas/terminals require HPA permits. Marina/terminal projects include piers, floats, ramps, wharves, dolphins, fender panels, and pilings for structures on or above the water.

For the purposes of this white paper:

- A **pier** is an elevated and stationary walkway supported by pilings that extends waterward of the shoreline.
- A **float** and a **dock** are both defined as a walkway or other surface that floats on the water.
- A **ramp** is defined as a walkway connecting a pier or other shoreward structure to a float and providing access between the two.
- A **wharf** is defined as an elevated and stationary structure oriented parallel to the shoreline, such that vessels can lie alongside to load and unload cargo and passengers.
- A **dolphin** is a buoy, pile, or group of piles used for mooring boats or group of piers used as a fender at a dock.
- A **fender panel** is a structure for protecting from collision with ships.
- A **piling** or **pile** is driven into the stream, lake, or ocean bed to support wharves and piers. It includes both structural and nonstructural pilings.
- A **marina** is a public or private facility providing vessel moorage space, fuel, or commercial services. Commercial services include but are not limited to overnight or live-aboard vessel accommodations (RCW 77.55.011(9)).
- A **terminal** is a public or private commercial wharf located in the navigable waters of the state and used, or intended to be used, as a port or facility for the storing, handling, transferring, or transporting of goods, passengers, and vehicles to and from vessels (RCW 77.55.011(10), with passengers added for purposes of this paper).

Marina/terminal projects are required to comply with all provisions specified in the Washington Administrative Code, including WAC 220-110-060 (freshwater overwater structures), WAC

220-110-300 (marine overwater structures), and 220-110-330 (marinas in saltwater areas). This analysis addresses the impacts of lawful activities, which are the only activities that can be authorized under an ESA Incidental Take Permit (ITP). This analysis also includes the uses and activities associated with the operation of these structures (i.e., vessel activities). WAC sections identified for analysis in this white paper are listed in Table 4-1.

Table 4-1. WAC sections potentially applicable to the Marinas/Terminals white paper.

Subactivity Type	Freshwater WACs (direct and indirect applicability)	Saltwater WACs (direct and indirect applicability)
Marinas	No specific WACs for marinas *220-110-050 (bank) 220-110-060 (overwater structures) 220-110-130 (dredging) 220-110-150 (large woody debris) *220-110-170 (outfalls) *220-110-223 (lake bank) 220-110-224 (ramps)	220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) *220-110-280 (non-SFRM bank) 220-110-290 (ramps) 220-110-300 (overwater structures) 220-110-320 (dredging) 220-110-330 (marinas)
Shipping & Ferry Terminals	No specific WACs for terminals *220-110-050 (bank) 220-110-060 (overwater structures) 220-110-130 (dredging) 220-110-150 (large woody debris) *220-110-170 (outfalls) *220-110-223 (lake bank) 220-110-224 (ramps)	No specific WACs for terminals 220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) *220-110-280 (non-SFRM bank) 220-110-290 (ramps) 220-110-300 (overwater structures) 220-110-320 (dredging) 220-110-330 (marinas)

* indicates WACs that may be related to the project type, but are not necessarily an implicit component of the activity type.
SFRM = single-family residential marine.

Marinas/terminals include over- and on-water structures such as piers, access ramps, boat launches/hoists, boat basins, vessel/barge access to piers and stations, and floating docks and structures. They may also include pump-out stations/facilities, water intake/discharge sites, and refueling stations/facilities. Marinas typically include considerable shoreline modification structures in the form of breakwaters, wingwalls, bulkheads, seawalls, and nearshore buildings. The effects of these shoreline modifications are covered in a separate white paper (Shoreline Modifications, Herrera 2007a). This Marinas white paper only addresses the effects of construction, operation, and repair of marinas/terminals, including discharges and effects associated with the facility and vessels using the facility and dredging for navigational purposes.

4.1 Marina/Terminal Structures and Area of Alteration

The area of potential alteration includes all the overwater structures and their associated dredged area; the area affected by changes in light regime from shading and artificial lighting; and the area affected by vessel propeller scour, vessel emissions and exhaust, and boat wakes. Furthermore, pollution from spillage and accidental discharges of toxins, waste, or stormwater may extend the area of alteration beyond the marina itself. The area of alteration and the effects on habitat-controlling factors (e.g., depth, substrate, slope, light, wave energy, hydrology, temperature, salinity, nutrients, and water quality; see Section 6 [*Conceptual Framework for Assessing Impacts*]) may be limited, if enclosed by breakwaters.

Marinas/terminals are planned facilities that incorporate many individual components of overwater structures, including all supporting pilings, buoys, and vessel access facilities. According to WDFW's Hydraulic Permit Management System (HPMS), HPAs have been issued for marina/terminal project types for public ports and private facilities. These projects were classified into three categories: (1) repair/maintenance, (2) replacement of creosote pilings with steel pilings, and (3) the addition of docks and floats to existing facilities. In addition to these projects, the Washington State Department of Transportation (WSDOT) was issued regional permits for removal and replacement of up to 40 piles per construction season for each Washington State ferry terminal, as well as regional permits for terminal cleaning, maintenance, and repair. In addition to these facilities, the U.S. Army Corps of Engineers (USACE) was granted permits for dock maintenance and replacement along the Columbia River.

5.0 Potentially Covered Species and Habitat Use

This white paper identifies what is known about activities associated with the construction, operation, and repair of marinas/terminals and how each can pose a risk of take for the 52 HCP species. To understand species-specific impacts, it is important to understand the geographic distribution and habitat use of each species. Table 5-1 lists the scientific name, Water Resource Inventory Area (WRIA) and Tidal Reference Area of occurrence, and the reproductive patterns and habitat requirements of each HCP species. Through the identification of species-specific habitat needs, the risk of take associated with the construction, operation, and repair of marinas/terminals can be identified. Once the potential for a take is identified, it can be avoided. If unavoidable, the risk of take can be minimized by design and/or through conservation and protection measures (see Section 9 [*Potential Risk of Take*] and the exposure-response matrices for each of these species presented in Appendix A).

Table 5-1. Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Chinook salmon	*Oncorhynchus tshawytscha*	01–42, 44–50	All	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries recognizes eight ESUs of Chinook salmon in Washington: (1) Upper Columbia River spring-run; (2) Snake River spring/summer run; (3) Snake River fall-run; (4) Puget Sound; (5) lower Columbia River; (6) Washington coast; (7) Mid-Columbia River spring-run; and (8) Upper Columbia River summer/fall-run. Chinook salmon exhibit one of two life-history types, or races: the stream-type and the ocean-type. Stream-type Chinook tend to spend 1 (or less frequently 2) years in freshwater environments as juveniles prior to migrating to salt water as smolts. Stream-type Chinook are much more dependent on freshwater stream ecosystems than ocean-type Chinook. Stream-type Chinook do not extensively rear in estuarine and marine nearshore environments; rather, they head offshore and begin their seaward migrations. Ocean-type Chinook enter salt water at one of three phases: immediate fry migration soon after yolk is absorbed, fry migration 60–150 days after emergence, and fingerling migrants that migrate in the late summer or fall of their first year. Ocean-type Chinook are highly dependent on estuarine habitats to complete their life history. Chinook generally feed on invertebrates but become more piscivorous with age. **Reproduction/Life History** Chinook runs are designated on the basis of adult migration timing: • Spring-run Chinook: Tend to enter fresh water as immature fish, migrate far upriver, and finally spawn in the late summer and early autumn. • Fall-run Chinook: Enter fresh water at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry. • Spring Chinook: Spawning occurs from mid-July to mid-December, and incubation lasts approximately 1.5–7 months, depending on temperature. Emergence follows, 6–8 months from fertilization. • Fall Chinook: Spawning occurs from late October to early December, with incubation occurring for 1–6 months. Emergence follows, approximately 6 months after fertilization. (Healey 1991; Myers et al. 1998; WDNR 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Coho salmon	*Oncorhynchus kisutch*	01–42, 44–48, 50	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes four ESUs of coho salmon in Washington: (1) Lower Columbia River; (2) Southwest Washington; (3) Puget Sound and Strait of Georgia; and (4) Olympic Peninsula. This species is found in a broader diversity of habitats than any of the other native anadromous salmonids. Fry feed primarily on aquatic insects and prefer pools and undercut banks with woody debris; adults feed on herring and other forage fish. **Reproduction/Life History** Coho adults spawn from September to late January, generally in the upper watersheds in gravel free of heavy sedimentation. Developing young remain in gravel for up to 3 months after hatching. Fry emerge from early March to late July. Coho rear in fresh water for 12–18 months before moving downstream to the ocean in the spring. Coho spend between 1 and 2 years in the ocean before returning to spawn. (Groot and Margolis 1991; Murphy and Meehan 1991; WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Chum salmon	*Oncorhynchus keta*	01, 03–05, 07–29	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes four ESUs of chum salmon in Washington: (1) Hood Canal summer run; (2) Columbia River; (3) Puget Sound/Strait of Georgia; and (4) Pacific Coast. Little is known about their ocean distribution; maturing individuals that return to Washington streams have primarily been found in the Gulf of Alaska. Chum migrate into rivers and streams of Washington coast, Hood Canal, Strait of Juan de Fuca, Puget Sound, and the Columbia River basin to spawn, but their range does not extend upstream above the Dalles Dam in the Columbia River. Fry feed on chironomid and mayfly larvae, as well as other aquatic insects, whereas juvenile fish in the estuary feed on copepods, tunicates, and euphausiids. **Reproduction/Life History** Chum salmon have three distinct run times: summer, fall and winter. Summer chum begin their upstream migration and spawn from mid-August through mid-October, with fry emergence ranging from the beginning of February through mid-April. Chum fry arrive in estuaries earlier than most salmon, and juvenile chum reside in estuaries longer than most other anadromous species. Chum salmon rear in the ocean for the majority of their adult lives. Fall chum adults enter the rivers from late October through November and spawn in November and December. Winter chum adults migrate upstream from December through January and spawn from January through February. Fall and winter chum fry emerge in March and April and quickly emigrate to the estuary. Chum salmon utilize the low-gradient (from 1–2 percent grade), sometimes tidally influenced lower reaches of streams for spawning. (Healey 1982; Johnson et al. 1997; Quinn 2005; Salo 1991; WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pink salmon	*Oncorhynchus gorbuscha*	01, 03–05, 07, 09–11, 16–19, 21	1–13	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes two ESUs of pink salmon in Washington, neither of which is listed: (1) Odd-year; and (2) Even-year. The most abundant species of salmon, with 13 stocks identified in Washington. They are the smallest of the Pacific salmon and mature and spawn on a 2-year cycle in Washington (primarily spawning during odd years). Adults are opportunistic feeders in marine habitat, foraging on a variety of forage fish, crustaceans, ichthyoplankton, and zooplankton. Juveniles primarily feed on small crustaceans such as euphausiids, amphipods, and cladocerans. **Reproduction/Life History** Pink salmon will spawn in rivers with substantial amounts of silt. Spawning occurs from August through October. Fry emerge from their redds in late February to early May, depending on water temperature, and migrate downstream to the estuary within 1 month. Juveniles remain in estuarine or nearshore waters for several months before moving offshore as they migrate to the Pacific Ocean, where they remain approximately 1 year until the next spawning cycle. (Hard et al. 1996; Heard 1991; WDNR 2005a, 2006a)
Sockeye salmon	*Oncorhynchus nerka*	01, 03–05, 07–11, 16, 19–22, 25–33, 35–37, 40, 41, 44–50	5, 8, 14	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries recognizes seven ESUs of sockeye salmon in Washington: (1) Snake river; (2) Ozette Lake; (3) Baker river; (4) Okanogan River; (5) Quinault Lake; (6) Lake Pleasant; and (7) Lake Wenatchee. WDFW recognizes an additional sockeye salmon stock in the Big Bear Creek drainage of Lake Washington. Kokanee (landlocked sockeye) occur in many lakes, with the larger populations in Banks and Loon lakes in eastern Washington and Lake Whatcom and Lake Washington-Sammamish in western Washington. Juveniles feed on zooplankton, and adults primarily feed on fish, euphausiids, and copepods. **Reproduction/Life History** Spawn in shallow, gravelly habitat in rivers and lakes during August to October. Juvenile sockeye rear in lakes for 1–2 years before migrating to the ocean. Emergence occurs within 3–5 months. (Gustafson et al. 1997; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Steelhead	*Oncorhynchus mykiss*	01, 03–05, 07–12, 14, 15, 17–41, 44–50	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes 15 Distinct Population Segments (DPSs) of steelhead, seven of which occur in Washington. During their ocean phase, steelhead are generally found within 10 and 25 miles of the shore; steelhead remain in the marine environment 2–4 years before returning to fresh water to spawn. Most steelhead spawn at least twice in their lifetimes. Escape cover, such as logs, undercut banks, and deep pools, is important for adult and young steelhead in the freshwater systems. The coastal west-side streams typically support more winter steelhead populations. **Reproduction** A summer spawning run enters fresh water in August and September, and a winter run occurs from December through February. Summer steelhead usually spawn farther upstream than winter populations and dominate inland areas such as the Columbia Basin. Spawning occurs from March to April for both winter and summer run steelhead. After hatching and emergence (approximately 3 months), juveniles establish territories, feeding on microscopic aquatic organisms and then larger organisms such as isopods, amphipods, and aquatic and terrestrial insects. Steelhead rear in fresh water for up to 4 years before migrating to sea. (Busby et al. 1996; McKinnell et al. 1997; WDNR 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	01–05, 07–30	All	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries has recognized three evolutionarily significant units (ESUs) in Washington: (1) Puget Sound; (2) Olympic Peninsula; (3) Southwestern Washington/Columbia River. USFWS has assumed sole jurisdiction for this species. No coastal cutthroat trout DPSs are listed under the ESA in Washington. Coastal cutthroat trout exhibit varied life-history forms including: • Resident (stays in streams after rearing in their natal streams) – Resident coastal cutthroat trout utilize small headwater streams for all of their lifestages. • Fluvial (migrates to larger rivers after rearing in their natal streams). • Adfluvial (migrates to lakes after rearing in their natal streams). • Anadromous (utilizes estuaries and nearshore habitat but has been caught offshore). Juveniles of all life forms feed primarily on aquatic invertebrates but are opportunistic feeders; adults tend to feed on smaller fish, amphibians, and crustaceans while foraging within the nearshore environment. **Reproduction/Life History** Coastal cutthroat trout are repeat spawners, and juveniles typically rear in the natal streams for up to 2 years. Spawning occurs from late December to February, with incubation lasting approximately 2–4 months. Emergence occurs after 4 months. (Johnson et al. 1999; Pauley et al. 1988; WDNR 2006a)
Redband trout	*Oncorhynchus mykiss gardnerii*	37–40, 45–49, 54–57	NA	**General Information (Habitats and Feeding)** Redband trout is a subspecies of rainbow trout found east of the Cascade Mountains, which prefer cool water that is less than 70°F (21°C), and occupy streams and lakes with high amounts of dissolved oxygen. Their food primarily consists of Daphnia and chironomids as well as fish eggs, fish, and insect larvae and pupae. **Reproduction/Life History** Spawn in streams with clean, small gravel from March through May. Incubation takes approximately 1–3 months, with emergence occurring between June and July. (USFS 2007)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Westslope cutthroat trout	*Oncorhynchus clarki lewisii*	37–39, 44–55, 58–62	NA	**General Information (Habitats and Feeding/Life-history Types)** Cutthroat trout tend to thrive in streams with extensive pool habitat and cover. The westslope is a subspecies of cutthroat trout with three possible life forms: • Adfluvial (migrates to lakes) • Fluvial (migrates to larger rivers) • Resident (stays in streams). The headwater tributaries used by resident cutthroat are typically cold, nutrient-poor waters that result in slow growth. Fluvial and adfluvial forms can exhibit more growth due to warmer water temperatures and nutrient availability. Fry feed on zooplankton, and fingerlings feed on aquatic insect larvae. Adults feed on terrestrial and aquatic insects. **Reproduction/Life History** Spawning: all three life forms spawn in small gravel substrates of tributary streams in the spring (March to July) when water temperature is about 50°F (10°C); incubation occurs during April to August, and emergence occurs from May through August. Fry spend 1–4 years in their natal stream before migrating to their ultimate habitat. (Liknes and Graham 1988; Shepard et al. 1984; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Bull trout	*Salvelinus confluentus*	01, 03–05, 07–23, 26, 27, 29–41, 44–55, 57–62	All	**General Information (Habitats and Feeding/Life-History Types)** Widely distributed in Washington; exhibit four life-history types: • Resident (stays in streams after rearing in their natal streams) • Fluvial (migrates to larger rivers after rearing in their natal streams) • Adfluvial (migrates to lakes after rearing in their natal streams) • Anadromous (bull trout in the nearshore ecosystem rely on estuarine wetlands and favor irregular shorelines with unconsolidated substrates). Young of the year occupy side channels, with juveniles in pools, runs, and riffles; adults occupy deep pools. Juvenile diet includes larval and adult aquatic insects; subadults and adults primarily feed on fish. **Reproduction/Life History** The migratory forms of bull trout, such as anadromous, adfluvial, and fluvial, move upstream by early fall to spawn in September and October (November at higher elevations). Although resident bull trout are already in stream habitats, they move upstream looking for suitable spawning habitat. They prefer clean, cold water (50°F [10°C]) for spawning. Colder water (36–39°F [2–4°C]) is required for incubation. Preferred spawning areas often include groundwater infiltration. Extended incubation periods (up to 220 days) make eggs and fry particularly susceptible to increases in fine sediments. Bull trout typically rear in natal streams for 2–4 years, although resident fish may remain in these streams for their entire lives; multiple life-history forms may occur in the same habitat environments. (Goetz et al. 2004; WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Dolly Varden	*Salvelinus malma*	01, 03, 05, 07, 17–22, 24	6–10, 14–17	**General Information (Habitats and Feeding/Life-History Types)** Species restricted to coastal areas and rivers that empty into them. Juveniles extensively use instream cover; while in the marine systems, they use beaches of sand and gravel. Prefer pool areas and cool temperatures. Feed opportunistically on aquatic insects, crustaceans, salmon eggs, and fish. Closely related to bull trout and exhibit the same life-history traits. Four life-history types occur: • Resident (stays in streams after rearing in their natal streams) • Fluvial (migrates to larger rivers after rearing in their natal streams) • Adfluvial (migrates to lakes after rearing in their natal streams) • Anadromous (migrates to marine waters after rearing in their natal streams). **Reproduction/Life History** Spawn and rear in streams from mid-September through November. Incubation lasts approximately 130 days. Juveniles can spend 2–4 years in their natal streams before migration to marine waters. (Leary and Allendorf 1997; WDNR 2005a; Wydoski and Whitney 2003)
Pygmy whitefish	*Prosopium coulteri*	08, 19, 39, 47, 49, 53, 55, 58, 59, 62	NA	**General Information (Habitats and Feeding)** In Washington, pygmy whitefish occur at the extreme southern edge of their natural range; pygmy whitefish were once found in at least 15 Washington lakes but have a current distribution in only nine. They occur most often in deep, oligotrophic lakes with temperatures less than 50°F (10°C), where they feed on zooplankton, such as cladocerans, copepods, and midge larvae. **Reproduction/Life History** Pygmy whitefish spawn in streams or lakes from July through November. They prefer pools, shallow riffles, and pool tail-outs when spawning in streams. Lake spawning by pygmy whitefish occurs at night. Spawning occurs by scattering their eggs over coarse gravel. Incubation and emergence timing are unknown, but eggs are believed to hatch in the spring. (Hallock and Mongillo 1998; WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Olympic mudminnow	*Novumbra hubbsi*	08–24	NA	**General Information (Habitats and Feeding)** Occur in the southern and western lowlands of the Olympic Peninsula, the Chehalis River drainage, lower Deschutes River drainage, south Puget Sound lowlands west of the Nisqually River, and in King County. They are generally found in quiet water with mud substrate, preferring bogs and swamps with dense aquatic vegetation. Mudminnows feed on annelids, insects, and crustaceans. **Reproduction/Life History** Adults spawn from November through June (peaking in April and May). Females deposit eggs onto vegetation where fry remain firmly attached for approximately 1 week after hatching. Incubation lasts approximately 8-10 days. (Harris 1974; Mongillo and Hallock 1999; WDNR 2005a, 2006a)
Lake chub	*Couesius plumbeus*	48, 61; other locations unknown	NA	**General Information (Habitats and Feeding)** Bottom dwellers inhabiting a variety of habitats in lakes and streams, but are known to prefer small, slow streams. In Washington, they are known only from the northeastern part of the state (small streams and lakes in Okanogan and Stevens counties). Juveniles feed on zooplankton and phytoplankton, whereas adults primarily feed on insects. **Reproduction/Life History** Lake chub move into shallow areas on rocky and gravelly substrates in tributary streams of lakes or lakeshores during the spring to spawn when water temperatures are between 55 and 65°F (13 and 18°C). The eggs are broadcast over large rocks and then settle into the smaller substrate, hatching after approximately 10 days. (WDNR 2005a; Wydoski and Whitney 2003)
Leopard dace	*Rhinichthys falcatus*	25–31, 37–41, 44–50	NA	**General Information (Habitats and Feeding)** In Washington, leopard dace inhabit the bottoms of streams and small to mid-sized rivers, specifically the Columbia, Snake, Yakima, and Simikameen Rivers, with velocities less than 1.6 ft/sec (0.5 m/sec); prefer gravel and small cobble substrate covered by fine sediment with summer water temperatures ranging between 59 and 64°F (15 and 18°C). Juveniles feed primarily on aquatic insects; adult leopard dace consume terrestrial insects. **Reproduction/Life History** Breeding habitat for dace generally consists of the gravel or cobble bottoms of shallow riffles; leopard dace breed in slower, deeper waters than the other dace species. The spawning period for dace is from May through July. The eggs adhere to rocky substrates. Fry hatch approximately 6–10 days after fertilization, and juveniles spend 1–3 months rearing in shallow, slow water. (WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Margined sculpin	*Cottus marginatus*	32, 35	NA	**General Information (Habitats and Feeding)** Endemic to southeastern Washington (smaller tributary streams of the Walla Walla and Tucannon River drainages) where habitat is in deeper pools and slow-moving glides in headwater tributaries with silt and small gravel substrate. They prefer cool water less than 68°F (20°C) and avoid high-velocity areas. Food includes immature aquatic insects, invertebrates, small fish, and eggs. **Reproduction/Life History** Spawning occurs in May and June primarily under rocks, root wads, or logs. The female deposits a mass of adhesive eggs in the nest, which is guarded by the male. Incubation duration unknown. (Mongillo and Hallock 1998; WDNR 2005a; Wydoski and Whitney 2003)
Mountain sucker	*Catostomus platyrynchus*	25–35, 37–41, 44–50	NA	**General Information (Habitats and Feeding)** Distribution restricted to Columbia River system. Found in clear, cold mountain streams less than 40 ft wide and in some lakes; prefer deep pools in summer with moderate current. Food consists of algae and diatoms. Juveniles prefer slower side channels or weedy backwaters. **Reproduction/Life History** Males reach sexual maturity in 2–3 years and females in 4 years. Spawning in June and July when water temperatures exceed 50°F (10°C). Spawning occurs in gravelly riffles of small streams when suckers move into those reaches to feed on algae. Spawning likely occurs at night when water temperatures are in a range of 51–66°F (10.5–19°C). Fertilized eggs fall into and adhere to the spaces between the gravel composite. Incubation period lasts approximatley 8-14 days. (Wydoski and Whitney 2003)
Umatilla dace	*Rhinichthys umatilla*	31, 36–41, 44–50, 59–61	NA	**General Information (Habitats and Feeding)** Umatilla dace are benthic fish found in relatively productive, low-elevation streams with clean substrates of rock, boulders, and cobbles in reaches where water velocity is less than 1.5 ft/sec (0.5 m/sec). Feeding is similar to that described for leopard dace. Juveniles occupy streams with cobble and rubble substrates, whereas adults occupy deeper water habitats. **Reproduction/Life History** Spawning behaviors are similar to those described for leopard dace, with spawning primarily occurring from early to mid-July. (WDNR 2005a, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific lamprey	*Lampetra tridentata*	01, 03–05, 07–35, 37–40, 44–50	All	**General Information (Habitats and Feeding)** Found in most large coastal and Puget Sound rivers and Columbia, Snake, and Yakima river basins. The larvae are filter feeders, residing in mud substrates and feeding on algae and other organic matter for at least 5 years. **Reproduction/Life History** From July through October, maturing Pacific lamprey enter fresh water and gradually move upstream to spawn the following spring. The nest usually consists of a shallow depression built in gravel and rock substrates. Eggs hatch in 2–4 weeks, with newly hatched larvae remaining in the nest for 2–3 weeks before moving downstream as larvae (ammocoetes). Juveniles migrate to the Pacific Ocean 4–7 years after hatching and attach to fish in the ocean for 20–40 months before returning to rivers to spawn. (WDNR 2005a; Wydoski and Whitney 2003)
River lamprey	*Lampetra ayresi*	01, 03, 05, 07–16, 20–40	1–9, 11–17	**General Information (Habitats and Feeding)** Detailed distribution records are not available for Washington, but they are known to inhabit coastal rivers, estuaries, and the Columbia River system. They have also been observed in Lake Washington and its tributaries. In the marine system, river lamprey inhabit nearshore areas. Adults are anadromous living in the marine system as parasites on fish. Adult river lamprey are believed to occupy deep portions of large river systems. The larvae feed on microscopic plants and animals. **Reproduction/Life History** Adults migrate back into fresh water in the fall. Spawning occurs in winter and spring. Eggs hatch in 2–3 weeks after spawning. Juveniles are believed to migrate from their natal rivers to the Pacific Ocean several years after hatching; adults spend 10–16 weeks between May and September in the ocean before migrating to fresh water. (WDNR 2005a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Western brook lamprey	*Lampetra richardsoni*	01, 03, 05, 07–14, 16, 20–40	NA	**General Information (Habitats and Feeding)** Found in small coastal and Puget Sound rivers and lower Columbia and Yakima river basins; spends entire life in fresh water. Adults are found in cool water (52–64°F [11–17.8°C]) on pebble/rocky substrate. Larvae (ammocoetes) are filter feeders, consuming primarily diatoms. Adults do not feed and die within a month of spawning. **Reproduction/Life History** Spawning generally occurs from April through July, with adults creating nests in coarse gravel at the head of riffles. Eggs hatch after about 10 days in water between 50 and 60°F (10 and 16°C). Within 30 days of hatching, ammocoetes emerge from the nests and move to the stream margin, where they burrow into silty substrates. Larvae remain in the stream bottom—apparently moving little—for approximately 4–6 years. (Wydoski and Whitney 2003)
Green sturgeon	*Acipenser medirostris*	22, 24, 28	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes two DPSs of green sturgeon, both of which can be found in Washington. The southern DPS is listed as threatened and the northern DPS is a species of concern. Habits and life history not well known. Washington waters with green sturgeon populations include the Columbia River, Willapa Bay, and Grays Harbor, in addition to marine waters. They spend much of their life in marine nearshore waters and estuaries feeding on fishes and invertebrates. **Reproduction/Life History** Spawning generally occurs in spring in deep, fast-flowing sections of rivers. Spawning habitat includes cobble or boulder substrates. Green sturgeon move upstream during spring to spawn and downstream during fall and winter. Large eggs sink to bottom. (Adams et al. 2002; Emmett et al. 1991; Kynard et al. 2005; Nakamoto and Kisanuki 1995; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
White sturgeon	*Acipenser transmontanus*	01, 03, 05–22, 24–37, 40–42, 44–61	All	**General Information (Habitats and Feeding)** Found in marine waters and major rivers in Washington, including the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. In marine environments, adults and subadults use estuarine and marine nearshore habitats, including some movement into intertidal flats to feed at high tide. Some landlocked populations exist behind dams on the Columbia River. Juveniles feed on mysid shrimp and amphipods; large fish feed on variety of crustaceans, annelid worms, mollusks, and fish. **Reproduction/Life History** Spawn in deep, fast-flowing sections of rivers (prefer swift [2.6–9.2 ft/sec (0.8–2.8 m/sec)] and deep [13–66 ft (4–20 m)] water) on bedrock, cobble, or boulder substrates. Spawning occurs from April through July, with incubation lasting approximately 7 days and emergence following in another 7 days. (Emmett et al. 1991; WDNR 2005a; Wydoski and Whitney 2003)
Eulachon	*Thaleichthys pacificus*	01–29 (mouths of major rivers)	14–17	**General Information (Habitats and Feeding)** Eulachon occur from northern California to southwestern Alaska in offshore marine waters. They are plankton-feeders, eating crustaceans such as copepods and euphausiids; larvae and post larvae eat phytoplankton and copepods. They are an important prey species for fish, marine mammals, and birds. **Reproduction/Life History** Spawn in tidal portions of rivers in spring when water temperature is 40–50^{o}F (4–10^{o}C), generally from March through May; use a variety of substrates, but sand and gravel are most common. Eggs stick to substrate and incubation ranges from 20–40 days (dependent on temperature). Larvae drift downstream to salt water where juveniles rear in nearshore marine areas. (Howell et al. 2001; Langer et al. 1977; Lewis et al. 2002; WDFW 2001; WDNR 2005a; Willson et al. 2006)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Longfin smelt	*Spirinchus thaleichthys*	01–03, 05–17, 22 and 24	1–9, 15–17	**General Information (Habitats and Feeding)** Marine species that spawns in streams not far from marine waters. They are anadromous, with some populations in Lake Washington that spawn in tributaries, including the Cedar River. Juveniles use nearshore habitats and a variety of substrates; juveniles feed on zooplankton. Adults feed on copepods and euphausiids. Most adults die after spawning. **Reproduction** Spawn in coastal rivers from October through December. Lake Washington populations spawn from January through April. Eggs hatch in approximately 40 days and the larvae drift downstream to salt water. (Gotthardt 2006; WDNR 2005a; Wydoski and Whitney 2003)
Pacific sand lance	*Ammodytes hexapterus*	NA	All	**General Information (Habitats and Feeding)** Widespread in Puget Sound, Strait of Juan de Fuca, and coastal estuaries. Schooling plankton feeders. Adults feed during the day and burrow into the sand at night. **Reproduction/Life History** Spawn on sand and beaches with gravel up to 1-inch in diameter at tidal elevations of +4–5 ft (+1.5 meters) to approximately the mean higher high water (MHHW) line from November through February. Emergence occurs from January to April. Larvae and young rear in bays and nearshore areas. (Garrison and Miller 1982; Nightingale and Simenstad 2001a; NRC 2001; Penttila 2000; Penttila 2001; WDFW 1997a)
Surf smelt	*Hypomesus pretiosus*	NA	All	**General Information (Habitats and Feeding)** Schooling plankton-feeding forage fish. They feed on a variety of zooplankton, planktonic crustaceans, and fish larvae. Adult surf smelt are pelagic but remain in nearshore habitats. Juveniles rear in nearshore areas, and adults form schools offshore; feed on planktonic organisms. Also an important forage fish. **Reproduction/Life History** Spawning occurs year-round in north Puget Sound, fall and winter in south Puget Sound, and summer along the coast. They spawn at the highest tides during high slack tide on coarse sand and pea gravel. Incubation is 2–5 weeks. Emergence varies with season: 27–56 days in winter, 11–16 days in summer. (Nightingale and Simenstad 2001a; NRC 2001; Penttila 2000; Penttila 2001; WDFW 1997c)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific herring	*Clupea harengus pallasi*	NA	1, 2, 4, 5, 8–13, 16, 17	**General Information (Habitats and Feeding)** Eighteen separate stocks in Puget Sound. Widely distributed throughout Puget Sound and coastal wetlands and estuaries. Pacific herring adults feed on small fish, copepods, decapod crab larvae, and euphausiids. Juveniles feed primarily on euphausiids, copepods, and small crustacean larvae. Are also an important forage fish. **Reproduction/Life History** Utilize intertidal and subtidal habitats (between 0 and -40 ft [0 and -12.2 m] mean lower low water [MLLW]) for spawning and juvenile rearing; spawning also occurs above MLLW. Spawning occurs from late January to early April. Eggs are adhered to eelgrass, kelp, seaweed, and sometimes on pilings. Eggs hatch after approximately 10 days. Larvae are pelagic. (Nightingale and Simenstad 2001a; Penttila 2000; Simenstad et al. 1979; WDFW 1997b)
Lingcod	*Ophiodon elongatus*	NA	All	**General Information (Habitats and Feeding)** The lingcod is a large top-level carnivore fish found throughout the West Coast of North America. Adult lingcod have a relatively small home range. Juveniles prefer sand habitats near the mouths of bays and estuaries, while adults prefer rocky substrates. Larvae and juveniles are generally found in upper 115 ft (35 m) of water. Adults prefer slopes of submerged banks with macrophytes and channels with swift currents. Larvae feed on copepods and amphipods; juveniles feed on small fishes; and adults on fish, squid, and octopi. **Reproduction/Life History** Spawn in shallow water and intertidal zone from January through late March. Egg masses adhere to rocks, and incubation is from February to June. Larvae spend 2 months in pelagic nearshore habitat. (Adams and Hardwick 1992; Emmett et al. 1991; Giorgi 1981; NMFS 1990; NRC 2001)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific cod	*Gadus macrocephalus*	NA	All	**General Information (Habitats and Feeding)** Pacific cod are widely distributed in relatively shallow marine waters throughout the northern Pacific Ocean (Washington's inland marine waters are considered the southern limit of populations). Adults and large juveniles are found over clay, mud, and coarse gravel bottoms; juveniles use shallow vegetated habitats such as sand-eelgrass. Feed opportunistically on invertebrates (worms, crabs, shrimp) and fishes (sand lance, pollock, flatfishes). Larvae feed on copepods, amphipods, and mysids. **Reproduction/Life History** Broadcast spawners during late fall through early spring. Eggs sink and adhere to the substrate. Incubate for 1–4 weeks, and larvae spend several months in the water column. Juvenile cod metamorphose and settle to shallow vegetated habitats. (Albers and Anderson 1985; Bargmann 1980; Dunn and Matarese 1987; Garrison and Miller 1982; Hart 1973; Nightingale and Simenstad 2001a; NMFS 1990; NRC 2001)
Pacific hake	*Merluccius productus*	NA	All	**General Information (Habitats and Feeding)** Pacific hake are schooling fish. The coastal stock of hake is migratory; Puget Sound stocks reside in estuaries and rarely migrate. Larvae feed on calanoid copepods; juveniles and small adults feed on euphasiids; adults eat amphipods, squid, herring, and smelt. **Reproduction/Life History** Puget Sound spawning occurs from March through May at mid-water depths of 50–350 ft (15–90 m); may spawn more than once per season. Eggs and larvae are pelagic. (Bailey 1982; McFarlane and Beamish 1986; NMFS 1990; NRC 2001; Quirollo 1992)
Walleye pollock	*Theragra chalcogramma*	NA	All	**General Information (Habitats and Feeding)** Widespread species in northern Pacific. Washington is the southern end of their habitat. Larvae and small juveniles are found at 200-ft (60-m) depth; juveniles use nearshore habitats of a variety of substrates. Juveniles feed on small crustaceans, adults feed on copepods, euphausiids, and young pollock. **Reproduction/Life History** Broadcast spawning occurs from February through April. Eggs are suspended at depths ranging from 330–1,320 ft (100–400 m). Pelagic larvae settle near the bottom and migrate to inshore, shallow habitats for their first year. (Bailey et al. 1999; Garrison and Miller 1982; Livingston 1991; Miller et al. 1976; NRC 2001)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Black rockfish	*Sebastes melanops*	NA	All	**General Information (Habitats and Feeding)** Adults prefer deep and shallow rock substrates in summer, deeper water in winter. Kelp and eelgrass are preferred habitat for juveniles that feed on nekton and zooplankton. Adults feed on amphipods, crabs, copepods, and small fish. **Reproduction/Life History** Spawning occurs from February through April; ovoviviparous incubation as with other rockfish species. Larvae are planktonic for 3–6 months, where they are dispersed by currents, advection, and upwelling. They begin to reappear as young-of-the-year fish in shallow, nearshore waters. (Kramer and O'Connell 1995; WDNR 2006a)
Bocaccio rockfish	*Sebastes paucispinis*	NA	All	**General Information (Habitats and Feeding)** Adults semidemersal in shallow water over rocks with algae, eelgrass, and floating kelp. Larvae feed on diatoms; juveniles feed on copepods and euphausiids. **Reproduction/Life History** Ovoviviparous spawning occurs year-round, with incubation lasting 40–50 days. Larvae and juveniles are pelagic. (Garrison and Miller 1982; Hart 1973; Kramer and O'Connell 1995; MBC Applied Environmental Sciences 1987; NRC 2001; Sumida and Moser 1984)
Brown rockfish	*Sebastes auriculatus*	NA	All	**General Information (Habitats and Feeding)** Utilize shallow-water bays with natural and artificial reefs and rock piles; estuaries used as nurseries; can tolerate water temperatures to at least 71°F (22°C); eat small fishes, crabs, and isopods. **Reproduction/Life History** Spawning occurs from March through June. Larvae are released from the female into the pelagic environment in May and June (ovoviviparous incubation). Larvae live in the upper zooplankton layer for up to 1 month before they metamorphose into pelagic juveniles. The pelagic juveniles spend 3–6 months in the water column as plankton. They then settle in shallow water nearshore, later migrating to deeper water. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Stein and Hassler 1989)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Canary rockfish	*Sebastes pinniger*	NA	All	**General Information (Habitats and Feeding)** Adults use sharp drop-offs and pinnacles with hard bottoms; often associated with kelp beds; feed on krill and occasionally on fish. Adults are mostly found at depths of 260–660 ft (80–200 meters) (with two recorded at 2,750 ft [838 meters]), tending to collect in groups around pinnacles and similar high-relief rock formations, especially where the current is strong. Young canary rockfish live in relatively shallow water, moving to deeper water as they mature. Juveniles feed on small crustacea such as krill larvae (and eggs), copepods, and amphipods, while adults eat krill and small fish. **Reproduction/Life History** Spawning is ovoviviparous and occurs from January through March. Larvae and juveniles are pelagic. (Boehlert 1980; Boehlert and Kappenman 1980; Boehlert et al. 1989; Hart 1973; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Sampson 1996)
China rockfish	*Sebastes nebulosis*	NA	All	**General Information (Habitats and Feeding)** Occur inshore and on open coast in sheltered crevices. Feed on crustacea (brittle stars and crabs), octopi, and fish. Juveniles are pelagic, but the adults are sedentary associating with rocky reefs or cobble substrates. **Reproduction/Life History** Spawning occurs from January through July; ovoviviparous incubation as with other rockfish species. Individual China rockfish spawn once a year. Larvae settle out of the plankton between 1 and 2 months after release. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Rosenthal et al. 1988)
Copper rockfish	*Sebastes caurinus*	NA	All	**General Information (Habitats and Feeding)** Occur both inshore and on open coast; adults prefer rocky areas in shallower water than other rockfish species. Juveniles use shallow and nearshore macrophytes and eelgrass habitat; feed on crustaceans, fish, and mollusks. **Reproduction/Life History** Spawning occurs from March through May, with ovoviviparous incubation from April to June. Larvae are pelagic in deeper water before moving inshore. Newly spawned fish begin settling near the surface around large algae canopies or eelgrass, when available, or closer to the bottom when lacking canopies. (Eschmeyer et al. 1983; Haldorson and Richards 1986; Kramer and O'Connell 1995; Matthews 1990; NRC 2001; Stein and Hassler 1989)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Greenstriped rockfish	*Sebastes elongates*	NA	All	**General Information (Habitats and Feeding)** Adults found in benthic and mid-water columns. They live at between 330 and 825 ft (100 and 250 m). As they age, greenstriped rockfish move to deeper water. They are solitary and are often found resting on the seafloor and living among cobble, rubble, or mud. Adults feed on euphausiids, small fish, and squid. **Reproduction/Life History** From 10,000 to over 200,000 eggs are produced by the females each season by ovoviviparous spawning. Greenstriped rockfish release one brood of larvae in Washington. Larval release varies, occurring generally from January through July, depending on geographic location. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001)
Quillback rockfish	*Sebastes maliger*	NA	All	**General Information (Habitats and Feeding)** Shallow-water benthic species in inlets near shallow rock piles and reefs. Juveniles use eelgrass, sand, and kelp beds. Feed on amphipods, crabs, and copepods. **Reproduction/Life History** Ovoviviparous spawning from April through July, with larval release from May to July. (Kramer and O'Connell 1995; WDNR 2006a)
Redstripe rockfish	*Sebastes proriger*	NA	All	**General Information (Habitats and Feeding)** Adults found from 330- to 1,000-ft (100- to 300-m) depths, and young often found in estuaries in high- and low-relief rocky areas. Juveniles feed on copepods and euphausiids; adults eat anchovies, herring, and squid. **Reproduction/Life History** Spawning is ovoviviparous, occurring from January through March. Larvae and juveniles are pelagic. (Garrison and Miller 1982; Hart 1973; Kendall and Lenarz 1986; Kramer and O'Connell 1995; NRC 2001; Starr et al. 1996)
Tiger rockfish	*Sebastes nigrocinctus*	NA	All	**General Information (Habitats and Feeding)** Semidemersal to demersal species occurring at depths ranging from shallows to 1,000 ft (305 m); larvae and juveniles occur near surface and range of depth; adults use rocky reefs, canyons, and headlands; generalized feeders on shrimp, crabs, and small fishes. **Reproduction/Life History** Ovoviviparous spawning peaks in May and June. Juveniles are pelagic. (Garrison and Miller 1982; Kramer and O'Connell 1995; Moulton 1977; NRC 2001; Rosenthal et al. 1988)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Widow rockfish	*Sebastes entomelas*	NA	All	**General Information (Habitats and Feeding)** Adults found from 330- to 1,000-ft (100- to 300-m) depths near rocky banks, ridges, and seamounts; adults feed on pelagic crustaceans, Pacific hake, and squid; juveniles feed on copepods and euphausiids. **Reproduction /Life History** Ovoviviparous spawning occurs from October through December. One brood of 95,000 to 1,113,000 eggs are produced by female widows per year. The season of larval release occurs earlier in the southern parts of their range than in the northern regions, likely January through April in Washington waters. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Laroche and Richardson 1981; NMFS 1990; NRC 2001; Reilly et al. 1992)
Yelloweye rockfish	*Sebastes ruberrimus*	NA	All	**General Information (Habitats and Feeding)** Adults are found from depths of 80–1,800 ft (24–550 m), near reefs and cobble bottom. Juveniles prefer shallow, broken-bottom habitat. Juveniles often hide in rock crevices; adults are demersal and solitary, tending to remain localized and not making extensive migrations. Adults feed on other rockfish species, sand lance, herring, shrimp, rock crabs, and snails. **Reproduction/Life History** Ovoviviparous spawning in late fall or early winter, with the larvae released from May to July. (Eschmeyer et al. 1983; Hart 1973; Kramer and O'Connell 1995; NRC 2001; Rosenthal et al. 1988)
Yellowtail rockfish	*Sebastes flavidus*	NA	All	**General Information (Habitats and Feeding)** Adults found from 165- to 1,000-ft (50- to 300-m) depths; adults semipelagic or pelagic over steep-sloping shores and rocky reefs. Juveniles occur in nearshore areas. Adults are opportunistic feeders on pelagic animals including hake, herring, smelt, squid, krill, and euphausiids. **Reproduction/Life History** Ovoviviparous spawning from October through December. Incubation is between January and March. Larvae and juveniles are pelagic swimmers. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; O'Connell and Carlile 1993)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Olympia oyster	*Ostrea lurida*	NA	1–14, 17	**General Information (Habitats and Feeding)** Species found throughout the inland waters of Puget Sound, as well as in Willapa Bay and possibly Grays Harbor; also grown commercially in Puget Sound. They occupy nearshore ecosystem on mixed substrates with solid attachment surfaces and are found from 1 ft (0.3 m) above MLLW to 2 ft (0.6m) below MLLW. Intolerant of siltation. **Reproduction/Life History** Reproduce spring to fall when water temperatures are between 54 and 61°F (12.5 and 16°C) by broadcast spawning. After 8–12 days, larvae develop into free-swimming larvae. Larvae are free-swimming for 2–3 weeks before they settle onto hard substrate, such as oyster shells and rocks. (Baker 1995; Couch and Hassler 1990; West 1997)
Northern abalone	*Haliotis kamtschatkana*	NA	10	**General Information (Habitats and Feeding)** Also known as pinto abalone. Presence in Washington is limited to the Strait of Juan de Fuca and the San Juan Islands. Occupies bedrock and boulders from extreme low water to 100 ft (30 m) below MLLW; usually associated with kelp beds. The abalone is completely vegetarian and uses its radula to scrape pieces of algae from the surface of rocks. **Reproduction/Life History** Broadcast spawners that release pelagic gametes that develop into free-swimming larvae using cilia to propel themselves. After up to a week, the larvae settle to the bottom, shed their cilia, and start growing a shell to begin sedentary adult life on crustose coralline algae. (Gardner 1981; NMFS 2007a; WDNR 2006b; West 1997)
Newcomb's littorine snail	*Algamorda subrotundata*	NA	14–17	**General Information (Habitats and Feeding)** Found in Grays Harbor and Willapa Bay on Washington coast; current distribution uncertain. Algae feeder occupying narrow band in *Salicornia* salt marshes above MHHW and is not considered a true marine gastropod. **Reproduction/Life History** Broadcast spawning in salt marshes. Other reproductive information unknown. (Larsen et al. 1995)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Giant Columbia River limpet	*Fisherola nuttalli*	35, 36, 40, 45, 47–49	NA	**General Information (Habitats and Feeding)** Also known as the shortface lanx, it occupies fast-moving and well-oxygenated streams. It is found in the Hanford Reach segment of the Columbia River, Wenatchee, Deschutes (OR), Okanogan, Snake, and Methow rivers. Prefers shallow, rocky areas of cobble to boulder substrates and diatom-covered rocks, and feeds by grazing on algae attached to rocks. **Reproduction/Life History** Broadcast external fertilization. Reproduction timing is unknown. (Neitzel and Frest 1989; Neitzel and Frest 1990; Pacific Biodiversity Institute 2007)
Great Columbia River spire snail	*Fluminicola columbiana*	35, 45, 48, 49; other locations unknown	NA	**General Information (Habitats and Feeding)** Also known as the Columbia pebblesnail and ashy pebblesnail, its current range is restricted to rivers, streams, and creeks of the Columbia River basin. It requires clear, cold streams with highly oxygenated water and is generally found in shallow water (less than 5 inches [13 cm] deep) with permanent flow on cobble-boulder substrates. Spire snails live on and under rocks and vegetation in the slow to rapid currents of streams where they graze on algae and small crustaceans. **Reproduction/Life History** They are short-lived, usually reaching sexual maturity within a year, at which time they breed and die. Unknown reproduction timing. (Neitzel and Frest 1989; Neitzel and Frest 1990; Pacific Biodiversity Institute 2007)
California floater (mussel)	*Anodonta californiensis*	30, 36, 37, 40, 42, 47–49, 52–54, 58–61	NA	**General Information (Habitats and Feeding)** In Washington, it is known to occur in the Columbia and Okanogan rivers and several lakes. Freshwater filter feeder requiring clean, well-oxygenated water for survival that is declining throughout much of its historical range. California floater mussels are intolerant of habitats with shifting substrates, excessive water flow fluctuations, or seasonal hypoxia. **Reproduction/Life History** Spring spawning occurs after adults reach 6–12 years in age. Fertilization takes place within the brood chambers of the female mussel. Fertilized eggs develop into a parasitic stage called glochidia, which attach to species-specific host fish during metamorphosis. After reaching adequate size, juvenile mussels release from the host and attach to gravel and rocks. (Box et al. 2003; Frest and Johannes 1995; Larsen et al. 1995; Nedeau et al. 2005; Watters 1999; WDNR 2006b)

Table 5-1 (continued). Range of HCP species and habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Western ridged mussel	*Gonidea angulata*	01, 03–05, 07–11, 13, 21–42, 44–55, 57–62	NA	**General Information (Habitats and Feeding)** Specific information on this species is generally lacking; reside on substrates ranging from firm mud with the presence of some sand, silt, or clay to coarse gravel in creeks, streams, and rivers. They require constant, well-oxygenated flow, and shallow water (<10 ft [3 m] depth). This species may tolerate seasonal turbidity but is absent from areas with continuous turbidity and is sensitive to water quality changes such as eutrophication or presence of heavy metals. **Reproduction/Life History** During breeding, males release sperm into the water and females must bring this into their shell for fertilization to occur. Larvae called glochidia are released by the female and attach to the gills of fish for 1–6 weeks; postlarval mussels hatch from cysts as free-living juveniles to settle and bury in the substrate. (COSEWIC 2003; WDNR 2006b)

Source: Modified from Jones & Stokes 2006.

[a] Water Resource Inventory Areas (WRIAs) are administration and planning boundaries for watershed areas, as established and managed by the Washington State Department of Ecology (Ecology). WRIA designations were formalized under WAC 173-500-040 and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. For WRIA boundary locations and related information, see URL = http://www.ecy.wa.gov/services/gis/maps/wria/wria.htm.

6.0 Conceptual Framework for Assessing Impacts

Marinas/terminals are located in shallow areas along the shoreline, at the edge of terrestrial and aquatic environments, where complex interactions between these diverse habitats occur. As overwater structures provide services for in-water activities, these facilities are known to affect HCP species through a number of direct mechanisms, such as causing bodily injury or mortality, or indirectly by altering the habitats upon which these species depend for critical ecological functions, such as reproduction, rearing, migration, or refugia. Alteration of the shoreline for the placement of a marina or terminal and the uses associated with that structure will affect, to varying degrees, the controlling factors of the aquatic ecosystem in which it is located. In this white paper, an **impact** is defined as an unnatural disturbance to habitat-controlling factors, such as light, wave energy, substrate, water quality parameters, littoral drift, or channel geomorphology. These controlling factors determine various aspects of the habitat structure (e.g., sand or cobble substrates, eelgrass or kelp, or overhanging riparian vegetation). For example, the habitat structure provided by shoreline overhanging vegetation can provide shade for species using nearshore shallow water and upper beach habitats. This shade serves the ecological function of regulating temperature and supporting the food web through organic litter and insect input. Figure 6-1 illustrates the conceptual framework used in this white paper to define marina/terminal impacts on HCP species and their habitats.

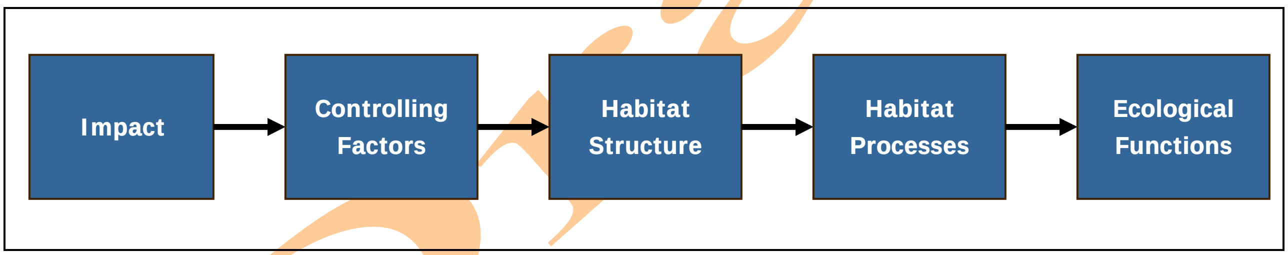

Figure 6-1. Conceptual framework for assessing impacts (source: Williams and Thom 2001).

Table 6-1 identifies the **mechanisms of impact** that are known to be associated with marinas/terminals in both freshwater and marine habitats. This white paper presents what is known about the effects of these mechanisms on those species being considered for coverage under a WDFW multispecies HCP. By identifying these impacts and the nature of the risks these impacts exert on the HCP species, measures can be taken to avoid and, if avoidance is not possible, minimize harmful impacts on these species and the habitats that support their growth and survival.

The identification of impact mechanisms associated with HPA-authorized activities that affect habitat was based on a model described by Williams and Thom (2001). For analyzing risk of take and refining the impact analysis as it pertains directly to listed species or species that will be addressed in the HCP, the "exposure-response" model developed by USFWS was used. Each of these models is discussed in more detail below.

Table 6-1. Impact mechanisms and submechanisms.

Impact Mechanism	Submechanisms
Construction and Maintenance Activities	Pile driving (elevated underwater noise) Construction vessel operation Channel/work area dewatering Navigation/maintenance dredging
Facility Operation and Vessel Activities	Grounding, anchoring, and/or prop wash Vessel maintenance and operational discharges Increased or altered ambient noise levels Ambient light modifications
Water Quality Modifications	Increased suspended solids Resuspension of contaminated sediment Introduction of toxic substances Altered dissolved oxygen levels Altered pH levels Use of creosote-treated wood Used of ACZA and CCA type C treated wood Increased stormwater and nonpoint source pollution
Riparian Vegetation Modifications	Riverine Altered riparian shading Altered ambient air temperature regime Altered stream bank and shoreline stability Altered allochthonous inputs Altered habitat complexity Altered groundwater-surface water exchange Marine Altered riparian shading Altered ambient air temperature regime Altered shoreline and bluff stability Altered allochthonous inputs Altered habitat complexity Altered freshwater inputs Lacustrine Altered riparian shading Altered ambient air temperature regime Altered shoreline stability Altered allochthonous inputs Altered habitat complexity Altered groundwater-surface water exchange
Aquatic Vegetation Modifications	Riverine and Lacustrine Altered autochthonous production Altered habitat complexity Marine Littoral Altered autochthonous production Altered habitat complexity
Hydraulic and Geomorphic Modifications	Riverine Altered channel geometry Altered flow velocity Altered substrate composition Altered sediment supply Altered groundwater-surface water exchange Altered hydrologic regime from stormwater
	Marine Altered wave energy Altered current velocities Altered nearshore circulation patterns Altered sediment supply Altered substrate composition Altered freshwater inputs Altered hydrologic regime from stormwater
	Lacustrine Altered wave energy Altered current velocities Altered nearshore circulation patterns Altered sediment supply Altered substrate composition Altered groundwater-surface water exchange Altered hydrologic regime from stormwater

The Williams and Thom model provides the framework for analysis based on the literature search; goals of the framework are to:

- Elucidate impacts associated with each HPA activity
- Determine how those impacts manifest themselves in impacts on habitat and habitat functions utilized by the species that will be addressed in the HCP
- Develop recommendations for impact avoidance, minimization, and mitigation measures that target the identified impacts.

The analysis process begins with an impact, which in this case would consist of activities authorized under an HPA for marinas/terminals. The impact will exert varying degrees of effect on controlling factors within the ecosystem (Williams and Thom 2001). Controlling factors are the physical processes or environmental conditions (e.g., flow conditions or wave energy) that control local habitat structure (e.g., substrate or vegetation). Habitat structure is linked to habitat processes (e.g., shading or cover), which are linked to ecological functions (e.g., refuge and prey production). These linkages form the "**impact pathway**" in which alterations to the environment associated with HPA-authorized activities can lead to impacts on the ecological function of the habitat for HCP species. **Impact mechanisms** are the alterations to any of the conceptual framework components along the impact pathway that can result in an impact on ecological function and therefore on HCP species.

For each HPA-authorized activity addressed in this white paper, several principal impact mechanisms were identified for each subactivity type, from a geomorphological, engineering, hydrologic, and biological perspective.

This impact analysis helped to identify the direct and indirect impacts that could potentially affect federally listed species and those species that will be addressed in the HCP. To further refine the analysis in each white paper, the exposure-response model (National Conservation Training Center 2004) was incorporated into the impact analysis. The exposure-response model evaluates the likelihood that adverse effects may occur as a result of species exposure to one or more stressors. This model takes into account the life-history stage most likely to be exposed and thereby affected.

The exposure-response model was incorporated as a series of matrices, presented in Appendix A, with results synthesized in Sections 7 and 9 (*Direct and Indirect Impacts* and *Potential Risk of Take*, respectively) of this white paper. In these species-specific exposure-response matrices, each mechanism and submechanism was initially examined and evaluated to:

- Identify and characterize specific impacts or stressors

- Evaluate the potential for exposure (potential for species to be exposed = identification of stressor, timing/duration/frequency/life-history form presence coincident with impact)
- Identify the species' anticipated response to stressor
- Identify measures that could reduce exposure
- Identify performance standards if appropriate
- Characterize the resulting effects of specific impacts on species.

With regard to exposure, standard language was used to indicate when an impact occurs, for how long, and how frequently the stressor or impact occurs; definitions of these terms used in the analysis are listed in Table 6-2.

Based on life-history information, an analysis of potential exposure was completed for each species. This included an analysis of the direct and indirect impacts (associated with each of the impact mechanisms) on the different lifestages of each species and likely responses of the species to these stressors. Impact minimization measures to reduce or avoid submechanism impacts were identified. A final conclusion regarding overall effect of the submechanism/stressor on the species is also presented in the table.

Where information was available, the cumulative effects associated with the major impact mechanisms were identified (Section 8 [*Cumulative Effects*]).

The information generated by the exposure-response analysis is used to summarize the overall risk of take associated with the impact mechanisms produced by each subactivity type. The summary risk of take analysis is presented in Section 9, which presents the risk of take associated with each subactivity type using: (1) a narrative discussion of the risk of take associated with each subactivity type by the specific associated submechanism of impact; and (2) risk of take assessment matrices that rate the risk of take resulting from each subactivity by impact mechanism and environment type. The risk of take ratings presented in the text and matrices in Section 9 are based on the rating criteria defined in Table 6-3.

This method of risk of take analysis helped identify specific thresholds associated with each of the impacts beyond which take will occur. Summary tables were prepared to indicate the potential for take by species for each major impact mechanism (Tables 9-1 through 9-6).

Based on the identification of impacts and risk of take analysis, additional recommendations (e.g., conservation, management, protection, BMPs) for minimizing or avoiding project impacts or risk of take were developed and presented in Section 11.

Table 6-2. Definitions of terms used in the exposure-response analysis.

Parameter	Description	Exposure	Definition
When	The timing during which stressor exposure occurs (e.g., time of day, season, associated with operations or maintenance)	–	Defined flexibly as appropriate for each stressor.
Duration	The length of time the receptor is expected to be exposed to the stressor	Permanent	Stressor is permanent (e.g., conversion of habitat to built environment)
		Long-term	Stressor will last for greater than five years to decades (e.g., time required for complete riparian recovery)
		Intermediate-term	Stressor will last from 6 months to approximately 5 years (e.g., time required for beach substrate to recover from construction equipment)
		Short-term	Stressor will last from days to 6 months (e.g., time required for invertebrate community to recolonize following dewatering)
		Temporary	Stressor associated with transient action (e.g., pile driving noise)
Frequency	The regularity with which stressor exposure is expected to occur and/or the time interval between exposure	Continuous	Stressor is ongoing and occurs constantly (e.g., permanent modification of habitat suitability)
		Intermittent	Stressor occurs routinely on a daily basis
		Daily	Stressor occurs once per day for extended periods (e.g., daytime structural shading)
		Common	Stressor occurs routinely (i.e., at least once per week or several times per month)
		Seasonal	Stressor occurs for extended periods during specific seasons (e.g., temperature effects occurring predominantly in winter and summer)
		Annual	Stressor occurs annually for a short period of time
		Interannual–decadal	Stressor occurs infrequently (e.g., pile driving associated with project construction and maintenance)

Table 6-3. Definitions of terminology used for risk of take determinations.

Risk of Take Code	Potential for Take	Definition*
H	High	Stressor exposure is likely to occur with high likelihood of individual take in the form of direct mortality, injury, and/or direct or indirect effects on long-term survival, growth, and fitness potential due to long-term or permanent alteration of habitat capacity or characteristics. Likely to equate to a Likely to Adversely Affect (LTAA) finding.
M	Moderate	Stressor exposure is likely to occur causing take in the form of direct or indirect effects potentially leading to reductions in individual survival, growth, and fitness due to short-term to intermediate-term alteration of habitat characteristics. May equate to an LTAA or a Not Likely to Adversely Affect (NLTAA) finding depending on specific circumstances.
L	Low	Stressor exposure is likely to occur, causing take in the form of temporary disturbance and minor behavioral alteration. Likely to equate to an NLTAA finding.
I	Insignificant	Stressor exposure may potentially occur, but the likelihood is discountable and/or the effects of stressor exposure are insignificant. Likely to equate to an NLTAA finding.
N	No Risk	No risk of take ratings apply to species with no likelihood of stressor exposure because they do not occur in habitats that are suitable for the subactivity type in question, or the impact mechanisms caused by the subactivity type will not produce environmental stressors.
?	Unknown	Unknown risk of take ratings apply to cases where insufficient data are available to determine the probability of exposure or to assess stressor response.

* LTAA = Likely to Adversely Affect; NLTAA – Not Likely to Adversely Affect.

7.0 Direct and Indirect Impacts

This section presents a review and synthesis of what is known about the potential direct and indirect impacts on the HCP species from the construction, operation, and repair of marinas/terminals in both marine and freshwater environments. For the purpose of this white paper, it is assumed that the impacts associated with demolition are similar in type and magnitude to those induced by construction, operation, and repair activities. A comprehensive impact analysis process was used to identify direct and indirect impacts that could be triggered by the six impact mechanisms (and associated submechanisms), identified in Section 6 (*Conceptual Framework for Assessing Impacts*), to each of the 52 HCP species.

Based on life-history information, an analysis of potential exposure was completed and the direct and indirect impacts identified for each species. This information is presented in a separate set of species-specific exposure-response matrices with the identification of likely responses of each species to such impacts (see Appendix A). This information served as the basis for the risk of take analysis presented later in this report (Section 9) and contributed to species-specific conclusions for each HPA-authorized activity type. The model used to conduct this analysis is described in Section 6. Note: some of the information presented in this white paper is reproduced from previously prepared white papers addressing the effects from dredging and overwater structures in marine environments (Nightingale and Simenstad 2001a, 2001b).

When summarizing direct and indirect impacts on fish and invertebrates, information is either grouped together or presented separately, depending on the nature and extent of available information. In cases where the physical effects are similar between fish and invertebrates, the discussion is grouped to avoid redundancy.

7.1 Construction and Maintenance Activities

The construction and maintenance activities mechanism of impact includes four submechanisms of impact, capturing a range of activities that are short-lived but intensive and are required to build facilities as well as to provide or maintain access to these facilities. The four submechanisms that have been identified for analysis in this white paper include: (1) pile driving (elevated underwater noise), (2) construction vessel operation, (3) channel/work area dewatering, and (4) navigation/maintenance dredging. These four submechanisms are likely to affect HCP species as they occur within the water. However, activities occurring landward of water bodies can also affect HCP species. These activities include staging and equipment access, including the use of heavy equipment around the wetted perimeter in riparian (marine, lacustrine, and riverine environments) and floodplain areas.

Direct and indirect impacts on the 52 HCP species are summarized below for each of these submechanisms, based on the literature review and subsequent analysis.

7.1.1 Pile Driving (Elevated Underwater Noise)

Projects permitted under the WDFW HPA program can produce underwater noise through a variety of mechanisms. These mechanisms include construction-related noise impacts from impulsive sources (i.e., short duration, high intensity noise from sources such as pile driving or materials placement), as well as continuous noise sources (e.g., vessel or equipment operation). The discussion presented in this section provides the noise-related analytical basis for the development of the exposure-response matrices (Appendix A) and the risk of take analysis (Section 9).

This section summarizes existing information on sources of underwater noise, how underwater noise is characterized, existing and proposed effects thresholds, and the magnitude of noise stressors associated with typical project construction and maintenance activities. This discussion is derived in part from a summary of current science on the subject developed by WSDOT (2006a).

7.1.1.1 Measurement of Underwater Noise

Underwater sound levels are measured with a hydrophone, or underwater microphone, which converts sound pressure to voltage, which is then converted back to pressure, expressed in pascals (Pa), pounds per square inch (psi), or decibel (dB) units. Derivatives of dB units are most commonly used to describe the magnitude of sound pressure produced by an underwater noise source, with the two most commonly used measurements being the instantaneous peak sound pressure level (dB_{PEAK}) and the root mean square (dB_{RMS}) pressure level during the impulse, referenced to 1 micropascal (re: 1μPa) (Urick 1983). The dB_{PEAK} measure represents the instantaneous maximum sound pressure observed during each pulse. The RMS level represents the square root of the total sound pressure energy divided by the impulse duration, which provides a measure of the total sound pressure level produced by an impulsive source. The majority of literature uses dB_{PEAK} re: 1μPa sound pressures to evaluate potential injury to fish. However, USFWS and NOAA Fisheries have used both dB_{PEAK} (for injury) and dB_{RMS} (for behavioral effects) re: 1μPa threshold values to evaluate adverse injury and disturbance effects on fish, marine mammals, and diving birds (Stadler 2007; Teachout 2007). dB_{RMS} values are used to define disturbance thresholds in fish species, meaning the sound pressure level at which fish noticeably alter their behavior in response to the stimulus (e.g., through avoidance or a "startle" response). dB_{PEAK} values are used to define injury thresholds in salmonids, meaning the sound pressure level at which injury from barotraumas may occur (i.e., physical damage to body tissues caused by a sharp pressure gradient between a gas or fluid-filled space inside the body and the surrounding gas or liquid). Unless otherwise noted, all sound pressure levels cited herein are in dB_{PEAK} or dB_{RMS} re: 1μPa.

Noise behaves in much the same way in air and in water, attenuating gradually over distance as the receptor moves away from the noise source. However, underwater sound exhibits a range of behaviors in response to environmental variables (Urick 1983). For example, sound waves bend upward when propagated upstream into currents and downward when propagated downstream in the direction of currents. Sound waves will also bend toward colder, denser water. Haloclines and other forms of stratification can also influence how sound travels. Noise shadows created by bottom topography and intervening land masses or artificial structures can, under certain circumstances, block the transmission of underwater sound waves. In freshwater systems, sound propagation is often influenced by depth and channel morphology. Underwater noise does not transmit as effectively when water depths are less than 3 feet due to the amplitude of the sound pressure wave (Urick 1983). Because underwater sound does not travel around obstructions, bends in a river or large changes in gradient will truncate sound propagation. This will limit the physical extent of noise related impacts.

Underwater noise attenuation, or transmission loss, is the reduction of the intensity of the acoustic pressure wave as it propagates, or spreads, outward from a source. Propagation can be categorized using two models, spherical spreading and cylindrical spreading. Spherical (free-field) spreading occurs when the source is free to expand with no refraction or reflection from boundaries (e.g., the bottom or the water surface). Cylindrical spreading applies when sound energy spreads outward in a cylindrical fashion bounded by the sediment and water surface. Because neither model applies perfectly in any given situation, most experts agree that a combination of the two best describes sound propagation in real-world conditions (Vagle 2003).

Currently, USFWS and NOAA Fisheries are using a practical spreading loss calculation, which accommodates this view (Stadler 2007; Teachout 2007). This formula accommodates some of the complexity of underwater noise behavior, but it does not account for a number of other factors that can significantly affect sound propagation. For example, decreasing temperature with depth can create significant shadow zones where actual sound pressure levels can be as much as 30 dB lower than calculated because sound bends toward the colder, deeper water (Urick 1983). Haloclines, current mixing, water depth, acoustic wavelength, sound flanking (i.e., sound transmission through bottom sediments), and the reflective properties of the surface and the bottom can all influence sound propagation in ways that are difficult to predict.

Given these complexities, characterizing underwater sound propagation inherently involves a large amount of uncertainty. An alternative calculation approach, known as the Nedwell model (not used by USFWS or NOAA Fisheries), indirectly accounts for some of these factors. Nedwell and Edwards (2002) and Nedwell et al. (2003) measured underwater sound levels associated with pile driving close to and at distance from the source in a number of projects in English rivers. They found that the standard geometric transmission loss formula used in the practical spreading loss model did not fit well to the data, most likely because it does not account for the aforementioned factors that affect sound propagation. They developed an alternative model based on a manufactured formula that produced the best fit to sound attenuation rates measured in the field. This model thereby accounts for uncharacterized site-specific factors that affect noise attenuation, but does not explicitly identify each factor or its specific effects. Because there is considerable uncertainty regarding how to model the many factors affecting underwater noise propagation, and this would require site specific information that cannot practically be obtained in many instances, the Services (i.e., USFWS and NOAA Fisheries) use the more conservative practical spreading loss model in ESA consultations (Stadler 2007; Teachout 2007).

7.1.1.2 Project-Related Noise Sources

The underwater noise produced by an HPA permitted project, either during construction or operation, is defined by the magnitude and duration of underwater noise above ambient noise levels. The action area for underwater noise effects in ESA consultations is defined by the distance required to attenuate construction noise levels to ambient levels, as calculated using the practical spreading loss calculation or other appropriate formula provided in evolving guidance from USFWS and NOAA Fisheries on this subject.

Although there are many sources of noise in the underwater environment, the following are typical sources of underwater noise associated with construction of marinas/terminals:

- Project construction: Equipment operation and materials placement
- Project operation: Vessel operation, equipment operation.

7.1.1.2.1 Materials Placement (Pile Driving)

Most sources of underwater noise potentially resulting from materials placement during HPA permitted projects have received relatively little direct study. Of the potential sources of construction-related noise, pile driving has received the most scrutiny because it produces the highest intensity stressors capable of causing noise-related injury. Other sources of underwater noise, such as dumping of large rock or underwater tool use, have received less study. Therefore, available data on noise levels associated with pile driving are presented here as a basis for comparison.

Two major types of pile driving hammers are in common use, vibratory hammers and impact hammers. There are four kinds of impact hammers: diesel, air or steam driven, hydraulic, and drop hammer (typically used for smaller timber piles). Vibratory hammers produce a more rounded sound pressure wave with a slower rise time. In contrast, impact hammers produce sharp sound pressure waves with rapid rise times, the equivalent of a punch versus a push in comparison to vibratory hammers. The sharp sound pressure waves associated with impact hammers represent a rapid change in water pressure level, with greater potential to cause injury or mortality in fish and invertebrates. Because the more rounded sound pressure wave produced by vibratory hammers produces a slower increase in pressure, the potential for injury and mortality is reduced. (Note that while vibratory hammers are often used to drive piles to depth, load-bearing piles must be “proofed” with some form of impact hammer to establish structural integrity.) The changes in pressure waveform generated by these different types of hammers are pictured in Figure 7-1.

Piling composition also influences the nature and magnitude of underwater noise produced during pile driving. Driven piles are typically composed of one of three basic material types: timber, concrete, or steel (although other special materials such as plastic may be used). Steel piles are often used as casings for pouring concrete piles. Noise levels associated with each of these types of piles are summarized in Table 7-1. Reference noise levels are denoted in both dB_{PEAK} and dB_{RMS} values, at the specified measurement reference distance.

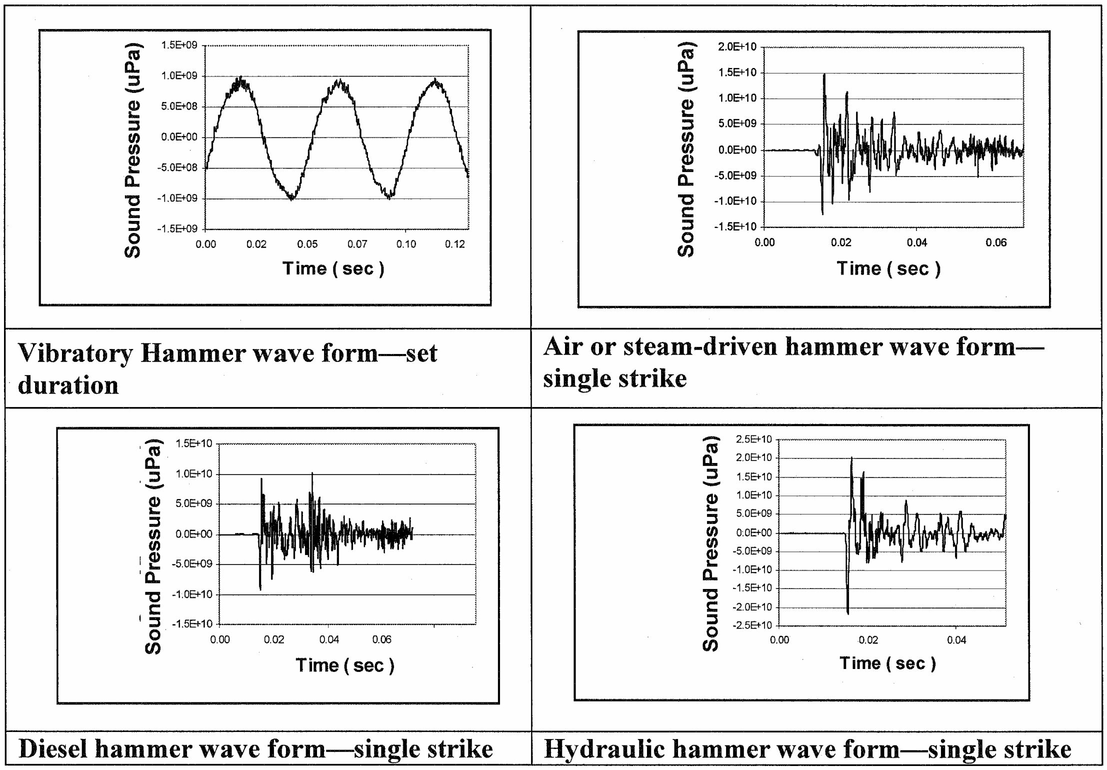

Figure 7-1. Sound pressure changes (or waveform) generated by hammer type (WSDOT 2006a)

Table 7-1. Reference noise levels, by structure type.

Material Type and Size	Impact Hammer Type	Reference Noise Levels[a]		Environment Type	Source
		dB_{PEAK}	dB_{RMS}		
12-inch timber	Drop	177 @ 10 m	165 @ 10 m	Marine	(Illingworth and Rodkin 2001)
24-inch concrete piles	Unspecified	188 @ 10 m	173 @ 10 m	Unspecified	[DesJardin 2003, personal communication cited by WSDOT (2006a)], (Hastings and Popper 2005)
Steel H-piles	Diesel	190 @10 m	175 @ 10 m	Marine	(Hastings and Popper 2005; Illingworth and Rodkin 2001)
12-inch steel piles	Diesel	190 @10 m	190 @ 10 m	Marine	(Illingworth and Rodkin 2001)
14-inch steel piles	Hydraulic	195 @ 30 m;	180 @ 30 m	Marine	(Reyff et al. 2003)
16-inch steel piles	Diesel	198 @ 10 m	187 @ 9 m	Freshwater	(Laughlin 2004)
24-inch steel piles	Diesel	217 @10 m	203 @ 10 m	Unspecified	(WSDOT 2006a)
24-inch steel piles	Diesel	217 @ 10 m	203 @ 10 m	Unspecified	(Hastings and Popper 2005)
30-inch steel piles	Diesel	208 @ 10 m	192 @10 m	Marine	(Hastings and Popper 2005)
66-inch steel piles	Hydraulic	210 @ 10 m	195 @ 10 m	Marine	(Reyff et al. 2003)
96-inch steel piles	Hydraulic	220 @ 10 m	205 @ 10 m	Marine	(Reyff et al. 2003)
126-inch steel piles	Hydraulic	191 @ 11 m	180-206 @ 11 m	Marine	(Reyff et al. 2003)
150-inch steel piles	Hydraulic	200 @ 100 m	185 @ 100 m	Marine	(Reyff et al. 2003)

[a] Metric distances are listed as they were provided in the source material; 9 m = 29.5 ft; 10 m = 32.8 ft; 11 m = 36 ft; 30 m = 98 ft; 100 m = 328 ft.
All sound pressure values in units re: 1µPa.

7.1.1.2.2 Vessel/Equipment Operation and Materials Placement (Non-Pile Driving)

In comparison to pile driving, data on noise levels produced by placement of other construction-related materials is limited. For example, measured noise levels associated with work on the Friday Harbor ferry terminal ranged between 133 dB_{peak} and 140 dB_{peak}, excluding pile driving. These noise levels were slightly higher than ambient levels, which include routine vessel traffic (WSDOT 2005). Nedwell et al. (1993) measured (Stadler 2007; Teachout 2007) These data suggest that noise associated with these activities, such as in-water tool use, placement of large rock and similar material, vessel operation, and in-water operation of heavy machinery, will generally produce substantially lower noise levels than those associated with pile driving. However, other construction-related noises may generate continuous noise for longer periods, with the effect of elevating ambient noise levels or masking ambient noises in the aquatic environment that fish would ordinarily use to identify prey and predators.

This effect may be of particular concern for projects that result in changes in vessel operation or equipment use that change ambient noise levels for longer periods (e.g., days to years). For example, vessel operation can significantly influence ambient noise levels. Large vessel engines can produce underwater sound up to 198 dB, and depth sounders can produce noise in excess of 180 dB (Buck 1995; Heathershaw et al. 2001). Hazelwood and Connelly (2005) monitored fishing vessel noise over a broad octave range from 10 Hz–40 kHz and documented noise levels ranging from 140–185 dB_{peak}, with the loudest noise occurring at the lower end of the octave range. Commercial sonar devices operating in a frequency range of 15–200 kHz can produce underwater noise ranging from 150–215 dB at maximum levels (Stocker 2002).

Ambient underwater noise levels serve as the baseline for measuring the disturbance created by project construction or maintenance. Both natural environmental noise sources and mechanical or human-generated noise contribute to the ambient or baseline noise conditions within and surrounding a project site. Therefore, these noise measurements, particularly those recorded in the vicinity of ferry terminals and other high-activity locations, are indicative of the level of noise levels that could be produced by project construction and operation.

Ambient noise levels have been measured in several different marine environments on the West Coast and are variable depending on a number of factors, such as site bathymetry and human activity. For example, measured ambient levels in Puget Sound are typically around 130 dB_{peak} (Laughlin 2005). However, ambient levels at the Mukilteo ferry terminal reached approximately 145 dB_{peak} in the absence of ferry traffic (WSDOT 2006a). Ambient underwater noise levels measured in the vicinity of the Friday Harbor ferry terminal project ranged between 131 and 136 dB_{peak} (WSDOT 2005). Carlson et al. (2005) measured the underwater baseline for the Hood Canal and found it to range from 115 to 135 dB_{RMS}. Heathershaw et al. (2001) reported open-ocean ambient noise levels to be between 74 and 100 dB_{peak} off the coast of central California. Note, however, that these ambient noise levels are typical conditions, and typical conditions can be punctuated by atypical natural events. For example, lightning strikes can produce underwater noise levels as high as 260 dB_{peak} in the immediate vicinity (Urick 1983).

Limited data are available on ambient noise levels in freshwater environments, but it is reasonable to conclude that they vary considerably based on available information. For example, high-gradient rivers, fast-flowing rivers, and large rivers and lakes with significant human activity are likely to produce more noise than lakes and slow-flowing rivers in more natural environments. Burgess and Blackwell (2003) measured ambient sounds in the Duwamish River in Seattle, Washington, (averaged over 20 seconds to 5 minutes) and found the sound to vary between 110 and 130 dB continuous sound exposure level (SEL) (SEL provides a measure of total sound pressure exposure and is expressed as dB re: $1\mu Pa^2$/second). Amoser and Ladich (2005) measured ambient noise levels in the mainstem Danube River, a smaller, fast-flowing tributary stream, a small lake, and a quiet river backwater. The river and stream represented fast-flowing habitats, the lake and backwater quiet, slow-flowing habitats. Sound behavior was complex. They found that ambient noise levels ranged from as low as 60 to as high as 120 dB_{peak} in the fast-flowing habitats, depending on the sound frequency (lower frequency sound was typically louder). Ambient noise in the slackwater habitats was considerably lower, ranging from 40 to 80 dB_{peak} across the frequency range (again with lower frequency sounds being loudest).

7.1.1.3 Direct and Indirect Effects on Fish

Most fish sense sounds, vibrations, and other displacements of water in their environment through their inner ear and with the lateral line running the length of each side of the fish and on the head. The lateral line is a mechano-sensory system that plays an indirect role in hearing through its sensitivity to pressure changes at close range. The hearing organs and lateral line system are collectively referred to as the acoustico-lateralis system. The hearing thresholds of different fish species vary depending on the structure and sensitivity of this system. Those families of fish known as hearing specialists include cyprinids (dace [e.g., Umatilla and leopard dace], minnows and carp), catastomids (suckers [e.g., mountain sucker]), and ictalurids (catfish), which collectively belong to the Ostariophysan taxonomic grouping of fishes. These fish possess a physical connection between the swim bladder and the inner ear, with the swim bladder acting as an amplifier that transforms the pressure component of sound into particle velocity component, to which the inner ear is sensitive (Moyle and Cech 1988). The hearing capacity of salmonids, on the other hand, is limited both in bandwidth and intensity threshold. The Atlantic salmon, for example, is functionally deaf at sound pressure wavelengths above 380 hertz (Hz) (Hawkins and Johnstone 1978). In these fish, the swim bladder does not likely enhance hearing.

Noise sources such as pile driving that produce high-intensity sound pressure waves can result in direct effects on fish, ranging from effects as limited as temporary stress and behavioral avoidance, to temporary or permanent injury in multiple organ systems (including hearing, heart, kidney, swim bladder, and other vascular tissue), to direct mortality (Popper and Fay 1973, 1993). Another potential effect includes masking of existing ambient noise reducing the ability of fish to sense predators or prey. These activities may also have indirect effects such as reducing the foraging success of these fish by affecting the distribution or viability of potential prey species. Numerous studies have examined the effects on fish associated with underwater noise and are discussed more fully below.

In general, injury and mortality effects from underwater noise are caused by rapid pressure changes, especially on gas-filled spaces in the body. Rapid volume changes of the swim bladder may cause it to tear, resulting in a loss of hearing sensitivity and hydrostatic control. Intense noise may also damage the tissue in hearing organs, as well as the heart, kidneys, and other highly vascular tissue. Susceptibility to injury is variable and depends on species-specific physiology, auditory injury, and auditory thresholds (Popper and Fay 1973, 1993). While species-specific data are limited, the available information indicates variable effects related to physiology, size, and age, as well as the intensity, wavelength, and duration of sound exposure.

Hardyniec and Skeen (2005) and Hastings and Popper (2005) summarized available information on the effects of pile driving-related noise on fish. Pile driving effects observed in the studies reviewed ranged broadly from brief startle responses followed by habituation to instantaneous lethal injury. The difference in effect is dependent on a number of factors, including: piling material, the type and size of equipment used, and mitigation measures; site-specific depth, substrate, and water conditions; and the species, size, and life-history stage of fish exposed.

Popper et al. (2005) exposed three species of fish to high-intensity percussive sounds from a seismic air gun at sound levels ranging between 205 and 209 dB_{Peak}, intending to mimic exposure to pile driving. Subject species included a hearing generalist (broad whitefish), a hearing specialist (lake chub), and a species that is intermediate in hearing (northern pike). They found that the broad whitefish suffered no significant effects from noise exposure, the lake chub demonstrated a pronounced temporary threshold shift in hearing sensitivity (i.e., hearing loss), and the northern pike showed a significant temporary hearing loss but less than that of the lake chub. The hearing sensitivities of lake chub and northern pike returned to their respective normal thresholds after 18 to 24 hours. High-intensity sounds can also permanently damage fish hearing (Cox et al. 1987; Enger 1981; Popper and Clarke 1976).

Enger (1981) found that pulsed sound at 180 dB was sufficient to damage the hearing organs of codfish (genus *Gadus*), resulting in permanent hearing loss. Hastings (1995) found that goldfish exposed to continuous tones of 189, 192, and 204 dB_{peak} at 250 Hz for 1 hour suffered permanent damage to auditory sensory cells. Injury effects may also vary depending on noise frequency and duration. Hastings et al. (1996) found destruction of sensory cells in the inner ears of oscars 4 days after exposure to continuous sound for 1 hour at 180 dB_{peak} at 300 Hz. In contrast, when the two groups of the same species were exposed to continuous and impulsive sound at 180 dB_{peak} at 60 Hz for 1 hour, and to impulsive sound at 180 dB_{peak} at 300 Hz repeatedly over 1 hour, they showed no apparent injury. Susceptibility to injury may also be life-history specific. Banner and Hyatt (1973) demonstrated increased mortality of sheepshead minnow eggs and embryos when exposed to broadband noise approximately 15 dB above the ambient sound level. However, hatched sheepshead minnow fry were unaffected by the same exposure.

Even in the absence of injury, noise can produce sublethal effects. Behavioral responses to sound stimuli are well established in the literature for many fish species. For example, Moore and Newman (1956) reported that the classic fright response of salmonids to instantaneous sound stimuli was the "startle" or "start" behavior, where a fish rapidly darts away from the noise source. Knudsen et al. (1992) found that in response to low-frequency (10 Hz range) sound, salmonids 1.6–2.4 in (40–60 mm) in length exhibited an initial startle response followed by habituation, while higher frequency sound caused no response even at high intensity. In a study of the effects of observed pile driving activities on the behavior and distribution of juvenile pink and chum salmon, Feist et al. (1992) found that pile-driving operations were associated with changes in the distribution and behavior of fish schools in the vicinity. Fish schools were two-fold more abundant during normal construction days in comparison to periods when pile driving took place. Blaxter et al. (1981) found Atlantic herring to exhibit an avoidance response to both continuous pulsed sound stimuli with habituation to more continuous stimuli occurring over time, and Schwarz and Greer (1984) found similar responses on the part of Pacific herring. Sound has also been shown to affect growth rates, fat stores, and reproduction (Banner and Hyatt 1973; Meier and Horseman 1977).

Prolonged underwater noise can also reduce the sensitivity of fish to underwater noise stimuli, with potentially important effects on survival, growth, and fitness. The fish auditory system is likely one of the most important mechanisms fish use to detect and respond to prey, predators, and social interaction (Amoser and Ladich 2005; Fay 1988; Hawkins 1986; Kalmijn 1988; Myrberg 1972; Myrberg and Riggio 1985; Nelson 1965; Nelson et al. 1969; Richard 1968; Scholik and Yan 2001; Scholik and Yan 2002; Wisby et al. 1964). Scholik and Yan (2001) studied the auditory responses of the cyprinid fathead minnow to underwater noise levels typical of human-related activities (e.g., a 50 horsepower outboard motor). They found that prolonged exposure decreased noise sensitivity, increasing the threshold level required to elicit a disturbance response for as long as 14 days after the exposure. Amoser and Ladich (2005) reported similar findings in common carp in the Danube River, noting that auditory ability in this hearing specialist species was measurably masked in environments with higher background noise. They reported similar but far less pronounced responses in hearing generalist species such as perch. These data suggest that elevated ambient noise levels have the potential to impair hearing ability in a variety of fish species, which may in turn adversely affect the ability to detect prey and avoid predators, but that this effect is variable depending on the specific sensitivity of the species in question. Feist et al. (1992) similarly theorized that it was possible that auditory masking and habituation to loud continuous noise from machinery may decrease the ability of salmonids to detect approaching predators.

7.1.1.4 Direct and Indirect Effects on Invertebrates

In general, information on the effects of underwater noise on invertebrates is limited, indicating that additional research on the subject is needed. What little data are available suggest some sensitivity to intense percussive underwater noise. In a study completed by Turnpenny et al. (1994), mussels, periwinkles, amphipods, squid, scallops, and sea urchins were exposed to high air gun and slow-rise-time sounds at between 217 and 260 dB_{peak}, analogous to extremely loud pile driving. One scallop suffered a split shell following exposure to 217 dB_{peak}, suggesting the potential for serious injury when percussive underwater noise exceeds these levels.

No research has been identified regarding the effects of lower intensity continuous underwater noise on invertebrates. However, operational noise is typically associated with sound pressures well below levels that have been observed to cause injury in shellfish, suggesting that HCP invertebrate species might not be subject to these effects. Because HCP invertebrates with the potential for stressor exposure are either filter feeders or grazers and are essentially non-motile, these species are unlikely to be subject to auditory masking effects that would limit the ability to sense predators and prey. Some potential may exist for disturbance-induced interruption of feeding behavior, but more research on this subject is necessary to determine this definitively.

7.1.2 Construction Vessel Operation

The operation of vessels during construction also presents several potential impacts including: (1) grounding, anchoring, and prop wash; (2) temporary ambient light modification; (3) water quality degradation; and (4) changes in ambient noise levels. Impacts 1 and 2 are addressed in detail in Section 7.2 (*Facility Operation and Vessel Activities*), and water quality impacts are addressed in detail below in Section 7.3 (*Water Quality Modifications*). Noise impacts associated with vessel operation are addressed below.

Data on noise levels produced by nonpile driving related construction activities are limited. What data are available tend to show that noise associated with these activities, such as in-water tool use, placement of steel piles and other large material, and in-water operation of heavy machinery, will generally produce substantially lower noise levels than those associated with pile driving. However, other construction-related noises may generate continued sound for longer periods with the effect of elevating ambient noise levels or masking ambient noises in the aquatic environment that fish would ordinarily use to identify prey and predators.

Measured noise levels associated with work on the Friday Harbor ferry terminal ranged between 133 dB_{peak} and 140 dB_{peak}, excluding pile driving. These noise levels were slightly higher than ambient levels, which include routine vessel traffic (WSDOT 2005). Nedwell et al. (1993) measured noise produced by underwater construction tools such as drills, grinders, and impact wrenches at 3.28 ft (1 m) from the source. When corrected for a reference distance 32.8 ft (10 m) from the source using the practical spreading loss model, the noise associated with these sources ranged from approximately 120 to 165 dB_{peak}.

7.1.3 Channel/Work Area Dewatering

Channel dewatering is typically associated with overwater structures constructed in riverine environments where working in dry conditions is desirable. However, permitted work in lacustrine and marine waters also requires that work be in conducted in "the dry." In many cases, construction of HPA-permitted projects may require the exclusion of streamflows or even the dewatering of the work area to protect aquatic life and/or provide a suitable environment for construction. These activities have the potential to cause direct and indirect effects on HCP species. Prior to dewatering, all fish and other vertebrate aquatic life are removed using a variety of methods. Fish and invertebrate exclusion and dewatering involve the placement of barriers (e.g., block nets, temporary berms, cofferdams) around a work area and the capture and removal of fish and other aquatic life within the work area. Electrofishing is a common practice used for fish capture in freshwater environments, as is the use of minnow traps, hand nets, beach seines, and other net-based capture methods. As electrofishing is ineffective in brackish or salt water, net-based capture methods are used in these environment types.

The direct effects of fish exclusion and dewatering include:

- Direct mortality, injury, and stress from electrical field exposure (i.e., electrofishing)
- Capture by netting, leading to direct mortality, injury, and stress
- Physical and thermal stress and possible trauma associated with handling and transfer during capture and transfer between temporary holding containers and release locations
- Stranding and asphyxiation
- Entrainment or impingement in block nets, dewatering pumps, and bypass equipment
- Increased stress, predation exposure, and habitat competition once relocated
- Increased competition for aquatic species forced to compete with relocated animals.

Exclusion areas may also create temporary barriers to fish passage, with attendant effects on migratory fish species.

7.1.3.1 Fish Removal and Exclusion

Fish are typically removed from dewatering work areas both by passive methods that allow fish to move out of the area during a slow dewatering process, or by active handling using hand nets, beach seining, or electrofishing gear. Fish are typically excluded from work areas using block nets. Because invertebrate species and some vertebrate species buried in the substrate are typically not removed, some HCP vertebrate and invertebrate species could be subject to injury or direct mortality.

Active fish removal includes the herding of fish with beach seines to areas not subject to dewatering as well as the use of block nets to exclude fish from the construction area. When all block nets are in place, nets or beach seines are used to capture any fish remaining in the construction area. These fish are then released to downstream or upstream areas outside of the construction area. Finally, electrofishing gear is used to ensure that as many fish as possible are removed from the construction area.

A biological opinion issued by NOAA Fisheries (2006) for a large stream crossing replacement project in the Snake and Clearwater basins found that activities associated with dewatering and the capture, handling, transport, and release of fish would strand some fish, disrupt normal behavior, and cause short-term stress, injury, stranding, and occasional mortality.

Of the various methods used for dewatering and fish handling, the majority of research has been conducted on incidental mortality and injury rates associated with electrofishing. Much of this research has focused on adult salmonids greater than 12 inches in length (Dalbey et al. 1996). The relatively few studies that have been conducted on juvenile salmonids suggest spinal injury rates lower than those observed for large fish, perhaps because juvenile fish generate less total electrical potential along a shorter body length (Dalbey et al. 1996; Sharber and Carothers 1988; Thompson et al. 1997). Electrofishing-related injury rates are variable, reflecting a range of factors from fish size and sensitivity, individual site conditions, to crew experience and the type of equipment used, with the equipment type being a particularly important factor (Dalbey et al. 1996; Dwyer and White 1997; Sharber and Carothers 1988). Electrofishing equipment typically uses continuous direct current (DC) or low-frequency pulsed DC equipment. The use of low-frequency DC (equal to or less than 30 Hz) is the recommended electrofishing method as it is associated with lower spinal injury rates (Ainslie et al. 1998; Dalbey et al. 1996; Fredenberg 1992). Even with careful selection of equipment, observed injury rates can vary. For example, one study in the Yakima River basin (McMichael et al. 1998) observed a 5.1 percent injury rate for juvenile steelhead captured using 30 Hz pulsed DC equipment. Ainslie et al. (1998) reported injury rates of 15–39 percent in juvenile rainbow trout using continuous and pulsed DC equipment, and found that while pulsed DC equipment produced injury more frequently, these injuries were less severe in nature.

7.1.3.1.1 Direct and Indirect Effects

It is notable that electrofishing capture typically has a low direct mortality rate, but it is reasonable to conclude that injuries induced by electrofishing could have long-term effects on survival, growth, and fitness. The few studies that have examined this question found that few juvenile salmonids die as a result of electrofishing-induced spinal injury (Ainslie et al. 1998; Dalbey et al. 1996). However, fish with more injuries demonstrated a clear decrease in growth rates, and in some cases growth was entirely arrested (Dalbey et al. 1996). In the absence of additional supporting information, it is reasonable to conclude that these same effects would affect many of the HCP fish species, but this conservative assumption may not be universally accurate. Studies of the effects of electrofishing on other fish species are more limited, but available data indicate that at least some HCP species may be less sensitive to injury-related effects. Holliman et al. (2003) exposed a threatened cyprinid (minnow) species to electrofishing techniques in the laboratory and found that the typical current and voltage parameters used to minimize adverse effects on salmonid species produced no evidence of injury. This suggests that other cyprinids such as leopard and spotted dace, lake chub, and suckers may also be less sensitive.

Beyond the effects of electrofishing, the act of capture and handling demonstrably increases physiological stress in fishes (Frisch and Anderson 2000). Primary contributing factors to handling-induced stress and death include exposure to large changes in water temperatures and dissolved oxygen conditions (caused by large differences between the capture, holding, and release environments); duration of time held out of the water; and physical trauma (e.g., due to net abrasion, squeezing, or accidental dropping). Even in the absence of injury, stress induced by capture and handling can have a lingering effect on survival and productivity. One study found that handling stress impaired predator evasion in salmonids for up to 24 hours following release and caused other forms of mortality (Olla et al. 1995).

In the biological opinion issued by NMFS (2006), the total number of fish harmed, injured, or hazed was estimated to be 4.8 times greater for the electrofished sites than it was for the non-electrofished sites. This difference is due primarily to greater fish handling during the clearing of fish prior to dewatering at electrofishing sites. The findings suggest that rapid dewatering prior to fish salvage at electrofishing sites encourages a greater degree of volitional movement of fish from the project site and likely reduces the risk of take.

Use of a bypass system is a common means of creating exclusion areas via dewatering and flow reduction. Partial dewatering is a technique used to reduce the volume of water in the work area to make capture methods more efficient. In riverine habitats, this method is used to move fish out of affected habitats to reduce the number of individuals exposed to capture and handling stress and potential injury and mortality. NOAA Fisheries has estimated that 50–75 percent of fish in an affected reach will volitionally move out of an affected reach when flows are reduced by 80 percent (NMFS 2006). However, volitional movement will lead to concentration of fish in unaffected habitats, increasing competition for available space and resources.

Failure to capture and remove fish or invertebrates from work areas must also be considered. Organisms left in the exclusion area would potentially be directly exposed to stranding and asphyxiation during dewatering or, if left inundated, to mechanical injury and/or high-intensity noise, turbidity, and other pollutants. Many species of fish, such as salmonids and larval lamprey, are highly cryptic and can avoid being detected even when using multiple pass electrofishing because they hide in large interstices or are buried in sediments (Peterson et al. 2005; Peterson et al. 2004; Wydoski and Whitney 2003).

NOAA Fisheries has estimated incidental take resulting from dewatering and fish handling associated with stream crossing projects. In calculating incidental take from these activities, the agency applied an estimated stranding rate of 8 percent for ESA-listed salmonids (which equates to 8 percent mortality) (NMFS 2006), based on an expected 45 percent capture efficiency using three-pass electrofishing (Peterson et al. 2004), and assuming a 25 percent injury rate.

As noted, research on fish injury and mortality associated with dewatering has focused predominantly on salmonids, relatively large fish species that respond well to this exclusion technique. Other species may have non-motile or cryptic life-history stages (e.g., lamprey ammocoetes buried in fine sediments) or life-history stages that cannot easily move to adjust to changes in flow or are not easily captured and relocated (e.g., adhesive eggs of eulachon, juvenile rockfish, and lingcod). In freshwater environments, examples of species and life-history stages that are sensitive to dewatering impacts include incubating salmonid eggs and alevins, lamprey ammocoetes, the adhesive eggs of eulachon, sturgeon, and other species. These life-history stages are relatively immobile and also difficult to capture and relocate efficiently. Therefore, they face a higher likelihood of exposure to stranding or entrainment in dewatering pumps, which would be expected to lead to mortality. In marine environments, the larval and juvenile life-history stages of rockfish, lingcod, Pacific cod, hake, pollock, herring, smelt, and sand lance are similarly immobile and difficult to capture and therefore vulnerable to the same effects.

7.1.3.2 Fish Entrainment

Dewatering requires a flow bypass system that may rely on gravity or pumps to convey water around the construction area. A pump intake hose or pipe has the potential to entrain fish.

7.1.3.2.1 Direct and Indirect Effects

When pumps are used for bypassing water around the work area, the hose or pipe is typically fitted with a mesh screen to prevent entrainment of animals into the hose and pump system. Measures to protect aquatic life (i.e., NMFS 1996; WDFW 1998) require the placement of screens approximately 2–4 ft from the end of the intake hose. This is intended to reduce the velocity of water passing at the screen and help to ensure that fish are not impinged upon the screen.

7.1.3.3 Alteration of Flow

Dewatering requires the temporary alteration of flow. The magnitude of flow alteration required to divert water around the construction depends on the size of the dewatered area. The alteration of flow has the potential to affect fish and invertebrates.

7.1.3.3.1 Direct and Indirect Effects

The direct effects of flow alteration during dewatering are related to fish removal and exclusion and are described in Section 7.1.3.1 (*Fish Removal and Exclusion*). The indirect effects of flow alteration include the temporary loss of access to a relatively small area.

7.1.3.4 Disturbance of Stream Bed

Stream bed disturbance can be extensive. If a structure is installed where one previously did not exist, then a permanent loss of stream bed and associated habitat components can occur.

7.1.3.4.1 Direct and Indirect Effects

The effects of stream bed disturbance pertaining to substrate modification are discussed in Sections 7.1.4 (*Navigation/Maintenance Dredging*), 7.2.1 (*Grounding, Anchoring, and/or Prop Wash*), and 7.6 (*Hydraulic and Geomorphic Modifications*). The effects of stream bed disturbance pertaining to the potential loss of riparian and aquatic vegetation are discussed in

Sections 7.4 (*Riparian Vegetation Modifications*) and 7.5 (*Aquatic Vegetation Modifications*), respectively.

7.1.3.5 Loss of Invertebrates

Most invertebrate species inhabit the substrate and are not removed during dewatering operations. Channel dewatering could result in a loss of invertebrate HCP species.

7.1.3.5.1 Direct and Indirect Effects

HCP invertebrate species demonstrate different sensitivity to the effects of dewatering and relocation than fish, with many species being relatively insensitive to the effects of handling, at least during adult life-history stages. For example, Krueger et al. (2007) studied the effects of suction dredge entrainment on adult western ridged and western pearlshell mussels in the Similkameen River (in Washington State) and found no evidence of mortality or significant injury. Suction dredge entrainment is expected to be a more traumatic stressor than removal and relocation by hand. These findings suggest that careful handling would be unlikely to cause injury. However, the authors cautioned that these findings were limited to adult mussels, and the potential for injury and mortality in juveniles remains unknown. Moreover, while entrainment mortality in adults is limited, other significant nonlethal effects are possible. For example, scattering of adult mussels during dredging may affect density-dependent reproductive success (Downing et al. 1993).

The sensitivity of other HCP invertebrate species, such as the giant Columbia River limpet and great Columbia River spire snail, is somewhat less certain. Adults may be easily removed and relocated during dewatering, but juveniles and eggs may be difficult to locate and remove effectively. This suggests the potential for mortality from stranding. In addition, the great Columbia River spire snail has suffered damage from periodic dewatering of reservoirs associated with dams due to decreased dissolved oxygen as the species requires dissolved oxygen for respiration (Watters 1999).

While handling-related injury and mortality are relatively unlikely, relocation may lead to significant nonlethal effects. For example, scattering of closely packed groups of adult mussels may affect reproductive success. Because female freshwater mussels filter male gametes from the water column, successful fertilization is density dependent (Downing et al. 1993).

Failure to locate and remove small or cryptic invertebrate species or life-history stages may result in stranding or concentrated exposure to other stressors within the exclusion area. Stranding caused by operational water level fluctuations was associated with mass mortality of California floater and western ridged mussels in Snake River reservoir impoundments (Nedeau et al. 2005).

7.1.3.6 Elevated Turbidity during Rewatering

Installation, operation, and removal of a stream bypass system in order to rewater a channel can increase turbidity. The in-water installation and removal work poses the highest risk of disturbing the stream bank and substrate and thereby resuspending sediments and increasing turbidity. Fish may experience short-term, adverse effects as a result of increased turbidity.

7.1.3.6.1 Direct and Indirect Effects

Rewatering of the exclusion area following construction is generally expected to result in a temporary increase in turbidity. The in-water installation and removal work poses the highest risk of disturbing the stream bank and substrate, thereby resuspending sediments and increasing turbidity. Fish may experience short-term, adverse effects as a result of increased turbidity. The effects of elevated turbidity during rewatering as they relate to increased sediment supply are discussed in Section 7.1.4.4 (*Turbidity*).

7.1.4 Navigation/Maintenance Dredging

Navigation or maintenance dredging is by far the most frequent form of dredging in Washington State. This type of dredging can convert intertidal habitat to subtidal habitat and shallower subtidal habitats to deeper subtidal habitats through periodic deepening to remove accumulated sediments that impede navigation to and from marinas/terminals. There are several different means by which dredging affects fish and invertebrates, the most significant being alteration of bathymetry, removal of aquatic vegetation, entrainment of benthic organisms, and turbidity and resuspension of contaminated sediments. These stressors are discussed below.

7.1.4.1 Altered Bathymetry and Substrate Composition

Large channel deepening projects can markedly alter ecological relationships through the change of freshwater inflow, tidal circulation, estuarine flushing, and freshwater and saltwater mixing. Miller et al. (1990) reported that only through comprehensive areal surveys over a minimum of four seasons before dredging, with follow-up surveys after dredging, could impacts of channel deepening on aquatic resources be determined. In a comparison between dredged and undredged areas in the Port of Everett's public marina, Pentec (1991) found catches of fish to be higher in the dredged area before dredging than after dredging. Catches decreased from about 90 fish per tow to about 3 fish per tow and from eight species to five species.

Depending on site characteristics, maintenance dredging may occur annually or at intervals of 10 years or longer. These different dredging timelines represent different disturbance regimes both in terms of the ability of the benthos to recolonize prior to redisturbance and the magnitude of benthic productivity affected by dredging. In a literature review report on dredge and disposal effects, Morton (1977) reported the range of effects on invertebrate communities to be from negligible to severe, with impacts ranging from short to long term. In general, this literature review found that short-term, small-scale dredging and dredge disposal projects affected benthic communities less than long-term, large-scale projects. This is likely due to the fact that benthic communities are more likely (and quicker) to recover from short-term, less intense, small-scale disturbances than from large-scale and intense disturbances over long time periods (Guerra-García et al. 2003; Dernie et al 2002). For example, in experiments conducted in sheltered sand flats, the benthic community recovered from lower intensity disturbance (i.e., sediment removal to a depth of 3.9 inches [10 cm]) within 64 days, whereas recovery from higher intensity disturbance (i.e., sediment removal to a 7.9-inch [20-cm] depth) required 208 days postdisturbance (Dernie et al 2002).

In a study to evaluate the effects of dredged material disposal on biological communities, Hinton et al. (1992) reported a significant increase in benthic invertebrate densities at a disposal site between June 1989 (predisposal) and June 1990 (postdisposal). Recolonization could have occurred by invertebrates burrowing up through newly deposited sediments or recruitment from surrounding areas (Richardson et al. 1977).

7.1.4.1.1 Direct and Indirect Effects

Dredging is often required during marina and terminal projects as a component of facility development, as well as during routine maintenance to maintain navigability. In marine environments converts intertidal into subtidal habitats, affecting the plant and animal assemblages that are uniquely adapted to the particular light, current, and substrate regimes of intertidal areas. By altering bathymetry and bottom substrates, such conversions are described as producing a habitat "trade-off" of intertidal and shallow-subtidal communities for deeper, subtidal communities. In lacustrine environments, dredging converts shallow-water littoral habitats into deeper water environments and may create a steeper bathymetric transition. This change in habitat characteristics may change the size and species distribution of fish in the localized environment, altering predator/prey dynamics. The effects of dredging on riverine environments are more complex still, because localized alteration of channel morphology can lead to dynamic shifts in channel form as the system adjusts to the changed conditions. These effects can extend a considerable distance beyond the bounds of the original dredging project.

Dredging activities result in short-term direct effects, including entrainment and potential mortality; periodic removal of potentially suitable habitats for fish and invertebrates; alteration of water circulation and subsequent nutrient, prey, and habitat availability; and increased turbidity and potential resuspension of contaminants. In addition, long-term and food web indirect effects can occur, such as reconfiguration of the benthos and the availability of nutrient and prey resources. Resulting impacts, as described in detail in Sections 7.3 (*Water Quality Modifications)*, 7.5 (*Aquatic Vegetation Modifications)*, and 7.6 (*Hydraulic and Geomorphic Modifications*), include mortality, injury, decreased foraging opportunity, decreased growth and fitness, and physiological and behavioral responses. Deposition of dredge spoils can bury existing habitats and benthic organisms, resulting in a similar suite of impacts. For invertebrates at dredge disposal sites, research has shown potential increases in densities.

7.1.4.2 Aquatic Vegetation Removal

Two studies of marina areas and ferry boat routes in the Baltic Sea archipelago found that boating activities associated with marinas and ferry boat routes affected the species distribution and richness for both aquatic vegetation and fish species (Eriksson et al. 2004; Sandstrom et al. 2005). Eriksson et al. (2004) found that boat traffic generated water movement that significantly affected the distribution of vegetation species. The important variables were found to be: (1) the stress of water movement (i.e., tearing or uprooting the vegetation); (2) depth; and (3) turbidity levels. Sandstrom et al. (2005) studied the same area for boating effects on fish recruitment, finding that marinas had different species compositions suggesting that boating activities affected the species composition. Sandstrom et al. (2005) found that the differences in the distribution of fish species in the marina and along the ferry routes reflected the particular species' dependence on aquatic vegetation for recruitment and rearing.

7.1.4.2.1 Direct and Indirect Effects

The effects of dredging have been documented by a number of studies (Byrnes et al. 2004; Cooper et al. 2007; Erftemeijer and Lewis 2006). These studies have documented that repeated dredging reduces the prevalence of seagrasses and macroinvertebrates; nonetheless, invertebrates conditioned for disturbance can respond quickly, and populations of benthic invertebrates can significantly recover (Bolam and Rees 2003; Robinson et al. 2005). However, even in the most optimistic studies, the impacts of dredging include lower bed productivity and diversity (Robinson et al. 2005).

In both marine and freshwater environments, dredging generally removes or disturbs benthic vegetation, potentially altering the distribution and abundance of prey resources, the availability of refugia, and water quality benefits provided by vegetation to various species. The time period between dredging activities will determine the capacity for recolonization of the submerged aquatic vegetation. Section 7.2.4 (*Ambient Light Modifications*) provides a further explanation of potential impacts of dredging activities on aquatic vegetation.

7.1.4.3 Entrainment

Entrainment occurs when an organism is trapped in the uptake of sediments and water being removed by dredging machinery (Reine and Clark 1998). Benthic infauna are particularly vulnerable to being entrained by dredging uptake, but mobile epibenthic and demersal organisms such as burrowing shrimp, crabs, and fish also can be susceptible to entrainment. Entrainment rates are usually described by the number of organisms entrained per cubic yard (cy) of sediment dredged (Armstrong et al. 1982).

Demersal fish, such as sand lance, sculpins, and pricklebacks, likely have the highest rates of entrainment as they reside on or in the bottom substrates, with life-history strategies of burrowing or hiding in the bottom substrate. This is also true in freshwater environments. For example, lamprey ammocoetes likely have a high risk of vulnerability to dredging due to the lengthy residence time in freshwater sediments in their early life-history stages. In general, larval fish that have little or no swimming capacity to avoid direct dredge impacts are also at significant risk of entrainment in dredge sites. Of particular concern for the purpose of this analysis are the HCP groundfish (lingcod, rockfish, Pacific cod, pollock, hake) and the forage fishes (herring, sand lance, and surf smelt), all of which have larval or juvenile life-history stages with low motility. The juvenile life-history stage of the groundfish species typically rear in shallow nearshore habitats, where dredging is likely to occur. Due to their demersal nature and limited motility, they face a higher risk of dredging entrainment.

Larger fish may also be susceptible to entrainment. Armstrong et al. (1982) found that larger fish were not necessarily able to avoid the hopper dredge, with the largest specimen being a 9.2-in (234-mm) tomcod. Tests of excluders mounted on the draghead of a hopper dredge showed that 66 percent fewer fishes (mostly flatfish and gunnels in the study) could be saved from entrainment through use of the device (Shaw 1996).

Buell (1992) found entrainment of juvenile white sturgeon (11.8–19.6 in [300–500 mm]) at a rate of 0.015 fish/cy. In another study, juvenile salmonids and eulachons were the dominant entrained taxa due to the dredge location in a constricted waterway, making it more difficult for salmonids to avoid the dredge operation (McGraw and Armstrong 1990; Larson and Moehl 1990).

Entrained bivalve larvae, such as larval oysters, are assumed to suffer 100 percent mortality by sediment smothering, anoxia, starvation, or desiccation even without direct mechanical impacts from pumping. However, the population-level effects of these stressors may be relatively limited. For example, concern for oyster larvae entrainment in Chesapeake Bay resulted in the development of a population model using conservative temporal and spatial distributions (Lunz 1985). The model predicted that entrainment would have minimal negative effect on the population, with the calculated mortality rate ranging between 0.005 and 0.3 percent of larval abundance. Lunz (1985) concluded that this represented no significant impact as the dredge entrained only a small fraction of the total water volume flowing past the dredge. Many species, particularly marine fish and invertebrates, have planktonic larval life-history stages that suffer naturally high mortality rates (in some cases exceeding 99 percent). Therefore, the potential mortality from entrainment is relatively insignificant in comparison (Lunz 1985).

Krueger et al. (2007) studied the effects of entrainment and burial caused by suction dredging on several species of freshwater mussels in the Similkameen River (in Washington State). They found that burial under greater than 15 inches (40 cm) of coarse sediment (gravel and cobble) caused mortality in the range of 10 percent of the test subjects. However, while the remaining mussels survived the 6-week test period, none of the individuals buried at this depth were able to extricate themselves. This suggests that burial could lead to much higher mortality rates. Burial with fine sediments is also likely to be associated with higher levels of mortality. Mussel mortality rates exceeding 90 percent have been observed following burial with silt (Ellis 1942), and burial has been implicated in large-scale mortality of western pearlshell mussels in the Salmon River in Idaho (Vannote and Minshall 1982).

7.1.4.3.1 Direct and Indirect Effects

Direct effects associated with entrainment include injury or mortality of fish and invertebrate species. Indirect effects include alteration of food web configuration or dynamics that could affect overall species survival or fitness.

7.1.4.4 Turbidity

Although the physics of turbidity generation can be calculated, adequate data do not exist to quantify the biological response in terms of threshold sediment dosages and exposure durations that can be tolerated by various marine and estuarine organisms. Numerical modeling simulations of dredging-related suspended-sediment plume dynamics are currently being developed under the USACE's Dredging Operations and Environmental Research Program. Present data indicate that responses to suspended sediments are highly species-specific, with some species having lethal effects at several hundred parts per million (ppm) in 24 hours and others having no effect at concentrations above 10,000 ppm for 7 days. Studies on east coast species have identified lethal concentration levels and Newcombe and Jensen (1996) have developed a predictive model for defining lethal and sublethal fish injury threshold levels for suspended solid concentrations. However, threshold studies for the temporary impacts of suspended sediment levels specific to aquatic environments in the Northwest are lacking.

Recent studies have shown that the size and shape of suspended sediments and the duration of exposure are important factors in determining the extent of adverse effects of increased turbidity on salmonids (Servizi and Martens 1987, 1991; Martens and Servizi 1993; Northcote and Larkin 1989; Newcombe and MacDonald 1991). Lake and Hinch (1999) found concentrations in excess of 40,000 ppm to elicit stress responses (e.g., decreased leukocrit), which correlate to occurrences of gill damage. Angular sediments, as opposed to rounder sediments, are associated with higher fish stress responses at lower sediment concentrations. This may be due to irritation caused by angular sediments that result in increased mucus production and decreased oxygen transfer. Although the causes of mortality were not clear, Lake and Hinch (1999) found that mortality occurred at concentrations of 100 parts per thousand (ppt), with no differences found in mortality rates in natural or more angular anthropogenically derived sediments.

In addition to size and shape, the concentration of suspended sediments would determine the severity of the responses elicited in aquatic organisms. Effects on aquatic organisms will differ based on their developmental stage. Suspended sediments may affect salmonids by altering their physiology, behavior, and habitat, all of which may lead to physiological stress and reduced survival rates. For example, high levels of suspended solids may be fatal to salmonids due to, for example, gill trauma, osmoregulation impairment, and changes in blood chemistry. Lower levels of suspended solids and turbidity may cause chronic sublethal effects, such as loss or reduction of foraging capability, reduced growth, reduced resistance to disease, increased stress, and interference with cues necessary for orientation in homing and migration (Lloyd 1987; Newcombe and MacDonald 1991; Bash et al. 2001).

Sigler et al. (1984) reported that suspended sediments have been shown to affect fish functions such as avoidance responses, territoriality, feeding, and homing behavior. Similarly, Wildish and Power (1985) reported avoidance of suspended sediments by rainbow smelt and Atlantic herring to be at 20 ppm and 10 ppm, respectively. In studies of coho behavior in the presence of short-term pulses of suspended sediment, Berg and Northcote (1985) found that territorial, gill flaring, and feeding behaviors were disrupted in the presence of higher turbidity levels. At higher levels of turbidities such as 30–60 nephelometric turbidity units (NTUs), social organization broke down, gill flaring occurred more frequently, and only after a return to turbidity of 1–20 NTUs was the social organization re-established. Similarly, feeding success was found to be linked to turbidity levels, with higher turbidity levels reducing prey capture success. The studies of Gregory and Northcote (1993) demonstrate that at particular levels of increased turbidity, juvenile salmon actually increase their feeding rates, while at other levels (such as >200 ppm), they demonstrated pronounced behavioral changes in prey reaction and predator avoidance. In a study of dredging impacts on juvenile chum salmon in Hood Canal (Washington), Salo et al. (1980) found that juvenile chum also showed avoidance reactions to low levels of turbidity ranging from 2 to 10 ppm above ambient concentrations. However, in related laboratory tests, Salo et al. (1980) found that avoidance was not shown until a concentration of 182 ppm was reached. In general, these behavioral thresholds vary across species and life-history stages. Consistent with their early reliance on nearshore estuarine habitats with relatively high turbidities compared to pelagic or freshwater habitats, juvenile chum salmon are classified as turbidity tolerant compared to other fishes.

Many fish species thrive in rivers and estuaries with naturally high concentrations of suspended sediments. It is currently unknown what behavioral mechanisms are triggered as various fish species encounter patches of increased turbidity, such as dredging plumes. Also unknown is what threshold of turbidity might be a cue to fish to avoid light-reducing turbidity. Simenstad (1990) described the behavioral effects that would affect migrating fishes, such as reduced foraging success, increased risk of predation, and migration delay, to be highly dependent upon the duration of exposure.

The final phase of salmon homing migration requires olfactory cues (Hasler et al. 1987; Hasler and Scholz 1983). In studies of returning Chinook spawners, Whitman et al. (1982) found that suspended ash at concentrations of 650 ppm did not influence homing performance. Preference experiments indicated that Chinook, when given the choice, preferred clean home water to municipal drinking water, with the presence of ash reducing the preference for home water. It was concluded that fish could recognize home water despite the ash suspension and that any reduced home-water preference was due to ash avoidance (Whitman et al. 1982).

Thresholds for lethal effects on clams and eastern oysters have been reported, with negative impacts on eastern oyster egg development occurring at 188 ppm of silt (Cake 1983) compared to a 1,000 ppm threshold for hard clam eggs (Mulholland 1984). Suspended solids concentrations of <750 ppm allowed for continued larval development, but higher concentrations for durations of 10–12 days showed lethal effects for both clams and oysters. However, turbidity concentrations of <750 ppm are unlikely to be experienced by HCP species at most marinas/terminals during navigation or maintenance dredging, particularly if standard BMPs are implemented.

When suspended sediment concentrations rise above the filtering capacities of bivalves, their food becomes diluted (Widdows et al. 1979). In environments with high algal concentrations, Clarke and Wilber (2000) reported that the addition of silt, in relatively low concentrations, showed increased growth on the part of mussels (Kiorboe et al. 1981), surf clams (Mohlenberg, and Kiorboe 1981), and eastern oysters. Bricelj and Malouf (1984) found that hard clams decreased their algal ingestion with increased sediment loads. However, no growth rate differences were observed between clams exposed to algal diets alone and clams with added sediment loads (Bricelj and Malouf 1984). Urban and Kirchman (1992) reported similarly ambiguous findings concerning suspended clay. Suspended clay (20 ppm) interfered with the ingestion of algae by juvenile eastern oysters, but it did not reduce the overall amount of algae ingested. Grant et al. (1990) found that the summer growth of European oysters was enhanced at low levels of sediment resuspension and inhibited with increased sediment deposition. It was hypothesized that the chlorophyll in suspended sediments may act as a food supplement that could enhance growth, but higher levels may dilute planktonic food resources, thereby suppressing food ingestion. Changes in behavior in response to sediment loads were also noted for soft-shelled clams under sediment loads of 100–200 ppm, with changes in their siphon and mantles over time (Grant and Thorpe 1991).

Collectively, these studies show no clear pattern of sublethal effects from elevated concentrations of suspended solids and thereby turbidity that could be generally applied across aquatic mollusks. This uncertainty is further complicated by the fact that many of the HCP invertebrate species are poorly studied. This indicates the need for directed studies on the sensitivity of these species before effects thresholds can be set. In the absence of this information, however, it is useful to consider that HCP invertebrates are all bottom-dwelling mollusks that have evolved to live in dynamic environments under conditions of variable turbidity. Therefore, sensitivity to turbidity-related stressors would be expected to occur only when conditions exceed the range of natural variability occurring in their native habitats.

7.1.4.4.1 Direct and Indirect Effects

The effects of turbidity have been documented in a number of studies on fish (e.g., Newcombe and Jensen 1996; Martens and Servizi 1993; Newcombe and MacDonald 1991; Lloyd 1987; Bash et al. 2001; Sigler et al. 1984; Salo et al. 1980; Hasler et al. 1987) as well as on invertebrate species (e.g., Cake 1983; Mulholland 1984; Widdows et al. 1979).

Size, shape, and concentration of suspended sediments as well as the duration of exposure are important factors in determining the extent of adverse effects of increased turbidity on HCP species. Effects on aquatic organisms will differ based on their developmental stage. Suspended sediments may affect HCP species by altering their physiology, behavior, and habitat, all of which may lead to physiological stress and reduced survival rates. However, many fish species thrive in rivers and estuaries with naturally high concentrations of suspended sediments.

Additional direct and indirect effects of turbidity on fish and invertebrates are summarized in Section 7.3 (*Water Quality Modifications*).

7.2 Facility Operation and Vessel Activities

This impact mechanism includes those activities associated with marinas/terminals that are recurrent and result in repetitive or long-term impacts. Submechanisms associated with facility operation and vessel activities include grounding, anchoring, and prop wash; vessel maintenance and operational discharges; increased or altered ambient noise levels; and ambient light modification. Each of these submechanisms is discussed below.

7.2.1 Grounding, Anchoring, and/or Prop Wash

The operation and placement of structures associated with recreational, transport, and shipping vessels affect aquatic ecosystems through a variety of mechanisms including the resuspension of benthic sediments, shoreline erosion, vehicle emissions, stormwater pollution, traffic-related disturbance, and direct mortality of individuals from collisions with vessels. Specific impact-types or stressors are addressed in greater detail below, namely benthic disturbance and turbidity, eelgrass and macroalgae disturbance, and freshwater aquatic vegetation disturbance.

7.2.1.1 Benthic Disturbance and Turbidity

The frequency of ferry traffic, sometimes every half hour throughout the day, makes prop wash effects at ferry terminals an exception to other docks. Prop wash and benthic disturbance by ferries are well documented for ferry terminals (Haas et al. 2002; Blanton et al. 2001; Parametrix 1996; Thom et al. 1997; Thom and Shreffler 1996; Olson et al. 1997; Francisco 1995; Shreffler and Gardiner 1999; Michelsen et al. 1999). Carrasquero (2001) and Kahler et al. (2000) provide a review of what is known about shoreline and overwater structure impacts in freshwater environments.

Prop wash or waves produced by boats and personal watercraft are also known to increase suspended sediments and turbidity through resuspension of shallow water sediments (Kennish 2002; Yousef et al. 1980; Yousef 1974). The effect of this increased turbidity may lead to decreased light levels, which could potentially affect the growth rates of submerged vegetation, upon which most HCP species depend (at least during their juvenile stages). Turbidity is also known to be associated with fish respiratory injury (Berg and Northcote 1985). Another risk from increased turbidity is the potential of increasing fine sediment deposition to downstream spawning beds, resulting in a loss of suitable spawning habitat (Hartman et al. 1996) and reduced disease tolerance (Redding et al. 1987).

Recreational boating can significantly increase turbidity (Yousef et al. 1980; Yousef 1974; Hilton and Phillips 1982; Warrington 1999). Some models predict a 44 percent increase in riverine turbidity due to recreational boating (Hilton and Phillips 1982). In some freshwater environments, such as lakes, turbidity can decline slowly, taking as much as 24 hours for water clarity to return to baseline levels (Yousef et al. 1980; Yousef 1974). Prop wash and waves are also known to be a primary cause of shoreline erosion (Gatto and Doe 1987; Mason et al. 1993). The number of boats in a given area has been correlated with wave height (Bhowmilk et al. 1991), with areas of high boat traffic exhibiting increased levels of shoreline erosion. Although it is difficult to quantify boat wake contributions to shoreline erosion, boat traffic has been found to contribute up to 50 percent of the factors responsible for shoreline erosion in small rivers less than 2,000 feet wide (Hurst and Brebner 1969). Sutherland and Ogle (1975) found prop wash and increased turbidity from jet boats to decrease salmon egg survival by 40 percent. In addition to turbidity, direct contact with spawning substrate can cause mortality.

7.2.1.1.1 Direct and Indirect Effects

Grounding, anchoring, and/or prop wash can cause benthic disturbance and turbidity, eelgrass and macroalgae disturbance, and freshwater aquatic vegetation disturbance. These effects have been well documented (e.g., Thom et al. 1997 and Thom and Shreffler 1996).

Prop wash or waves produced by boats and personal watercraft can cause shoreline erosion (Gatto and Doe 1987; Mason et al. 1993; Hurst and Brebner 1969) and increase suspended sediments and turbidity (Hilton and Phillips 1982; Kennish 2002; Yousef et al. 1980; Yousef 1974). The effect of this increased turbidity may decrease light levels, which could potentially affect the growth rates of submerged vegetation, upon which most HCP species depend. Turbidity is also known to be associated with fish respiratory injury (Berg and Northcote 1985) and increased sediment deposition on downstream spawning habitat (Hartman et al. 1996).

Additional impacts on fish and invertebrates from benthic disturbance are discussed in Sections 7.1.4 (*Navigation/Maintenance Dredging*) and 7.3 *(Water Quality Modifications*).

7.2.1.2 Eelgrass and Macroalgae Disturbance

During normal operation of marinas/terminals, the displacement of sediments due to increased currents can threaten the integrity of eelgrass. The typical effects vary with both distance and propeller speed, both of which may be important factors in loosening sediment particles and eroding eelgrass. In addition, increased propeller speed may result in greater amounts of suspended matter and bubbles, which reduce light levels on the bottom and interfere with photosynthesis by eelgrass.

Following a study of 44 shallow, sheltered soft-bottom dominated inlets on the Baltic Sea, Eriksson et al. (2004) found that recreational boating activities and ferry boat traffic significantly affected aquatic vegetation both in percent cover and species richness. These effects were largely attributed to water movement generated by boating activity and turbidity blocking light transmission, as well as vessel prop wash. These findings are consistent with numerous studies on the effects of disturbance on eelgrass beds (Sargent et al. 1995; Loflin 1995; Haas et al. 2002). Boat prop wash has also been found to stimulate the resuspension of nutrients and contaminants that can stimulate algal blooms, such as nitrogen and phosphorous, as well as increased turbidity (Haas et al. 2002; Michelsen et al. 1999; Thom et al. 1997; Thom and Shreffler 1996; Parametrix 1996). The result of this sediment disturbance and increased turbidity is to decrease available light for aquatic plants. The resulting increased algal growth may also lead to eutrophication and reduction of dissolved oxygen levels due to respiration during desiccation of the algal material. The result of increased turbidity and lower dissolved oxygen has effects throughout the food web, as described in Section 7.3 (*Water Quality Modifications*).

7.2.1.2.1 Direct and Indirect Effects

Direct and indirect effects on fish and invertebrates are discussed in Sections 7.3 (*Water Quality Modifications*) and 7.2.4 (*Ambient Light Modifications*).

7.2.1.3 Freshwater Aquatic Vegetation Disturbance

Similar effects are also documented for freshwater systems. Lagler et al. (1950) reported the clearing of vegetation from outboard motor prop wash within 1 foot of the vegetation.

7.2.1.3.1 Direct and Indirect Effects

Direct and indirect effects on fish and invertebrates are discussed in Sections 7.3 (*Water Quality Modifications*) and 7.2.4 (*Ambient Light Modifications*) below.

7.2.2 Vessel Maintenance and Operational Discharges

Nutrient and contaminant loading from vessel discharges, engine operation, prop scouring, bottom paint sloughing, boat wash-downs, haul-outs, boat scraping, painting, and maintenance activities pose risks such as sediment contamination and water quality degradation (Cardwell et al. 1980; Cardwell and Koons 1981; Eisler 1998; Hall and Anderson 1999; Krone et al. 1989a, 1898b; Waite et al. 1991), which is discussed in detail in Section 7.3 (*Water Quality Modifications*). Studies demonstrate that contaminants introduced to the aquatic environment and ingested by aquatic organisms are incorporated into the food web and can ultimately interfere with animal reproductive viability and population sustainability (Jones 1996; Johnson et al. 1993, 1995; Johnson and Landahl 1994; Lee 1985; O'Neill et al. 1995; West 1995, 1997).

7.2.2.1 Direct and Indirect Effects

Given the large numbers of vessels typically associated with a marina and the large-sized vessels using terminals, the potential effects on fish and invertebrate growth, survival, and fitness in the vicinity of these maritime structures from these types of discharges could be significant. In general these effects include contamination of the food web via bioaccumulation. Other potential effects are described in detail in Section 7.3 (*Water Quality Modifications*).

7.2.3 Increased or Altered Ambient Noise Levels

Ambient underwater noise levels serve as the baseline for measuring the disturbance created by project construction. Both natural environmental noise sources and mechanical or human-generated noise contribute to the ambient or baseline noise conditions within and surrounding a project site. Many specific measurements of ambient noise levels include sounds produced by vessels and other human activities. As such, these noise measurements, particularly those taken in the vicinity of ferry terminals and other high-activity locations, are indicative of the level of noise produced by marina operation.

Ambient noise levels have been measured in several different marine environments on the West Coast and are variable depending on a number of factors, such as site bathymetry and human activity. For example, measured ambient levels in Puget Sound are typically around 130 dB_{peak} (Laughlin 2005). However, ambient levels at the Mukilteo ferry terminal reached approximately 145 dB_{peak} in the absence of ferry traffic (WSDOT 2006a). Ambient underwater noise levels measured in the vicinity of the Friday Harbor ferry terminal project ranged between 131 and 136 dB_{peak} (WSDOT 2005). Carlson et al. (2005) measured the underwater baseline for the Hood Canal and found it to range from 115 to 135 dB_{RMS}. Heathershaw et al. (2001) reported open-ocean ambient noise levels to be between 74 and 100 dB_{peak} off the coast of central California. Note, however, that these ambient noise levels are typical conditions, and typical conditions can be punctuated by atypical natural events. For example, lightning strikes can produce underwater noise levels as high as 260 dB_{peak} in the immediate vicinity (Urick 1983).

Far less data are available on ambient noise levels in freshwater environments, but it is reasonable to conclude that they vary considerably. For example, high-gradient rivers, fast-flowing rivers, and large rivers and lakes with significant human activity are likely to produce more noise than lakes and slow-flowing rivers in more natural environments. Burgess and Blackwell (2003) measured ambient sounds in the Duwamish River (averaged over 20 seconds to 5 minutes) and found the sound to vary between 110 to 130 dB (sound pressure level, SPL). These values were averaged over time and did not specify peak or RMS. Amoser and Ladich (2005) measured ambient noise levels using similar units in the mainstem Danube River, a smaller, fast-flowing tributary stream, a small lake, and a quiet river backwater. The river and stream represented fast-flowing habitats, the lake and backwater quiet, slow-flowing habitats. Sound behavior was complex. They found that ambient noise levels ranged from as low as 60 to as high as 120 dB in the fast-flowing habitats, depending on sound frequency (lower frequency sound was typically louder). Ambient noise in the slackwater habitats was considerably lower, ranging from 40 to 80 dB across the frequency range (again with lower frequency sounds being loudest).

Vessel operation can significantly influence ambient noise levels. For example, large vessel engines can produce underwater sound up to 198 dB, and depth sounders can produce noise in excess of 180 dB (Buck 1995; Heathershaw et al. 2001). Hazelwood and Connelly (2005) monitored fishing vessel noise over a broad octave range from 10–40 kHz and documented peak noise levels ranging from 140–185 dB, with the loudest noise occurring at the lower end of the octave range. Commercial sonar devices operating in a frequency range of 15–200 kHz can produce underwater noise ranging from 150–215 dB at maximum levels (Stocker 2002).

Scholik and Yan (2001) studied the auditory responses of the cyprinid fathead minnow to underwater noise levels typical of human-related activities (e.g., a 50 horsepower outboard motor). They found that prolonged exposure to elevated ambient noise levels increased the threshold level required to elicit a disturbance response, and that this effect lasted as long as 14 days after the exposure. Amoser and Ladich (2005) reported similar findings in common carp in the Danube River, noting that auditory ability in this hearing specialist species was measurably masked in environments with higher background noise. They reported similar but far less pronounced responses in hearing generalist species such as perch. These data suggest that elevated ambient noise levels have the potential to impair hearing ability in a variety of fish species, which may in turn adversely affect the ability to detect prey and avoid predators. Similarly, Feist et al. (1992) theorized that it was possible that auditory masking and habituation to loud continuous noise from machinery may decrease detection by salmonids of approaching predators.

7.2.3.1 Direct and Indirect Effects on Fish

Facility and vessel operational activities are expected to produce intermittent, continuous noise for the life of the marina or terminal project. In general, noise levels produced by small to moderate sized vessel operations are relatively low in comparison to those levels shown to cause injury in the studies referenced above for construction projects. Responses to these effects may range from minor changes in behavior, to increased predation risk or lowered foraging efficiency, to potential injury. For additional details, see Section 7.1.1.3 (*Direct and Indirect Effects on Fish*).

7.2.3.2 Direct and Indirect Effects on Invertebrates

No research has been identified regarding the effects of underwater noise levels approximating marina operations on invertebrates. However, operational noise is typically associated with sound pressures well below levels that have been observed to cause injury in shellfish (see Section 7.1.1 [*Pile Driving (Elevated Underwater Noise*)]), suggesting that HCP invertebrate species would not be subject to these effects. As HCP invertebrates with the potential for stressor exposure are either filter feeders or grazers and are essentially non-motile, these species are unlikely to be subject to auditory masking effects that would limit their ability to sense predators and prey. Some potential may exist for disturbance-induced interruption of feeding behavior, but more research on this subject is necessary to determine this definitively.

7.2.4 Ambient Light Modifications

Along marine, riverine, and lake shorelines, marinas (as a collection of individual piers) and shipping or ferry terminals are known to affect light availability and the aquatic habitats upon which HCP species depend. A considerable body of literature, cited in this section, provides evidence that shading from these structures can reduce ambient daytime aquatic light availability to levels below the light threshold levels required for aquatic plant photosynthesis and fish feeding and movement. These facilities can also alter ambient nighttime light through the use of artificial light. In the case of terminals that berth large vessels, documented shade casting includes the reflective effects of sediment resuspension and bubbles generated by high propulsion prop wash in shallow environments (Thom et al. 1996; Haas et al. 2002; Blanton et al. 2001). Each of these stressors (daytime shading and nighttime lighting effects on fish behavior, and decreased light penetration effects on aquatic vegetation) is discussed in detail below, following a brief overview of fish vision to provide context for the analysis.

Although this section limits its discussion of vessel activities to light limitation, additional effects of vessel propulsion gear are also covered further in Section 7.3 (*Water Quality Modifications*) and Section 7.2 (*Facility Operation and Vessel Activities*).

7.2.4.1 Fish Vision

Light perception by fish is dependent upon the light transmission qualities of the water environment coupled with the spectral qualities of the fish retinal visual pigments (Ali 1959, 1975; Brett and Groot 1963; Fields 1966; Hoar 1951; Hoar et al. 1957; McDonald 1960; McFarland and Munz 1975; Mork and Gulbrandsen 1994; Nemeth 1989).

Habitat and genetics determine the light absorption capacities of fish visual pigments. Capacities differ across the solar spectral compositions specific to the habitats upon which these species depend for growth and survival (Wald et al. 1957; Browman et al. 1993; Coughlin and Hawryshyn 1993; Hawryshyn and Harosi 1993, Novales-Flamarique and Hawryshyn 1996).

Light is received by the fish retina. This light reception triggers physiologic responses. The visual cell layers consist of two types of photoreceptors, rods, and cones. These retinal pigments have different light thresholds and respond to light and dark with changes in their relative positions. When the light intensity is above the retinal pigment and cone thresholds, the eye assumes the light-adapted state. When the light intensity falls below threshold values, the cones expand away, and the eye assumes a dark-adapted state (Ali 1959). In freshwater laboratory studies, Ali (1959) found that when the light drops below particular thresholds, the school disbands and feeding by visual means ceases, with the extent of expansion and elongation dependent upon ambient conditions (Ali 1975).

The time period for such physiologic changes in response to light variations varies across species and lifestages. At the juvenile stage, the time required for light-adapted chum and pink salmon fry to fully adapt to dark conditions was found to range from 30 to 40 minutes. However, the time required for dark-adapted fry to adapt to increased light conditions was found to range from 20 to 25 minutes (Brett and Ali 1958; Ali 1959; Protasov 1970). During these transition periods, the juvenile chum's visual acuity ranges from periods of blindness to a slightly diminished capacity, depending upon the magnitude of light intensity contrasts. As the animals become older, the time required for light adaptation generally shortens. The time necessary to adapt to the dark, on the other hand, tends to increase with age. The progression of retinal changes from one state to another is influenced by the intensity of the introduced light and the intensity of light to which the fish have been previously exposed (Ali, 1962, 1975; Fields 1966; Protasov 1970; Puckett and Anderson 1987). It is the contrasts in light levels that determine the changes the eye undergoes and the speed of transition from one state to another. Fish previously exposed to higher light intensities become dark-adapted more slowly than those previously exposed to lower light intensities (Ali 1962). A review of the literature covering juvenile salmon behavioral responses to ambient and artificial light also revealed species-specific behavioral differences. Species that occupy and defend stream territories, such as coho, tend to be quiescent at night, while species that disperse to estuaries, such as Chinook, pink, and chum, typically school, show nocturnal activity, and demonstrate an aversion to light (Godin 1982; Hoar 1951).

The teleost fishes, a classification that includes all HCP fish species with the exception of the lampreys and the sturgeon, depend on sight for feeding, prey capture, and schooling. For these fishes, sight is the primary sensory organ used for spatial orientation, prey capture, schooling, predator avoidance, and migration. By interfering with sight, modification of the underwater light environment may affect these fundamental activities. For example, the underwater light environment has been shown to determine the ability of fishes to see and capture their prey (Ali 1962, 1975; Fields 1966; Hoar et al. 1957; Johnson et al. 1998; McDonald 1960; Mork and Gulbrandsen 1994; Nightingale and Simenstad 2001a).

Juvenile and larval fish are primarily visual feeders, with starvation being the major cause of larval mortality in marine fish populations. Survival has been found to be linked to the ability to locate and capture prey and avoid predation (Britt 2001). This ability depends on sufficient light. Tribble (2000) found the swimming and feeding behavior of juvenile and larval sand lance to be reduced with low-light levels. Similar to other juvenile fishes with cone-based vision, the retinal cells of larval sand lance exhibit limited visual acuity in low-light environments. Their visual acuity increases with growth, with an eventual development of rod vision that provides them with vision in light-limited environments. Rods appear to develop at 0.94-in (24-mm) fork length, and full adult visual acuity develops at 1.38-in (35mm) fork length. This visual development prepares them for transition to deeper waters.

Tribble (2000) reports that the visual development of Pacific sand lance reflects the respective habitats they occupy given their size. At 1.97 in (50 mm) in length, they begin to move into deeper pelagic waters where the light environment changes, and their light requirements for prey capture change in response to the light wavelengths characteristic of that habitat. Many juvenile fishes using nearshore habitats, such as the Pacific sand lance (Tribble 2000), salmonids (Ali 1959), and lingcod (Britt 2001), share this sensitivity to ultraviolet (UV) wavelengths reflected in shallow nearshore marine habitats. Similar to salmonids, yellow perch and sand lance have been found to lose UV sensitivity with growth. Browman et al. (1993) reports this loss of UV sensitivities to be size-related rather than age-dependent and to likely correlate with the time that such fishes move from shallow to deeper water habitats and move from feeding on small crustaceans and other zooplankton to larger food items. As zooplankton reflect short wavelength light, such as UV, this provides an advantage for juvenile fishes with UV sensitivity feeding upon zooplankton in shallow nearshore waters. The ability of zooplankton to reflect UV is likely due to high concentrations of amino acids that protect them from the damaging effects of UV radiation.

7.2.4.2 Daytime Shading and Fish Behavior

The growth and survival of submerged aquatic plants (benthic and planktonic) are dependent on identified light levels, known as photosynthetically active radiation (PAR). Light levels falling below PAR are known to limit the photosynthesis for a suite of aquatic photosynthesizers, such as diatoms, epiphytes, eelgrass, and other autotrophs important to HCP species. For example, on average in Puget Sound, instantaneous mid-day PAR greater than approximately 150 µM/m^2/sec is required to maintain eelgrass growth. Instantaneous PAR of approximately 325 µM/m^2/sec is required to support maximum densities (Thom et al. 1998).

Light availability observed at multiple terminals in Puget Sound ranges from 0 to almost 9 PAR units under the Kingston terminal, with Port Townsend, Clinton, and Vashon terminals ranging from 0.5 to 1 PAR, and light availability varying significantly at different points under the terminal (Simenstad et al. 1999). Although these light data were recorded during the summer on clear days (when light levels were optimal), under-terminal light levels were found to affect fish behavior at some terminals (Simenstad et al. 1999). Similarly, based on a combination of light measurements, visual fish survey, and acoustic tagging and telemetry fish tracking undertaken over a 7-week period between April 20 and June 3, 2005, Southard et al. (2006) found under-terminal light levels at the Anacortes, Bainbridge, Clinton, Edmonds, Fauntleroy, Kingston, Mukilteo, Port Townsend, Southworth, and Vashon terminals to deter or delay juvenile salmon movement along the nearshore. This effect was found to be dependent upon nearshore morphology, tidal level, and terminal design features affecting light availability.

Behaviors important to the growth and survival of fishes, such as migration, schooling, and feeding, are known to be altered by changes in light availability. For example, abrupt transitions from light to dark can cause juvenile Chinook salmon to alter their migration pathway from the nearshore (shallow water) to deeper water or avoid an overwater structure altogether (Tabor et al. 2004.) Some salmonids commence or terminate these behaviors in response to specific light levels or thresholds. In a snorkel and beach seine survey of Seattle marine shorelines, Toft et al. (2004) reported that juvenile salmon avoided swimming beneath overwater structures, while other animals (such as crabs and sculpin) were found in these under-dock habitats. Large groups of juvenile salmonids were found in the vicinity of overwater structure sites; however, most juvenile salmonids were observed at the edge of the overwater structure or farther away, with only one school observed underneath a structure. Similarly, only one Pacific sand lance was observed under an overwater structure, with most being along the periphery or in the general vicinity of the overwater structures. In general, most fish were not observed underneath overwater structures. This study suggests that the under-pier environment, in particular shading effects, could affect the behavior and movement of salmon along the nearshore area (Toft et al. 2004; Simenstad et al. 1999; Able et al. 1998).

Shade cast by overwater structures in the freshwater environment can be used by some fish as cover and can increase predation on juvenile salmonids (Tabor et al. 1998). Indeed, in freshwater environments of western Washington, largemouth and smallmouth bass are common predators of juvenile salmonids, and several authors have documented the use of overwater structures by bass (Carrasquero 2001; Kahler et al. 2000). Interactions of smallmouth bass and juvenile salmonids depend on timing of salmonid outmigration, salmonid species, and residence of the juvenile salmonids (Carrasquero 2001).

In marine environments, shading also influences prey abundance and prey capture. In New York Harbor, Able et al. (1998) found juvenile fish abundance to be reduced under piers when compared to open water or areas with only piles but no overwater structure. This is likely due to both limitations in prey abundance and prey capture under structures. In a New York study of pier impacts on fish growth and prey resource abundance, Duffy-Anderson and Able (1999) compared growth rates of caged juvenile fish under municipal piers to those of fish caged at pier edges and in open water beyond piers. Those fishes caged under the piers showed periods of starvation, which could potentially make these individuals more vulnerable to predation, physiological stress, and disease. Along the pier edge, they found growth rate variability to be extremely high and likely related to light levels. They concluded that light availability is likely an important component of feeding success. They concluded that large piers do not appear to be suitable habitat for some species of juvenile fishes and that increased sunlight enhances growth.

The addition of floating piers is also known to affect nearshore ecology by shifting population structures to non-native species as a result of shading. In southern California, Reish (1961) observed a succession of attached organisms occurring on marina floats with an apparent climax community of the *Mytilus* mussel and *Ulva* algae after the floats were in the water for 6 months. In the presence of particular dinoflagellates such as *Gonyaulax catenella*, the ingestion of *Mytilus* can be extremely poisonous. In abundance, *Ulva* spp., an opportunistic green macroalgae, is known to reduce light and oxygen and create an anoxic environment (Hull 1987; Hernandez et al. 1997). Through shading, the algae *Ulva* is capable of triggering habitat shifts resulting in declines of eelgrass and concomitant increases in *Ulva* (Wilson and Atkinson 1995; Wilson 1993). The Puget Sound Expedition, a survey of nonindigenous species, sampled dock-fouling organisms on floats at 26 marinas throughout the entire Puget Sound region and identified 39 nonindigenous species (Cohen et al. 1998).

7.2.4.2.1 Direct and Indirect Effects

In response to daytime shading, fish potentially modify migration direction or behavior, resulting in increased energy expense. Shading can also reduce foraging success and increase potential exposure to predation. In addition, shading can modify species assemblages to a degree that available habitat is rendered unsuitable for native fish or invertebrate species. For invertebrates, shading can alter the suitability of habitat and reduce foraging opportunity as well as the availability of nutrients, resulting in decreased survival, growth, and fitness.

7.2.4.3 Nighttime Artificial Lighting

Artificial night-light-induced changes to ambient nighttime conditions appear to affect fish migration behavior and place some species at risk of increased predation (Prinslow et al. 1979;

Weitkamp and Campbell 1980; Weitkamp and Schadt 1982; Ratte and Salo 1985; Fields 1966; Johnson et al. 1998). Prinslow et al. (1979) reported changes to fish assemblages and predation rates during a study of the effects of high-intensity security lights on a naval base (Bangor) in Puget Sound’s Hood Canal. At that site, the level of intensity of artificial night lighting appeared to influence the behavior of fishes, with significantly greater light intensities (200–400 lux) attracting aggregations of juvenile chum and other small fishes. This aggradation suggested a potential to delay chum outmigration through the canal. Spiny dogfish, a Puget Sound shark, also appeared to be attracted to security lighting, likely due to the illumination of aggregating prey. Although herring and sand lance were not the subject of the study, Prinslow et al. (1979) reported potential exposure of herring and Pacific sand lance to predation due to the effects of the security lighting. Prinslow et al. (1979) suggested that based on study observations, the continuous use of high-intensity security lighting at the Bangor wharves could contribute to increased predation of HCP species.

Similarly, in a study of lighted and nonlighted areas along the Cedar River in the City of Renton, Washington, Tabor et al. (2001) found increased nighttime lighting intensities to have a profound effect on the behavior of salmon fry. Results indicated that increased levels of nighttime artificial light intensity, measured at lighted building and bridge sites, appeared to cause sockeye fry to delay migration and move to the low-velocity and lighted shoreline habitats, where they were found to be more vulnerable to increased predation. Even small increases in light intensity levels appeared to affect fry behavior. Tabor found nightly downstream migration of sockeye fry to be initiated after light intensity was less than 1 lux. However, with the addition of 32 lux, migration almost completely stopped. Given such changes to the habitat, Tabor et al. (1998) reported that a reduction in the intensity of artificial night lighting could benefit these sockeye salmon.

In a study comparing urban and rural nighttime light regimes for lake environments, Moore et al. (2006) found the relative intensity of illumination to increase along the suburban-to-urban gradient, under both clear and cloudy conditions, with the nighttime surface light intensity for urban lakes ranging from 7 to 48 times the light intensity for lakes in rural environments. An effect of the higher nighttime light intensities found in urban environments was the suppression of vertical migration of zooplankton in urban lakes (Moore et al. 2006). Nighttime light intensities have also been found to affect fish foraging, schooling, spawning, and vertical movement in the pelagic zone (Blaxter 1975; Gliwicz 1986; Robertson et al. 1988; Luecke and Wurtsbaugh 1993; Appenzeller and Legget 1995; Contor and Griffith 1995).

A number of studies have shown that fish respond quite differently to various lighting types, such as flickering strobe, mercury, or halogen light sources (Fields and Finger 1954; Hoar et al. 1957; Fields 1966; Prinslow et al. 1979; Puckett and Anderson 1987; Nemeth 1989; Johnson et al. 1998). In Washington State, fish responses to increased nighttime underwater light intensities have been found to pose potentially significant population effects including changes in light-mediated predation rates on fish, reduction in prey capture efficiency by increased fish avoidance behavior, and slowing of migratory behavior (Prinslow et al. 1979; Tabor et al. 1998, 2001). For example, in freshwater laboratory experiments, Tabor et al. (1998) found that prickly and torrent sculpin were capable of preying on sockeye fry in complete darkness, but predation rate declined with increasing light intensity. Tabor et al. (1998) speculated that an increase in predator avoidance ability by sockeye fry with increasing light intensity potentially explained this inverse relationship. Slowing of migratory behavior and subsequent increased sculpin predation rates on sockeye fry with increasing light intensity were also observed in simulated stream experiments (Tabor et al. 1998).

Studies examining the use of artificial light for guiding salmonids safely through migration barriers, such as hydroelectric dams, have found measurable differences in different species' responses to both the quantity and quality of the light stimulus. For example, Puckett and Anderson (1987) found juvenile salmon to be attracted to incandescent light when encountering a decrease in ambient light intensity. In the case of steelhead, Puckett and Anderson (1987) found the fish to initially avoid the mercury light and then to swim toward the light, likely following adaptation.

7.2.4.3.1 Direct and Indirect Effects

Nighttime lighting can result in altered migration behavior and timing (interruption or stalling as a result of attraction to light sources) as well as increased predation (as a result of aggregation). Subsequently, fish survival is reduced.

7.2.4.4 Decreased Light Penetration

7.2.4.4.1 Marine Environments

The basis for nearly all life in the sea is the photosynthetic activity of aquatic autotrophs such as algae, cyanobacteria, benthic microalgae, benthic macroalgae (kelps and seaweeds), and seed plants (such as seagrasses, mangroves, and salt-marsh plants) (Nybakken and Bertness 2005). These photosynthesizers rely on the availability of light for photosynthesis (Govindjee 1975). Plant growth, survival, and depth of water column penetration are directly related to light availability (Dennison 1987; Kenworthy and Haunert 1991).

The maximum depth of plant survival increases with increasing light penetration into the water column (Dennison et al. 1993). The level of light penetration is dependent upon water depth, water clarity (dissolved particulates reflect, refract, absorb, and scatter incident radiation), and light absorption by plant material in the water column.

Shade from overwater structures limits marine littoral vegetation, such as eelgrass. Many studies have focused on light limitation effects under ferry terminals in Washington State (Backman and Barilotti 1976; Bulthuis and Woelkerling 1983; Olson et al. 1997; Penttila and Doty 1990; Shafer 1999, 2002; Loflin 1995; Burdick and Short 1999; Fresh et al. 1995; Blanton et al. 2001; Thom et al. 1996, 1997; Thom and Shreffler 1996; Parametrix 1996; Visconty 1997; Shreffler and Moursund 1999; Blanton et al. 2001; Glasby 1999; Haas et al. 2002; Reish 1961; Simenstad et al. 1988). Some of these studies focused on prey resource availability for juvenile salmon at ferry and shipping terminals in Puget Sound and found that these structures negatively affect prey availability (Haas et al. 2002; Blanton et al. 2001). In a study comparing light levels under the Clinton, Bainbridge, and Southworth terminals, Blanton et al. (2001) found terminal orientation to the arc of the sun, terminal height and width, construction materials, and piling type to influence the shadow cast on the nearshore environment and its effect on the littoral vegetation. Similarly, in a study comparing the Clinton, Edmonds, and Port Townsend terminals, Thom and Shreffler (1996) found similar light limitation effects on littoral vegetation, and Haas et al. (2002) found effects of underwater light limitation under the Bainbridge, Clinton, and Southworth ferry terminals.

Marine littoral vegetation is important for the colonization of organisms that are important prey resources for HCP species, such as Newcomb's littorine snail, Pacific sand lance, Pacific herring, Pacific cod, northern abalone, surf smelt, steelhead and coastal cutthroat trout, salmon (pink, chum, coho, and Chinook), Olympia oyster, bull trout, Dolly Varden, rockfish, longfin smelt, eulachon; and walleye pollock (Chambers et al. 1999; Orth et al. 1984; Gardner 1981; NRS Canada 2004; Couch and Hassler 1989; Larsen et al. 1995; Goetz et al. 2004; Johnson et al. 1999; Norris 1991; Myers et al. 1998; Pauley et al. 1988; Busby et al. 1996; West 1997; Matthews 1987).

In studies on outmigrating juvenile chum in Hood Canal, Simenstad and Salo (1980) found juvenile chum fry (1.2–1.8 in [30–45 mm]) feeding extensively upon small, densely distributed harpacticoid copepods, selecting the largest copepods available. Similarly, Miller et al. (1976) reported that juvenile chum fed predominantly on epibenthic harpacticoid copepods. As the fish grew in size, their diet content was composed of larger epibenthos and pelagic crustaceans. Consistent with other studies, the highest densities of harpacticoid copepods occurred in magnitudes 4–5 times higher in eelgrass stands than in sand habitat without eelgrass.

Similarly, in a study of the Drayton Harbor marina, Thom et al. (1988) reported that during the study period from September 1987 to October 1988, juvenile salmon density was by far the highest on April 29 at the eelgrass habitat site that was also found to support, by far, the highest salmon prey density and the highest epibenthos density on that date. Total fish density increased dramatically immediately following a peak in maximum epibenthos and the most rapid increase in Zostera biomass (Thom et al. 1988). These epibenthic prey assemblages of copepods, such as the harpactioids, are known to feed on bacteria, epiphytes, plant detritus, and diatoms. It is consistently documented that vegetation assemblages associated with eelgrass, in particular, support increased magnitudes of juvenile salmonid epibenthic prey (Thom et al. 1988; Simenstad and Salo 1980; Simenstad et al. 1980, 1988; Cordell 1986).

The limitation of habitat for key prey resources likely affects migration patterns and the survival of many juvenile fish species. For smaller fish less than 1.97 in (50 mm) in length, residence times along particular shorelines are thought to be a function of prey abundance (Simenstad and Salo 1980).

<u>Direct and Indirect Effects</u>

Effects on fish associated with decreased light penetration include reduced foraging success and altered migration timing due to a reduction in primary productivity and associated reductions in prey species. Decreased light penetration and shading impacts on vegetation could also result in increased energy expense or potential exposure to predation resulting from loss of suitable habitat and cover. For invertebrates, alteration of the suitability of habitat could reduce foraging opportunity as well as the availability of nutrients, resulting in decreased survival, growth, and fitness.

7.2.4.4.2 Riverine/Lacustrine Environments

Based on lease authorization data, the Washington State Department of Natural Resources (WDNR) reported that: (1) of the total of 390 marinas in Washington State, 133 are in freshwater environments; (2) of the 59 total terminals and shipyards, 26 are in fresh water; and (3) of 44 leases for ferry terminals, five are in fresh water (WDNR 2005b). Although much of the available information on pier and dock impacts is from the study of marine environmental impacts, the effects of light limitation on aquatic vegetation and the importance of aquatic vegetation for prey and refugia to the HCP species are largely similar.

Aquatic primary producers, such as benthic algae, macrophytes, and phytoplankton, play key roles in the trophic support of stream ecosystems. In general, benthic algae occur in the form of microscopic unicellular algae, forming thin layers or assemblages called periphyton. Macrophytes include angiosperms rooted in the stream bottom, mosses, and other bryophytes. These include many forms such as rooted plants with aerial leaves, floating attached plants with submerged roots, floating unattached plants, and rooted submerged plants (Murphy 1998).

A small algal biomass in a stream can support a much larger biomass of consumers due to rapid turnover (Murphy 1998; McIntire 1973; Hershey and Lamberti 1992). Although aquatic primary production is sometimes underrated due to the small amount of algae and plants present in many streams, it is a basic energy source for freshwater ecosystems. Light is a controlling factor of primary production, with increased light and nutrients stimulating primary production and increasing the production of invertebrates and fish, or by lower light reducing overall productivity (Murphy 1998). Although aquatic plants and algae are adapted to low-light intensity, there is a critical light level at which respiration equals photosynthesis, known as the compensation point. Below the compensation point, such plants would eventually starve to death as they would respire food faster than they could produce it (Murphy 1998).

Productivity in fresh water is reduced commensurate with the degree that shade from marinas or terminals reduces the light level of the aquatic environment. This loss of aquatic vegetation in the freshwater system poses both direct and indirect effects on HCP species that depend on aquatic vegetation for any one of their life-history stages, such as green and white sturgeon, California floater and western ridged mussels, mountain sucker, lake chub, great Columbia River limpet, pygmy whitefish, leopard and Umatilla dace, Olympic mudminnow, bull trout, Dolly Varden, and Pacific salmon (Watters 1999; Frest and Johannes 1995; Mongillo and Hallock 1998; Hallock and Mongillo 1998, 1999; Hughes and Peden 1989).

The uptake of carbon, nitrogen, and phosphorous by these plants provides important nutrients to fish and invertebrate consumers. This aquatic primary production is the source of autochthonous organic matter and part of the source of allochthonous matter in each stream reach. Invertebrate grazing of these primary producers by snails, caddisflies, isopods, minnows, and other grazers is an important pathway of energy flow. For stream herbivores, for example, benthic diatoms are the most nutritious and easily assimilated food source (Lamberti et al. 1989). The availability of algae regulates the distribution, abundance, and growth of invertebrate scrapers (Hawkins and Sedell 1981; Gregory 1983), an important food source for fish. Juvenile salmonids, as drift-feeders, focus on food from autochthonous pathways. Invertebrate scrapers and collector-gatherers are known to be most frequently eaten by salmonids (Hawkins et al. 1982; Murphy and Meehan 1991; Bilby and Bisson 1992). Although terrestrial and adult aquatic insects are important (Bjorrn and Reiser 1991), juvenile salmon in streams have been found to be primarily supported by autochthonous organic matter (Bilby and Bisson 1992).

Freshwater macrophytes are also known to modify their physicochemical environment by slowing water flow, trapping sediments, and altering temperature and water chemistry profiles. Through the trapping of particles by plant fronds, they also change the nature of the surrounding sediments by increasing the organic content and capturing smaller grain size than substrate in uncolonized areas (Chambers et al. 1999).

Lakes can have similar shading impacts from marinas/terminals (Jennings et al. 2003; Garrison et al. 2005; White 1975). In a study on the influence of piers and bulkheads on the aquatic organisms in Lake Washington, White (1975) reported that light levels under piers were consistently lower, and this light reduction resulted in reduced phytoplankton production. In general, the larger the overwater structure, the larger the area of light limitation and reduction of phytoplankton production. Also, macrophytes were generally absent or sparse under piers. In the fall, grazing invertebrates were found outside of piers where macrophytes were abundant; in the spring, grazing invertebrates were found under piers where they could graze on periphyton during the spring (White 1975). Studies conducted at piers on lakes in Wisconsin also report the loss of submerged lake vegetation due to dock shading (Garrison et al. 2005; Jennings et al. 2003). This loss of vegetation from shade would pose an indirect effect on the HCP species that rely on the species supported by that vegetation, as well as a direct effect on those covered species that feed on that vegetation or the detritus it supplies.

The density of coho salmon fry in the summer has been found to be directly related to the abundance of algae. High density of fry can result from smaller feeding territories (Dill et al. 1981) due to increased invertebrate prey (Murphy 1981; Hawkins et al. 1982). Increases in vertebrate production have been found to occur primarily in the spring and early summer, coincident with the primary production cycle of benthic algae (Murphy 1998). Therefore, the reduction of light availability to the aquatic ecosystem due to shading from a large ferry/shipping terminal or marina could have an adverse effect on a local freshwater ecosystem and the HCP species that depend upon these ecosystems. In the case of coho salmon fry, the reduction in prey area (i.e., smaller feeding territories) poses a direct effect on the fitness, growth, and survival of the affected fry.

Direct and Indirect Effects

Effects on fish and invertebrates associated with decreased light penetration in freshwater environments are similar to those discussed previously for marine environments.

7.3 Water Quality Modifications

The construction of marinas or ferry/shipping terminals will have an impact on nearshore water quality both during the construction phase and during operation of the facilities. The primary water quality parameters that will potentially be affected include suspended sediment levels, benthic sediment contamination (including metals and hydrocarbon contamination), introduction of toxic substances, dissolved oxygen levels, pH levels, leaching of contaminants as a result of treated wood and stormwater, and nonpoint source pollution. All of these parameters are important factors in determining the suitability of marine and freshwater habitats for the HCP species.

The construction and operation of marinas and large transportation terminals are known to affect these water quality parameters and introduce contaminants through the use of treated wood products, vessel waste and ballast water discharges, vessel maintenance and operations-related oil and fuel spills, structural impacts on natural shoreline geomorphology and vegetation, and stormwater pollution sources. Michelsen et al. (1999) found that large vessels, such as ferries,have the capacity to resuspended and transport contaminants along the Seattle urban waterfront, which can increase the risk of exposure to various species. Cardwell et al. (1980) and Crecelius et al. (1989a, 1989b) have documented water quality characteristics in marinas in the Puget Sound region, and numerous studies have identified contaminant loadings and biological effects on fish and other organisms in Puget Sound waterways (Johnson at Landahl 1994, 1995; Johnson et al. 1993, 2007; Arkoosh et al. 1991, 1994, 1998, 2001, 2004; Varanasi et al. 1992, 1993; Williams et al. 1998; Whyte et al. 2000; Myers et al. 2003; Loge et al. 2005; Jones 1996; Sandhal et al. 2007; Stehr et al. 2000).

7.3.1 Increased Suspended Solids

There are many sources of suspended sediment associated with marinas and ferry terminals. Disturbance of sediment during construction or operation of ferry terminals and marinas or stormwater runoff from associated impervious surfaces can increase the amount of particulate matter suspended in the water column (Bash et al. 2001). Also, vessel prop wash in shallow areas has been identified as a mechanism for the resuspension and transport of contaminated sediments along urban waterfronts, such as Seattle (Michelsen et al. 1999). This increase in sediments is known to have direct and indirect effects on the growth or reproduction of at least one life-history stage of each of the 52 HCP species. This section addresses the impacts of elevated suspended sediment on both fish and invertebrate species.

Several of the studies cited in this section present information in turbidity level units in the place of suspended sediment concentrations to infer effects thresholds. Turbidity is commonly used as a surrogate for suspended sediment concentrations, but the relationship between these measures is site specific. Where available the equivalent suspended sediment concentration is provided, otherwise the turbidity value is provided. Because this complicates the interpretation of this information, a brief discussion of the relationship between turbidity and suspended sediment concentrations is provided here.

The International Standards Organization (ISO) defines turbidity as the "reduction of transparency of a liquid caused by the presence of undissolved matter" (Lawler 2005), as measured by turbidimetry or nephelometry. Turbidity can be caused by a wide range of suspended particles of varying origin and composition. These include inorganic materials like silt and clay, and organic materials such as tannins, algae, plankton, micro-organisms and other organic matter. The term suspended sediments refers to inorganic particulate materials in the water column. Suspended sediments can range in size from fine clay to boulders, but the term applies most commonly to suspended fines (i.e., sand size or finer material). Because suspended sediments are a component of turbidity, turbidity is commonly used as a surrogate measure for this parameter. However, the accuracy of the results is dependent on establishing a clear correlation between turbidity and suspended sediment concentrations to account for the influence of organic materials. This correlation is site specific, given the highly variable nature of organic and inorganic material likely to occur in a given setting.

Suspended solids in the water column are primarily measured by turbidity and total suspended solids (TSS). Turbidity measurements reflect the optical or refractory characteristics of the material suspended in the water. Turbidity is caused by a mixture of water molecules, dissolved substances, and suspended matter. The ability of a particle to scatter light depends on the size, shape, and relative refractive index of the particular particle and the light wavelength. Turbidity is not only a measure of the amount of sediments that may be suspended in the water but also the clarity of the water. This has a direct impact on biota because reduced clarity occludes photosynthetically active radiation (Govindjee 1975; Olson et al. 1996; Strickland 1958; Sheldon and Boylen 1977; Thom and Shreffler 1996; Luning 1981; Simenstad et al. 1999), as well as limits vision-based feeding opportunities for predators (Aksnes and Utne 1997). In all types of aquatic habitats, alterations to water clarity have been found to alter predator and prey assemblages and behavior (Williams and Ruckelshaus 1993; Bash et al. 2001).

Total suspended solids are a measure of the mass of solids (particles greater than 0.45 microns) for a given volume of water. Suspended solids consist of organic and inorganic particulates that can include bound or sorbed nutrients, metals, and organic chemicals. The size, concentration, and chemical composition of suspended sediments can affect biota through benthic smothering (Terrados et al. 1998), gill trauma (Au et al. 2004), and contamination with toxic substances (Malins et al. 1984).

Background turbidity in the Pacific Northwest differs across the various landscapes. Watershed background turbidity is dependent upon the geologic material and weathering processes, precipitation levels, and the geomorphology that determines the velocity of water transport for watersheds and basins across the Northwest (Bash et al. 2001, Welch et al. 1998). Many species have adapted to living in high suspended sediment conditions (Lake and Hinch 1999) and the impact of suspended sediment on fish physiology may be ameliorated by reduced predation pressure, as has been shown for emigrating Pacific salmon in the clear water Harrison and turbid Fraser Rivers of British Columbia (Gregory and Levings 1998). Consequently, rigorous sampling is required to determine the background turbidity of those waters associated with a given facility.

7.3.1.1 Direct and Indirect Effects on Fish

Elevated turbidity and suspended solids affect the suitability of spawning beds (Heywood and Walling 2007), prey resource availability (Mazur and Beauchamp 2003), and fish physiology (Berry et al. 2003). This section summarizes studies that have quantified the direct and indirect effects of elevated suspended solids and turbidity on fishes. It also addresses the degree of suspended sediment impacts associated with terminal and marina operation.

Newcombe and MacDonald (1991) identified the effects of suspended solids on salmonids as: (1) lethal effects that can cause overall population declines with long-term effects; (2) sublethal effects, such as tissue injury or physiologic alterations to an animal, with effects that may not lead to immediate death but may produce mortalities and population declines over time; and (3) behavior effects that alter animal behavior and have the potential of immediate death or population decline and mortality over time. Although these effects can be chronic and may not lead to immediate death, they may produce mortalities and population declines over time. Bash et al. (2001) group the effects of turbidity on salmonids as: (1) physiological effects that include gill trauma, osmoregulation, blood chemistry changes, and reproduction and growth effects; (2) behavioral effects that include avoidance, territoriality, foraging, predation, and homing/migration effects; and (3) habitat effects that include reduced spawning habitat due to increased deposition of suspended fines to stream beds, which are known to fill in interstitial spaces in stream bed gravels and lower the suitability of stream bed spawning and egg and larval rearing habitat, and effects on hyporheic upwelling that reduce the levels of dissolved oxygen in the gravels (Bash et al. 2001). These effects hold for all salmonid species and many others, such as sturgeon, pygmy whitefish, and dace species (Sigler 1990; Wildish and Power 1985; Salo et al. 1980; Nightingale and Simenstad 2001a; Bash et al. 2001; Pitt et al. 1995; Chapman 1988; Welch et al. 1998; Quinn and Peterson 1994; Williamson 1985; Hallock and Mongillo 1998; Wydoski and Whitney 2003).

7.3.1.1.1 Lethal Effects

Studies on salmonids exposed to volcanic ash attributed acute mortality in suspended sediment mixtures to reduced oxygen uptake (Newcomb and Flagg 1983; Noggle 1978). Fish must keep their gills clear for oxygen exchange. In the presence of high loads of suspended sediment, they engage a cough reflex to perform that function. Due to increased metabolic oxygen demand with increased temperatures and the need to keep pathways free of sediments for oxygen uptake, increased temperature and reduced oxygen levels combine to reduce the ability of fish to cough and maintain ventilation rates. Such cumulative stressors are thought to be likely contributors to mortality when exposure to high suspended sediment levels occurs for extended durations (Servizi and Martens 1991).

Although juveniles of many fish species thrive in rivers and estuaries with naturally high concentrations of suspended solids, studies have shown that suspended solids concentration as well as the duration of exposure can be important factors in assessing risks posed to salmonid populations (McLeay et al. 1987; Servizi and Martens 1987, 1992; Northcote and Larkin 1989; Newcombe and MacDonald 1991). Lake and Hinch (1999) found concentrations of suspended solids in excess of 40,000 ppm to elicit stress responses (e.g., decreased leukocrit, indicating reduced immunity response) in juvenile coho salmon, while McLeay et al. (1987) found 20 percent mortality of Arctic grayling at a concentration of 100,000 ppm. Concentrations of suspended solids of this magnitude would only be associated with terminals and marinas during the construction phase or during any subsequent dredging operations. However, other studies have shown lethal effects at much lower concentrations.

Servizi and Martens (1991) exposed juvenile coho salmon to natural Fraser River suspended sediments and found a 96-hour LC_{50} (i.e., the concentration at which a 50 percent population mortality was observed) of only 22,700 ppm. Using the identical apparatus and sediment source, juvenile sockeye salmon had a 96 hour LC_{50} of 17,600 ppm (Servizi and Martens 1987), and an LC_{50} of 31,000 ppm for juvenile Chinook salmon (Servizi and Gordon 1990).

7.3.1.1.2 Sublethal Effects

Studies on a variety of fishes, including sockeye and Chinook (Newcomb and Flagg 1983), coho, four-spine stickleback, cunner, and sheepshead minnow (Noggle 1978), attribute chronic and acute impacts from high suspended solids to reduced oxygen uptake, as described directly above. The stress induced by these conditions can lead to compromised immune defenses and reduced growth rates. Sigler et al. (1984) noted reduced growth rates in juvenile steelhead and coho salmon at concentrations as low as 100 ppm, while Servizi and Martens (1992) noted increased cough frequency in juvenile coho at concentrations of approximately 240 ppm.

7.3.1.1.3 Behavioral Effects

Sigler et al. (1984) reported that suspended sediments have been shown to affect fish behavior such as avoidance responses, territoriality, feeding, and homing. Similarly, Wildish and Power (1985) reported avoidance of suspended sediments by rainbow smelt and Atlantic herring to be at 20 ppm and 10 ppm, respectively. Berg and Northcote (1985) reported that short-term pulses of sediments trigger changes in social organization of coho salmon, with the return to lower turbidities allowing for the re-establishment of previous social organization. Turbidity may also trigger a predation cover response for salmonids. The studies of Gregory and Northcote (1993) demonstrate that at particular levels of increased turbidity, juvenile salmon actually increase their feeding rates, while at certain threshold levels (such as >200 ppm) they demonstrated pronounced behavioral changes in prey reaction and predator avoidance. In a study of dredging impacts in Hood Canal, Salo et al. (1980) found that juvenile chum also showed avoidance reactions to various levels of turbidity. These behavioral thresholds vary across species and life-history stages. Consistent with their early reliance on nearshore estuarine habitats, which have relatively high turbidity levels compared to pelagic or freshwater habitats, juvenile chum are classified as turbidity tolerant compared to other fishes.

It is not known what behavioral mechanisms are triggered when various fish species encounter patches of increased turbidity in their otherwise naturally turbid waters to which they are accustomed. Simenstad (1990) identifies the behavioral effects that would affect migrating fishes, such as reduced foraging success, increased risk of predation, and migration delay to be highly dependent upon the duration of exposure. The primary determinant of risk level is likely to lie in the spatial and temporal overlap between the area of elevated turbidity, the degree of turbidity elevation, the occurrence of fish, and the options available to the fish relative to carrying out the critical function of their present life-history stage.

To the extent that turbidity blocks light transmission, it poses the risk of diminishing prey resources and triggering behavioral changes of HCP species. If increased turbidity conditions are experienced in the shallow nearshore area, the impacts on fish would likely be to the juvenile life-history stage. The results of Britt (2001), Britt et al. (2001), Tribble (2000), and Ali (1975) indicate the importance of light transmission to the fitness and survival of larval and juvenile estuarine fish.

7.3.1.1.4 Habitat Effects

Increased turbidity is known to compromise the survivability of submerged aquatic vegetation (Parkhill and Gulliver 2002; Terrados et al. 1998) such as eelgrass (Erftemeijer and Lewis 2006) because it limits the amount of sunlight the plants receive. Eelgrass is associated with important rearing habitats for a suite of marine fishes, like Pacific cod, Pacific salmon, rockfish, Pacific herring, walleye pollock, and rockfish (Murphy et al. 2000; Simenstad et al. 1999; Nightingale and Simenstad 2001a; Gustafson et al. 2000). Increased turbidity can also bury the plants if sediment in suspension settles out (Mills and Fonseca 2003). In a study of the impact of sedimentation on seagrass in southeast Asia, Terrados et al. (1998) noted an approximate 50 percent decline in the number of seagrass species and a precipitous decline in seagrass biomass with a 15 percent increase in the clay content of the sediments.

Although there are many sources of suspended sediment associated with marinas and ferry terminals, sedimentation impacts on seagrass associated with marinas/terminals are likely to occur during dredging operations. The time period between dredging activities will determine the capacity for recolonization of the submerged aquatic vegetation (see Section 7.1.4, *Navigation/Maintenance Dredging).*

7.3.1.2 Direct and Indirect Effects on Invertebrates

As with fish, although there are many sources of suspended sediment associated with marinas/terminals, sedimentation impacts are most likely to occur during dredging operations. The extent of the operation as well as the time period between dredging activities will likely determine the degree of effects on invertebrate species.

Numerous studies have shown increased biomass of invertebrate (Cardoso et al. 2007; Seitz et al. 2005) and vertebrate species (Ferraro and Cole 2007; Pihl et al. 2006) in association with seagrass presence. Thus, sedimentation-related impacts on seagrass associated with marina/terminal operation would likely impact the HCP species.

High turbidity and the resulting excessive siltation in nearshore marine habitats are known to decrease the suitability of larval settling habitat for the northern or Pinto abalone (NMFS 2007a). High sediment loads are also known to decrease survival rates of the abalone by impeding respiration and feeding efficiency. High turbidity levels due to high nutrient loads are also known to have an effect on the Pinto abalone by creating dense filamentous algae blooms that these shellfish may not be able to consume and that may cover important food resources. Impacts on kelp beds, which are important rearing habitat for abalone, limit the growth and survival of these shellfish in the marine nearshore environment. To the degree that marinas/terminals affect bull kelp and giant kelp habitat, they also affect the growth and survival of these invertebrates (WDNR 2005a).

High sediment loads may decrease survival rates by impeding respiration and feeding efficiency. Suitable habitat for the freshwater bivalve California floater is characterized by low turbidity levels. Limiting factors identified by Larsen et al. (1995) include sediment, debris, siltation, or bedload movement that is known to smother or crush juvenile clams and cover and kill adults. Similarly, WDNR (2005a) reported that increased suspended solids and sediment loads may impede floater feeding and cause mortality through smothering (Watters 1999).

Estuarine habitat loss and pollution are considered the greatest threats Newcomb's littorine snail, which uses nearshore ecosystems and coastal waters. This snail uses the narrow strip of land supporting pickleweed. Changes to the marsh in the form of effluent and waste that stem from turbidity or lack of water clarity have been known to destroy habitat and nearly extirpate populations in California, Oregon, and Grays Harbor (Larsen et al. 1995). Destruction or modification of tidelands and tidal wetlands poses a significant impact on this species. The planktonic larvae of the nearshore marine Olympia oyster, found in lower intertidal areas at 1 to 2 ft elevation or in tidal channels, require a firm substrate, such as rock or shell. This species is particularly intolerant of siltation and grows best on firm substrates with substantial water flow (West 1997; Couch and Hassler 1990). Activities that produce discharges containing high levels of sulfites and toxins have been known to threaten these oyster populations. The freshwater western ridged mussels are filter feeders that require constant water flow. They typically reside in stable, nonshifting habitats and are absent from areas with continuous turbidity or high nutrient content. Like the California floater mussel, increased suspended solids and sedimentation impede their ability to feed and can smother them (Watters 1999).

7.3.2 Resuspension of Contaminated Sediments

Contaminated sediments are an issue with marinas/terminals when proposed construction occurs near contaminated sites. Dredging and vessel activity can contribute to the resuspension of benthic materials, thereby increasing the availability of contaminated sediments for biotic assimilation. Contaminated sediments are of particular concern due to the risk of contaminant transport and exposure posed to aquatic organisms through bioaccumulation and biomagnification in the marine food web. These risks can also be passed on to humans through the consumption of seafood.

Once contaminants are present in the system, processes that pose risks of contaminant transport include natural and anthropogenic aquatic disturbances such as storms, spills, bioturbation by animals, vessel prop wash, and dredging-related activities. When a stormwater plume eventually mixes and disperses along the seafloor, it results in the deposition of sediments with accumulations of stormwater inputs, including polycyclic aromatic hydrocarbons (PAHs), dichloro-diphenyl-trichloroethane (DDT), and polychlorinated biphenyls (PCBs). The potential result is an alteration to the seafloor biology. Those organisms residing within or upon the substrates that are less mobile, such as mollusks, may receive these accumulated stormwater inputs over long periods of time (Bay et al. 1999).

7.3.2.1 Direct and Indirect Effects

In general, marinas and ferry terminals are highly likely to introduce toxic substances directly (e.g., during construction and maintenance of the facilities) and indirectly (during vessel operations) into the aquatic environment. Hence, they can affect fish and invertebrate species.

Numerous studies have shown that fishes and invertebrates exposed to contaminants may bioaccumulate and concentrate trace pollutants to levels deemed harmful. This accumulation of contamination in biota occurs after contaminants are passed between two or more trophic levels. These chemicals can be found in contaminated sediment in industrial or highly urbanized areas. Studies in the Pacific Northwest by Stein et al. (1995) and Johnson et al. (2007) have indicated that PCB and PAH concentrations in juvenile Chinook salmon tissue are highest in industrial areas (e.g., Duwamish estuary, Columbia River).

Large vessels (i.e., more than 82 ft [25 m] in length) are allowed to use tributyltin bottom paint, which is highly toxic to aquatic organisms. Studies have shown that tributyltin can biomagnify through algae, invertebrate, and vertebrate species (Mamelona and Pelletier 2003).

The direct and indirect effects on fish and invertebrates associated with toxic substances are similar to those identified in the following sections: *Use of Creosote-treated Wood Products* (Section 7.3.3); *Use of ACZA and CCA Type C Treated Wood* (Section 7.3.4); and *Introduction of Toxic Substances* (Section 7.3.5).

7.3.3 Use of Creosote-treated Wood Products

Creosote and other wood preservative products used on dock structures pose additional water quality and sediment contamination risks associated with contaminant leaching. Creosote can also directly affect fish and invertebrates species that are associated with treated-wood piles in both marine and freshwater environments. For example, Pacific herring can spawn on creosote-treated wood piles, thereby becoming exposed to a number of chemical pollutants contained in creosote (Vines et al. 2000). The current state of knowledge on the biological effects of creosote-treated routes of exposure is summarized in several major literature reviews: Meador et al. (1995) addressed the bioaccumulation of PAHs in marine fishes and invertebrates; Poston (2001) reviewed treated wood impacts on aquatic environments; and two Stratus documents (Stratus 2005a, 2005b) summarized what is known about the impacts of creosote (as well as chromated copper arsenate [CCA] and ammoniacal copper zinc arsenate [ACZA]-treated wood products, as addressed below in Section 7.3.4, *Use of ACZA and CCA Type C Treated Wood*). The major routes of exposure for aquatic animals were found to be through the uptake of waterborne chemicals, including interstitial water of sediments (IWS) and through trophic transfer; while the direct uptake of sediment-bound chemicals appears to be negligible (Meador et al. 1995). This section addresses the impacts associated with the use of creosote.

Creosote, a distillate of coal tar, can include PAHs, alkyl-PAHs, tar acids, phinolics, tarbases, N-heterocyclics (quiolines and carbazoles), S-heterocyclics (thiophenes), O-heterocyclics/furans (dibenzofuran), and aromatic amines (such as aniline). However, 85–90 percent of the mass of creosote is from PAHs. Stratus (2005a) evaluated results from laboratory tests on the leaching of PAHs from creosote-treated pilings. Leaching rates in fresh water and salt water both increased with higher water temperatures. In a study of aging effects on leaching (Ingram 1982), it was found that treated wood installed for 12 years in sea water appeared to have reduced leaching rates by more than 25 percent. Kang et al. (2003) determined leach rates in fresh water for two flow rates (0.47 and 1.3 in/sec [1.2 cm/sec and 3.3 cm/sec]). The 1.3 in/sec (3.3 cm/sec) flow rate was associated with double the leaching of the 0.47 in/sec (1.2 cm/sec) flow rate. Xiao et al. (2002) found the greatest leaching rates to occur in warm, turbulent water. Poston (2001) reviewed 20 years of research on creosote-treated wood and found that the greatest risks to water quality from creosote-treated wood were in the leaching of trace metals and PAHs over time, with lighter-weight PAHs degrading rapidly and higher-weight PAHs contributing to chronic contamination, particularly to surrounding sediments. The majority of leaching takes place within a few months of immersion (Poston 2001). Special care must also be taken when removing creosote-treated material to avoid pulsed release of contaminants to the environment (Poston 2001; WDNR 2005d).

7.3.3.1.1 Direct and Indirect Effects

The greatest impacts of creosote-treated wood are on benthic and burrowing organisms near the treated wood structures. Areas of lower pH and reduced water circulation are at greater risk of contamination. Metals from creosote-treated wood generally become incorporated into the local sediments and are usually undetectable in ambient waters. Table 7-2 lists the probable effects threshold concentrations for freshwater sediment.

Poston (2001) concluded that riverine salmon spawning substrates do not typically accumulate PAHs or metals but that salmonids are potentially at some risk of exposure from consumption of contaminated prey. For example, diffusible creosote-derived compounds from weathered creosote-treated pilings have been shown to affect the embryonic development in Pacific herring, a salmon prey (Vines et al. 2000). If adult salmon feed on herring that have been exposed to creosote-derived compounds, it is feasible that these components could then affect salmon through such food web interaction.

Table 7-2. Probable effects concentrations for freshwater sediment.

Name	Definition	Concentration (ppm [mg/kg] dry wt)					Reference
		Basis	As	Cr	Cu	Zn	
Lowest effects level	Level that can be tolerated by the majority of benthic organisms	Field data on benthic communities	6	26	16	120	Persaud et al. 1991
Biological threshold effects level	Concentration that is rarely associated with adverse biological effects	Compiled results of modeling, laboratory, and field studies on aquatic invertebrates and fish	5.9	37.3	35.7	123	Smith et al. 1996
Minimal effects threshold	Concentration at which minimal effects are observed on benthic organisms	Field data on benthic communities	7	55	28	150	Environment Canada 1992
Effects range–low	Concentration below which adverse effects would rarely be observed	Field data on benthic communities and spiked laboratory toxicity test data	33	80	70	120	Long and Morgan 1991
Survival and growth threshold effects level	Concentration below which adverse effects on survival or growth are expected to occur only rarely	Laboratory toxicity tests on the amphipod *Hyalella azteca* using field-collected sediment	11	36	28	98	Ingersoll et al. 1996; USEPA 1996
Consensus threshold effects concentration	Concentration below which adverse effects are expected to occur only rarely	Geometric mean of above published effect concentrations	9.79	43.4	31.6	121	MacDonald et al. 2000

Sources: Jones & Stokes 2006 and Stratus 2005b.
As = arsenic; Cr = chromium; Cu = copper; Zn = zinc.

7.3.4 Use of ACZA and CCA Type C Treated Wood

CCA treatment contains chromium, copper, and arsenic acid. These water-soluble treatments are used to protect wood from wood-boring organisms and fungi. Stratus (2005b) reviewed and evaluated models developed to predict the leaching rate of metals from treated wood. The Stratus (2005b) review concluded that the chemical processes associated with the chemical fixing process are complex and poorly understood (Lebow and Tippie 2001). Stratus (2005b) found the most important factors affecting the leaching rates of metals from treated wood to be: (1) the metal being considered (Cu, Cr, As, or Zn); (2) post-treatment procedures used to fix the treatment chemical and remove excess treatment solution; (3) duration of post-treatment exposure to water; (4) loading or retention of treatment solution in the wood; (5) ambient water quality conditions (including salinity, pH, and temperature); (6) current speed; and (7) physical features of the wood surface (including surface area-to-volume ratio). Lebow and Tippie (2001) found that water-repellent stain, latex paint, or oil-based paint greatly reduced arsenic, chromium, and copper leaching rates. Stratus (2005b) compared the applicability of laboratory studies to field conditions and concluded that much higher leaching rates are likely to occur in the field than that observed in the laboratory. The majority of leaching takes place within a few months of initial immersion. WDNR guidance provides specific measures to avoid the pulsed release of contaminants from treated materials during their removal from the environment (WDNR 2005d).

Metals from treated wood can contaminate sediment and affect benthic communities. A study by Brooks (2004) on the Olympic Peninsula found insignificant increases in arsenic, copper, and zinc in sediments and water at three out of four pier sampling sites, as well as minimal uptake by shellfish. Weis et al. (1993) found that oysters growing on CCA-treated wood pilings had higher metals concentrations and a greater incidence of histopathological lesions compared to oysters collected from nearby rocks. In a subsequent study, Weis and Weis (1996) fed snails algae that were grown on CCA-treated docks, and the snails in turn suffered mortality. Finally, Weis and Weis (1994) found significantly lower biomass and diversity of sessile epifaunal communities on treated wood panels compared to untreated panels. Studies such as these indicate that the primary trophic pathway for contaminants from treated wood is through invertebrates and algae either growing on or attached to treated wood.

The U.S. Environmental Protection Agency (USEPA) has established aquatic life criteria (ALC) (i.e., concentration criteria) for the constituent metals that may leach from ACZA – or CCA Type C – treated wood (USEPA 2002, in Stratus 2005b). The ALC have been established for criterion maximum concentrations (CMCs) for acute exposure and criterion chronic concentrations (CCCs) for chronic exposure for both salt water and fresh water (refer to Table 7-3). In both fresh and salt water, invertebrates are the species most sensitive to copper, chromium VI, zinc, and arsenic (Stratus 2005b). These ALC appear to be appropriate for acute lethal impacts of copper and chromium VI (Stratus 2005b), but avoidance responses and olfactory neurotoxicity may occur in salmonids at sublethal copper concentrations, even with brief exposure (Hansen et al. 1999, Baldwin et al. 2003, Sandahl et al. 2004, all in Stratus 2005b); in addition, there may be a risk of bioaccumulated toxicity in salmonid prey species at the chronic chromium VI criterion (Stratus 2005b).

There does not appear to be a pattern of sensitivity among species with respect to chromium III, but the ALC (established only for fresh water) appear to be protective of fish, particularly salmonids (Stratus 2005b). If chromium III toxicity is related to salinity (similar to chromium VI and copper), then the application of the freshwater criteria to salt water would include a margin of safety. The ALC for zinc are water hardness-dependent and do not appear to be protective of salmonids in fresh water of low hardness (30 ppm) (Hansen et al. 2002, in Stratus 2005b); however, the ALC for zinc in salt water are likely protective of salmonids (Stratus 2005b).

Avoidance behavior has also been observed among salmonids at zinc concentrations below or slightly above the ALC (Sprague 1964, Sprague 1968, Black and Birge 1980, all in Stratus 2005b). The ALC for arsenic are likely to be protective of salmonids (Stratus 2005b). Overall, the ALC are suitable for assessing the impacts of ACZA and CCA Type C−treated wood on water quality and the potential risk to HCP species (Stratus 2005b).

Table 7-3 Water quality criteria for the protection of aquatic life ("aquatic life criteria") for water soluble chemicals used in treating wood.

Chemical	Freshwater CMC (ppb)	Freshwater CCC (ppb)	Saltwater CMC (ppb)	Saltwater CCC (ppb)
Arsenic	340	150	69	36
Copper[e]	7.0[a]	5.0[a]	4.8	3.1
Copper (2003)	BLM[b]	BLM[b]	3.1	1.9
Chromium III	323	42	None (850)[c]	None (88)[d]
Chromium VI	16	11	1,100	50
Zinc	65[a]	65[a]	90	81

[a] Criteria are hardness-dependent. Criteria values calculated using site-specific hardness based on the equations presented in USEPA (2002). Hardness-dependent criteria values are presented for a hardness of 50 ppm (as CaCO3).
[b] Criteria developed using site-specific chemistry and the Biotic Ligand Model (BLM).
[c] No saltwater CMC. As a proxy, the lowest reported LC50 from the USEPA database is reported (Lussier et al. 1985) divided by a factor of two.
[d] No saltwater CCC. As a proxy, the lowest reported chronic value from the USEPA database is reported (Lussier et al. 1985) divided by a factor of two.
[e] From USEPA 2002.
From draft ALC guidance on copper provided by USEPA in 2003 that relies on the BLM for calculating freshwater criteria based on site-specific water chemistry.
Notes: CMC = criterion maximum concentration; CCC = criterion chronic concentration; ppb = parts per billion (i.e., micrograms per liter).
Source: Sources: Jones & Stokes 2006 and Stratus 2005b.

7.3.4.1.1 Direct and Indirect Effects

Metals from treated wood can contaminate sediment and affect benthic communities, limiting food resources for fish and exposing fish to metals contamination through the consumption of contaminated prey (Stratus 2005b). Treated wood is used extensively in marinas and ferry terminals. Ferry terminals in particular are associated with numerous and large treated pilings. The research indicates that invertebrates (in particular burrowing and attached organisms) are significantly affected by the contaminants associated with treated wood. Additionally, the trophic transfer of metals and hydrocarbons may adversely affect other fishes.

7.3.5 Introduction of Toxic Substances

Additional potential sources of toxic contaminants in marina and ferry terminal facilities include hydrocarbons from leaking engines and spills and vessel maintenance and operational discharges, as described in Section 7.2.2 (*Vessel Maintenance and Operational Discharges*). Petroleum-based contaminants, such as fuel, oil, and some hydraulic fluids, contain PAHs, which could be acutely toxic to salmonids at high levels of exposure and could also cause chronic lethal and sublethal effects on aquatic organisms (Hatch and Burton 1999). Misitano et al. (1994) exposed larval surf smelt to Puget Sound (Eagle Harbor) sediments with high concentrations of PAHs and found 100 percent mortality after 96 hours of exposure. After diluting the sediments and repeating the experiments, they found that the larvae that did not expire within 96 hours suffered from decreased growth rates.

Table 7-4 depicts effects thresholds for PAHs in surface water for Pacific herring, zooplankton, mysids and marine amphipods, and trout.

Table 7-4. Effects thresholds for PAHs in surface water.

Organism	Exposure Source	Toxicity	Concentration (ppb)	Citation
Mysid (*Mysidopsis bahia*)	Elizabeth River, Virginia, sediment extracts	24-hr lethal concentration of a chemical within a medium that kills 50% of sample population	180	Padma et al. 1999
Amphipod (*Rhepoxynius abronius*)	Eagle Harbor, WA sediment extracts	96-hour 24-hr lethal concentration of a chemical within a medium that kills 50% of sample population	1,800	Swartz 1989
Pacific herring	PAHs leaching from 40-year old pilings	24-hr lethal concentration of a chemical within a medium that kills 50% of sample population	50	Vines et al. 2000
Zooplankton	PAHs leaching from pilings placed in microcosms	No observable effects concentration	11.1	Sibley et al. 2004
Zooplankton	Commercial creosote added to microcosms	No observable effects concentration	3.7	Sibley et al. 2001
Pacific herring	PAHs leaching from 40-year old pilings	Significant reduction in hatching success and increased abnormalities in surviving larvae	3	Vines et al. 2000
Zooplankton	Commercial creosote added to microcosms	Concentration of a chemical within a medium that kills 50% of sample population	2.9	Sibley et al. 2001
Trout	Commercial creosote added to microcosms	Lowest observable effects concentration for immune effects	0.6	Karrow et al. 1999

Sources: Jones & Stokes 2006 and Stratus 2005a.
ppb = parts per billion.

7.3.5.1 Direct and Indirect Effects

The direct and indirect effects on fish and invertebrates associated with toxic substances are similar to those identified in Section 7.3.2 (*Resuspension of Contaminated Sediments*). In general, marinas and ferry terminals are highly likely to introduce toxic substances directly (e.g., during construction and maintenance of the facilities) and indirectly (during vessel operations) into the aquatic environment. Potential toxic substances include PAHs and PCBs from resuspension and contaminated sediments (Bay et al. 1999); tributyltin from vessel painting activities (Mamelona and Pelletier 2003); and creosote-derived contaminants from treated wood (e.g., Poston 2001 and WDNR 2005d). Fish and invertebrate species exposed to toxic substances may exhibit an increased incidence of developmental abnormalities, decreased survival, behavioral changes such as avoidance or stress resulting in reduced growth or fitness or delayed migration, bioaccumulation of toxins in tissue, and increased disease incidence.

7.3.6 Altered Dissolved Oxygen Levels

Dissolved oxygen (DO) content is critical to the growth and survival of the 52 HCP species. The amount of oxygen dissolved in natural waters is dependent upon temperature, physical mixing, respiration, photosynthesis, and—to a lesser degree—atmospheric pressure. These parameters can vary diurnally and seasonally and depend on activities such as daytime photosynthesis oxygen inputs and nighttime plant respiration processes that deplete dissolved oxygen levels. Dissolved oxygen concentration is temperature dependent; as temperatures rise, the gas-absorbing capacity of the water decreases, and the dissolved oxygen saturation level decreases. Reduced dissolved oxygen levels can be due to increased temperature, organic or nutrient loading, increased benthic sedimentation (Welch et al. 1998), or chemical weathering of iron and other minerals.

Marinas/terminals, through the discharge of wastes or disturbance to bottom sediments from large or multiple vessels, can increase carbon, nutrient, and sediment loading in their zone of influence, thereby affecting local dissolved oxygen levels. It has also been hypothesized that resuspension of large quantities of anoxic sediments, as can occur with dredging operations associated with ferry terminals and marinas, may reduce dissolved oxygen levels in surrounding water as a result of oxidation reactions (Nightingale and Simenstad 2001a).

The construction and existence of marinas/terminals affect nearshore primary production through shoreline hardening, construction disturbance, and shading. These impacts, previously addressed in Sections 7.1 (*Construction and Maintenance Activities*) and 7.2 (*Facility Operation and Vessel Activities*) will result in reduced primary production beneath docks and correspondingly lower dissolved oxygen levels. Depressed dissolved oxygen from reduced primary production combined with potential carbon loading from vessel and nearshore waste sources can lead to low benthic dissolved oxygen levels (McAllister et al. 1996).

7.3.6.1 Direct and Indirect Effects on Fish

Juvenile salmon are highly sensitive to reductions in dissolved oxygen concentrations (USFWS 1986) and consequently are among the more vulnerable HCP species with regard to dissolved oxygen impairment. Salmon generally require dissolved oxygen levels of greater than 6 ppm for optimal survival and growth, with lethal 1-day minimum concentrations of around 3.9 ppm (Ecology 2002). Different organisms at different lifestages require different levels of dissolved oxygen to thrive. Table 7-5 lists the minimum recommended dissolved oxygen concentrations for salmonids and stream-dwelling macroinvertebrates. The dissolved oxygen thresholds presented in this table were derived from more than 100 studies representing over 40 years of research.

It should be noted that in Table 7-5, recommendations exist for dissolved oxygen thresholds in categories other than lethality. Fish are mobile organisms and, where possible, will avoid dissolved oxygen levels that would cause direct mortality. However, this avoidance behavior in and of itself can affect fitness or viability. Stanley and Wilson (2004) found that fish aggregate above the seasonal hypoxic benthic habitat in the Gulf of Mexico, while Eby et al. (2005) found that fish in the Neuse River Estuary, North Carolina, were restricted by hypoxic zones to shallow, oxygenated areas, where in the early part of the summer about 1/3 fewer prey resources were available. Studies such as these reveal how dissolved oxygen can change fish distributions relative to habitat and potentially exclude fishes from reaching foraging and rearing areas. Sublethal dissolved oxygen levels can also increase the susceptibility to infection (Welker et al. 2007) and reduce swim speeds (Ecology 2002).

Table 7-5. Summary of recommended dissolved oxygen levels for full protection (approximately less than 1 percent lethality, 5 percent reduction in growth, and 7 percent reduction in swim speed) of salmonid species and associated macroinvertebrates.

Life-history Stage or Activity	Oxygen Concentration (ppm)	Intended Application Conditions
Incubation through emergence	≥9.0–11.5 *(30 to 90-DADMin)* and No measurable change when waters are above 52°F (11°C) (weekly average) during incubation.	Applies throughout the period from spawning through emergence Assumes 1-3 ppm will be lost between the water column and the incubating eggs
Growth of juvenile fish	≥8.0–8.5 *(30-DADMin)* and ≥5.0-6.0 *(1-DMin)*	In areas and at times where incubation is not occurring
Swimming performance	≥8.0-9.0 *(1-DMin)*	Year-round in all salmonid waters
Avoidance	≥5.0-6.0 *(1-DMin)*	Year-round in all salmonid waters
Acute lethality	≥3.9 *(1-DMin)* ≥4.6 *(7 to 30-DADMin)*	Year-round in all salmonid waters
Macroinvertebrates *(stream insects)*	≥8.5-9.0 *(1-DMin or 1-DAve)*	Mountainous headwater streams
	≥7.5-8.0 *(1-DMin or 1-DAve)*	Mid-elevation spawning streams
	≥5.5-6.0 *(1-DMin or 1-DAve)*	Low-elevation streams, lakes, and nonsalmonid waters
Synergistic effect protection	≥8.5 *(1-DAve)*	Year-round in all salmonid waters to minimize synergistic effect with toxic substances

Source: Ecology 2002.
1-DMin = annual lowest single daily minimum oxygen concentration.
1-DAve = annual lowest single daily average concentration.
7-, 30-, 90-DADMin = lowest 7-, 30- or 90-day average of daily minimum concentrations during incubation period, respectively.

In freshwater environments, eggs can become oxygen-starved through the deposition of suspended fines on spawning gravels. Fine sediment fills interstitial spaces in stream bed gravels and lowers oxygen exchange through the hyporheos. This process could potentially impact many of the HCP species, such as Pacific salmon, sturgeon, pygmy whitefish, and dace species (Sigler 1988; Wildish and Power 1985; Nightingale and Simenstad 2001a; Bash et al. 2001; Chapman 1988; Welch and Lindell 1992; Quinn and Peterson 1994; Williamson 1985; Pitt et al. 1995; Hallock and Mongillo 1998; Wydoski and Whitney 2003).

7.3.6.2 Direct and Indirect Effects on Invertebrates

The effects of low oxygen concentrations on invertebrates have been documented in both fresh water and marine environments. Little consensus exists concerning low dissolved oxygen criteria for macroinvertebrates, and tolerances to hypoxic conditions are taxonomically specific. Many invertebrates are adapted to live in benthic low-energy environments where dissolved oxygen concentrations are naturally low; consequently, these organisms can withstand hypoxic conditions. Other taxa, including Hirudinea, Decapoda, and many aquatic insects, tolerate dissolved oxygen levels below 1.0 ppm (Hart and Fuller 1974; Nebeker et al. 1992). Kaller and Kelso (2007) found benthic macroinvertebrate density, including mollusks, to be greatest in low dissolved oxygen areas of a Louisiana wetland, while a literature review by Gray et al. (2002) found that in marine environments, invertebrates were not affected by low dissolved oxygen until concentrations fell below 1–2 ppm. Benthic dissolved oxygen levels can seasonally drop below this threshold in productive systems that receive high biochemical oxygen demand (BOD) loadings. For instance, depressed benthic dissolved oxygen levels in Hood Canal, Washington, have been associated with spot shrimp decline (Peterson and Amiotte 2006). This reduction in dissolved oxygen levels in turn has been linked to biochemical oxygen demand loading from leaking or improperly sited septic tanks. This same process of decreased benthic dissolved oxygen associated with high biochemical oxygen demand loading in poorly flushed areas could potentially take place in and around marinas and ferry terminals. Marinas in particular are characterized by breakwaters that reduce circulation, as well as potentially high biochemical oxygen demand loading from vessel and watershed waste sources. Consequently, the conditions for depressed benthic dissolved oxygen exist in marinas/terminal areas and have been documented (McAllister et al. 1996).

7.3.7 Altered pH Levels

The pH of fresh and salt water normally ranges from 6.5–8.5 (Schlesinger 1997). The construction of docks or other structures using concrete can affect the pH of surrounding waters if the uncured concrete is allowed to contact the receiving water body. Uncured concrete can dissolve in water and, depending on temperatures, can raise the pH level to as high as 12, which is far outside the livable range for all of the HCP species (Ecology 1999). This impact will be greatest during construction when concrete wash-off and slurries come into contact with water (Dooley et al. 1999); however, once construction is complete, concrete may still affect the surrounding environment. Curing concrete surfaces can exhibit pH values as high as 13 during the 3 to 6 months it takes for concrete to cure underwater (Dooley et al. 1999). This elevated pH prevents attached macroalgae growth during this period.

Altered pH from curing concrete will increase pH to levels that can affect fish, invertebrates, and their food. But this effect is localized and, as stated above, should last no more than 6 months. Consequently, it is estimated that this impact mechanism will be most significant for large projects in areas with poor water circulation.

7.3.7.1 Direct and Indirect Effects

Fish have adapted to the ambient pH levels of their particular habitat, and they tend to have narrow ranges of pH tolerance. The effects of high pH levels that are outside of their tolerance range can include death; damage to gills, eyes, and skin; and an inability to excrete metabolic wastes (DFO 2007). Elevated pH has been shown to increase ammonia toxicity in fish because the organisms have difficulty excreting ammonia waste through their gills when ambient conditions are characterized by elevated ammonia and pH. It has been shown that at ambient ammonia concentrations of 5.0 ppm, mortality of tambaqui (also known as pacu), a neotropical fish, increased from 0 to 15 to 100 percent at a pH of 7, 8, and 9, respectively (de Croux et al. 2004). Consequently, if ammonia concentrations are elevated due to waste dumping from recreational vessels or from upland sources, the toxicity may be compounded by elevated pH from construction activities.

pH alone can affect fish exposed to alkaline conditions. In a rainbow trout toxicity study, a pH above 8.4 caused an increase in glucose and cortisol levels, and a pH above 9.3 caused mortality (Wagner et al. 1997). Elevated pH can also affect invertebrates. In a study of the freshwater Malaysian prawn, Cheng and Chen (2000) noted a 38 percent decrease in haemocyte (invertebrate blood cells) count when pH dropped below 5.0 or rose above 9.0. This is an indication of invertebrate stress at pH levels outside the normal range of 6.5–8.5, which likely also applies to many HCP species.

Alterations in pH can also affect invertebrates. The majority of research on the effect of pH on invertebrates is related to the impact of acidification on abundance and diversity; consequently, there is little research on the impact of elevated pH on invertebrates. In a study of the freshwater Malaysian prawn, Cheng and Chen (2000) noted a 38 percent decrease in haemocyte (invertebrate blood cell) count when pH dropped below 5 or rose above 9. In another study, Bowman and Bailey (1998) found that zebra mussels have an upper pH tolerance limit of 9.3 through 9.6. From these studies, it can be assumed that pH levels that exceed a pH of between 9 and 10 will have a negative impact on invertebrate HCP species. As indicated above, pH levels on and around curing concrete can exceed this pH threshold and thus there is the potential for impact on local invertebrate communities.

7.3.8 Increased Stormwater and Nonpoint Source Pollution

Sources of stormwater pollutants have been reviewed and summarized in numerous reports (Barber et al. 2006; Barrett et al. 1995; Yonge et al. 2002; Young et al. 1996). Sources of stormwater pollution can be classified into three general categories: atmospheric deposition, vehicles (including fuels and exhaust emissions), and direct and indirect deposition and application (Table 7-6).

Atmospheric deposition refers to substances that are deposited on land surfaces from the air. This deposition can be transported to receiving water bodies via stormwater runoff from marina/terminal facilities. The atmospheric deposition can contain pollutants such as nutrients, particulates, PAHs, PCBs, and heavy metals. Metals are emitted from near and distant industrial sources. Incomplete combustion of fossil fuels contributes nutrients and PAHs in deposition materials. PCBs primarily originate from historic usage of these compounds in industrial applications. Most pollutants associated with automobiles originate from engine wear and exhaust, lubricants, rusting, and tire wear. Brake pad wear is a source of copper and zinc, which are the metals most commonly found in highway runoff; tires contain zinc; some older brakes contain lead; and wheel-balance weights are made primarily of lead. The direct and indirect deposition and application category includes maintenance activities in the vicinity of marinas/terminals (e.g., the application of fertilizers, herbicides, and pesticides), roadway/parking lot maintenance (e.g., deicing and road repairs), and animal wastes.

Table 7-6. General source categories of roadway pollutants.

Source Category	Pollutants
Atmospheric deposition	Particulates, nitrogen, phosphorus, metals, PAHs, and PCBs
Vehicles	Particulates, rubber, asbestos, metals, sulfates, bromide, petroleum, and PAHs
Direct and indirect deposition and application	Particulates, nitrogen, phosphorus, metals, sodium, chloride, sulfates, petroleum, pesticides, and pathogens

PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls.

Some of these contaminants (particularly those originated from vehicles) may collect on those impervious surfaces associated with marinas and ferry terminals and be routed to nearshore environments with relatively little physical and/or biological treatment. Increased runoff and loadings of the pollutants noted above will degrade sediment and ambient water quality in the immediate vicinity of the facility and affect the aquatic food web. Food web impacts associated with stormwater are similar to those addressed above for vessel maintenance and operational discharges and include increased suspended solids, resuspension of contaminated sediments, and the introduction of toxic substances.

7.3.8.1.1 Direct and Indirect Effects

Impacts on fish and invertebrates resulting from exposure to stormwater and other nonpoint source pollution include all of the impacts associated with altered pH levels, reduced dissolved oxygen levels, contaminant exposure, and increased suspended solids. In general, it is likely that stormwater/nonpoint pollutants originated from marinas/terminals can affect the surrounding aquatic environment and thereby HCP species. The magnitude of the effects would depend on the area associated with the impervious surfaces. Each of these topics is discussed in detail in its respective subsection within Section 7.3 (*Water Quality Modifications*).

7.4 Riparian Vegetation Modifications

Riparian zones are the upland areas adjacent to water bodies that form the transition zones between terrestrial and aquatic systems; riparian zones are an important component of freshwater, estuarine, and marine systems. Removal or disturbance of riparian vegetation during construction or other activities permitted under HPAs is an impact mechanism that may expose the HCP species to stressors. Submechanisms of impact associated with riparian vegetation removal include altered riparian shading, ambient air temperature regime, shoreline and bluff stability, allochthonous inputs, habitat complexity, and groundwater-surface water interaction or freshwater inputs. These potential impact mechanisms and related ecological stressors are discussed below for marine and freshwater environments.

7.4.1 Marine Environments

7.4.1.1 Altered Riparian Shading/Altered Ambient Air Temperature Regime

In marine environments, riparian vegetation does not have a significant influence on overall water temperature. The influence of shade on water quality parameters such as temperature is not well established. In general, seasonal air temperature conditions, winds, currents, stratification, and tidal exchange will play more dominant roles in determining marine water temperatures (Brennan and Culverwell 2004).

Shade may strongly influence temperatures in discrete areas or habitat types under specific circumstances, such as the upper intertidal zone, tidal pools, pocket estuaries, and other habitat types that become temporarily isolated or exposed by tidal dynamics. These systems can experience increased variability in temperature and microclimate conditions in the absence of protective shading. Microclimatic conditions in the upper intertidal zone are demonstrably influenced by riparian vegetation. Rice (2006) compared microclimate parameters at a Puget Sound beach with bulkheads and no overhanging riparian vegetation to those at an adjacent unmodified site with extensive riparian vegetation. He documented significant differences in light intensity, air temperature, substrate temperature, and humidity levels at the modified site. Differences in peak substrate temperatures were particularly striking, averaging nearly 20°F (11°C) higher at the modified site (81°F [27.3°C] versus 61.7°F [16.5°C]). Temperature plays an important role in determining the distribution, abundance, and species' survival in the upper intertidal zone. Surf smelt spawn at the highest tide lines at high slack tide near the water's edge on coarse sand or pea gravel. Egg development is temperature dependent, with marine riparian vegetation serving to maintain lower temperatures for fish that spawn in the summer during high-temperature periods (Penttila 2000).

In addition, large woody debris (LWD) generated by riparian vegetation provides cover for fishes at high tide and attachment sites for invertebrates (see Section 7.4.1.4 [*Altered Habitat Complexity*], below).

7.4.1.1.1 Direct and Indirect Effects

The effects of modification of riparian vegetation on fish have not been as well studied in marine systems as in the freshwater environment. However, given the limited capacity for shade to influence water temperatures in the nearshore marine environment, the direct and indirect effects of this impact mechanism on most fish species are likely to be negligible. An identified data gap is the effect of the loss of shade for predation avoidance and other factors influencing fish survival in the nearshore environment.

In contrast, riparian shade strongly influences microclimate conditions in the upper intertidal zone. Loss of riparian shade is correlated with increased substrate temperatures and reduced humidity, which in turn are indicative of increased desiccation stress (Rice 2006). This is a significant finding because temperatures and desiccation are significant stressors that limit the survival of many upper intertidal organisms, including HCP forage fish species, specifically sand lance and surf smelt (Brennan and Culverwell 2004). Penttila (2001) reported much higher egg mortality rates among surf smelt for eggs deposited on unshaded beaches compared to those sites with intact overhanging riparian vegetation. The hypothesized mechanism causing the observed higher rate of mortality was increased egg desiccation due to longer periods of direct sun exposure at sites with insufficient riparian vegetation to provide shade and other favorable microclimate conditions. The findings of Rice (2006) comparing differences in microclimate conditions and surf smelt spawn survival on shaded versus unshaded beaches strongly support this hypothesis.

Invertebrates present in habitats that are temporarily isolated or exposed by tidal dynamics could potentially be directly affected by loss of shade and microclimatic effects resulting from riparian vegetation modification. In general, however, because shading from riparian vegetation does not likely affect water temperatures in the marine environment, impacts on aquatic invertebrates associated with this mechanism are anticipated to be negligible. For example, Olympia oysters are potentially directly affected by microclimate effects stemming from loss of shade due to riparian modification. However, this species tends to occur in the lower intertidal zone, below mean lower low water (MLLW) (Dethier 2006). As such, oyster colonies are not as influenced by riparian shade and are inundated for longer periods of time, meaning that the influence of riparian zone conditions on temperature and desiccation is far more limited.

7.4.1.2 Altered Shoreline and Bluff Stability

Marine riparian vegetation clearly plays a role in stabilizing marine shorelines, particularly bluffs and steep slopes (Brennan and Culverwell 2004; Lemieux et al. 2004; Desbonnet et al. 1995; Myers 1993), but the specific mechanisms are not as well understood as they are in freshwater environments. The extent to which vegetation affects beach and slope stability varies depending on shoreline characteristics and the types of vegetation present (Lemieux et al. 2004; Myers 1993). On steeper slopes, marine riparian vegetation helps to bind the soils and protect against destabilization, slides, and cave-ins that can imperil structures and disrupt the ecology of the nearshore by increasing sedimentation and burying vegetation (Clark et al. 1980; Brennan and Culverwell 2004). On shorelines with shallower slopes, marine riparian vegetation dissipates wave energy, reducing erosion and promoting the accumulation of sediments.

7.4.1.2.1 Direct and Indirect Effects

Sedimentation and siltation impacts resulting from destabilized shorelines and bluffs can alter the ability of marine shorelines to support eelgrass beds (Finlayson 2006) and other marine littoral vegetation (Clark et al. 1980). This reduces habitat complexity, alters potential allochthonous inputs, and reduces the potential prey base available to the HCP species by inhibiting colonization by organisms upon which fish and invertebrates depend and altering the epibenthic assemblages upon which numerous fish species are dependent.

7.4.1.3 Altered Allochthonous Inputs

Allochthonous inputs of organic material and large wood from marine riparian systems also have demonstrable effects on nearshore habitat conditions. While the importance of allochthonous inputs of litter is not as well documented as the linkages established for freshwater systems, its importance to marine ecosystems is nonetheless apparent (Lemieux et al. 2004; Brennan and Culverwell 2004). Marine riparian vegetation is a known source of organic matter, nutrients, and macroinvertebrate prey items, and the recruitment of these materials is diminished when riparian vegetation is removed or modified (Lemieux et al. 2004; Spence et al. 1996; Maser and Sedell 1994; Williams et al. 2001; Brennan et al. 2004). Stomach analyses of juvenile salmon have shown significant number of terrestrial insects, with higher numbers of insects found in those samples along marine shorelines with intact marine riparian vegetation (Sobocinski 2003).

7.4.1.3.1 Direct and Indirect Effects

The removal of marine riparian vegetation demonstrably leads to a decreased input of terrestrial organic matter and nutrients (Lemieux et al. 2004; Spence et al. 1996; Maser and Sedell 1994; Williams et al. 2001; Brennan et al. 2004). Recent studies indicate that terrestrial insect-fall comprises major portions of the diets of salmonids known to be most dependent upon shallow marine nearshore habitats (i.e., Chinook and chum salmon, coastal cutthroat trout) (Levings and Jamieson 2001; Brennan et al. 2004; Brennan and Culverwell 2004; Toft and Cordell 2006). Accordingly, vegetation modifications that reduce the abundance of terrestrial insects and/or reduce the likelihood of insect recruitment to the marine environment (e.g., removal of overhanging branches) are likely to result in localized reductions in the prey base available for these species.

For aquatic invertebrates, the reduction of allochthonous inputs from riparian vegetation would inhibit nutrient inputs that contribute to the productivity of the intertidal food web and associated prey resources or forage base.

7.4.1.4 Altered Habitat Complexity

In marine environments, driftwood and/or large woody debris (LWD) help build and maintain beach habitat structure. Documented LWD functions for beach stability include its contribution to roughness and sediment trapping (Gonor et al. 1988; Brennan and Culverwell 2004) and to inputs of organic matter, moisture, and nutrients that assist in the establishment and maintenance of dune and marsh plants (Williams and Thom 2001). Eilers (1975) found that piles of downed trees in the Nehalem salt marsh (Oregon) trapped enough sediment to support vegetation, wherein marsh islands that trapped sedge seeds provided an elevated substrate for less salt-tolerant vegetation. Herrera (2005) suggested that driftwood at the top of the beach may also slow littoral drift and erosion by reducing wave energy and wave reflection energy and by creating pockets where larger sediments will accumulate. It has been suggested that estuarine wood can affect water flow and subsequent formation of bars and mudbanks (Gonor et al. 1988). The beneficial habitat structure functions of LWD along marine shorelines may be maximized if trees that fall perpendicular to beaches typically remain in place, as in the case of a recent study founding that local fallen trees tend to stay in place along Thurston County shorelines (Herrera 2005). The perpendicular alignment of LWD across the beach provides LWD structure for the widest possible portion of the aquatic habitat, thus maximizing the potential area for sediment trapping and contributions of organic matter.

Marine shorelines that have been modified by human activities tend to have less LWD and driftwood than unmodified beaches (Higgins et al. 2005; Herrera 2005). This occurs through several mechanisms. For example, MacDonald et al. (1994) reported that shoreline armoring limited driftwood accumulation on a beach. Higgins et al. (2005) suggested that the mechanisms for the apparent reduction in LWD appeared to be the removal of adjacent riparian vegetation during and following placement of bank protection; reduced shoreline roughness at armored sites, which causes more LWD to be transported away; and limited upper intertidal and backshore areas that allow for LWD deposition above tidal elevations that are routinely inundated. Because LWD is used in some marine soft−shore armoring instances to attenuate wave energy and lessen the potential for erosion, it is assumed that naturally occurring LWD on beaches would do the same, but this has not been empirically tested. Herrera (2005) described how multiple layers of LWD along a shoreline could provide effective energy dissipation, decreasing the amount of wave reflection during high water levels by increasing the roughness of the shoreline and by decreasing its slope relative to a vertical bulkhead.

7.4.1.4.1 Direct and Indirect Effects

The removal or reduction of LWD in nearshore areas introduces the potential for direct impacts on fish and invertebrates via altered habitat suitability by reducing potential cover and stability of existing habitats. Indirect effects on habitat could include the reduced potential for development of future habitat. A reduction in LWD may also introduce altered food web dynamics as a result of reduced nutrient and organic material inputs to the nearshore environment, which could present indirect impacts on both invertebrates and fish.

7.4.1.5 Altered Groundwater Inputs

Marina or terminal facilities have the potential to interrupt or alter the flow of groundwater to the nearshore environment. Depending on site-specific conditions, this may limit the transport of nutrients in groundwater to the nearshore environment (Williams and Thom 2001), or may lead to localized increases in substrate temperature due to the loss of cool groundwater flow (Penttila 2001).

7.4.1.5.1 Direct and Indirect Effects

Riparian vegetation modifications can alter soil characteristics of site vegetation, infiltration rates, and groundwater transport that provides freshwater seepage to the intertidal zone. Alteration of these functions can directly reduce or eliminate rearing habitat for Olympia oysters and other marine organisms that use freshwater seeps along marine shorelines. These changes could also inhibit the suitability of marine shorelines for supporting eelgrass beds (Finlayson 2006). By affecting eelgrass habitat, these alterations could generate indirect food web effects for both invertebrates and fish.

7.4.2 Riverine and Lacustrine Environments

7.4.2.1 Altered Riparian Shading

Removal of riparian vegetation as part of marina and shipping/ferry terminal projects affects water temperature in riverine and lacustrine environments through a number of mechanisms. The dominant mechanism is the effect of shading on solar radiation exposure. The influence of shade on water temperature generally diminishes as the size of the stream increases because of the proportionally reduced area in which riparian vegetation can insulate against solar radiation and trap air next to the water surface (Knutson and Naef 1997; Quinn 2005; Poole and Berman 2001; Murphy and Meehan 1991). Alternatively, riparian vegetation removal and alteration can also cause surface waters to gain or lose heat more rapidly because the ability to regulate ambient temperatures is reduced (Quinn 2005; Bolton and Shellberg 2001; Poole and Berman 2001; Knutson and Naef 1997; Murphy and Meehan 1991). Still-water systems, such as lakes or ponds, are subject to the same effects. These effects are generally less pronounced, however, because these systems have a greater amount of unshaded surface area, large water volumes, and are often seasonally stratified. As such, water temperatures generally change gradually through the year with the seasons and show less change from night to day. However, loss of shading of nearshore littoral habitats can result in changes to water temperature of a sufficient magnitude to create thermal barriers for various fish species (Carrasquero 2001), perhaps leading to changes in species composition.

7.4.2.1.1 Direct and Indirect Effects

Reduced riparian shade can result in temperatures outside the optimal growth range for fish and invertebrate species. For example, a study found that for age-0 bull trout, the upper lethal temperature is 70°F (20.9°C), and optimal growth occurred at 56°F (13.2°C); feeding declined significantly above 61°F (16°C) (Selong et al. 2001). Also, a laboratory study showed that Dolly Varden displayed decreased appetite above 61°F (16°C), and temperatures were lethal above 68°F (20°C) (Takami et al. 1997).

Temperature changes can result in direct effects on fish and invertebrates including mortality, altered growth and fitness, seasonal thermal barriers inhibiting migration and access to habitat and prey (fish only), as well as indirect effects stemming from the alteration of food web patterns. The effects of an altered temperature regime on host fish species may also lead to effects on invertebrate species with parasitic life-history stages.

7.4.2.2 Altered Ambient Air Temperature Regime

In addition to the effects of shading, a broad array of research has shown that alteration of riparian vegetation can strongly affect temperatures even when adequate stream shading is still provided. Riparian vegetation restricts air movement, providing an insulating effect that regulates ambient air temperatures. Alteration of riparian buffer width and vegetation composition can degrade this insulating effect, leading to greater variability in ambient air temperatures that in turn influence water temperatures (AFS and SER 2000; Bartholow 2002; Barton et al. 1985; Beschta and Taylor 1988; Beschta et al. 1988; Beschta 1991, 1997; Brosofske et al. 1997; Brown 1970; Chen et al. 1992, 1993, 1995, 1999; Johnson and Jones 2000; May 2003; Murphy and Meehan 1991; Spence et al. 1996; USFS et al. 1993; Sridhar et al. 2004; Sullivan et al. 1990; Theurer et al. 1984). For example, Chen et al. (1995) found that maximum air temperatures at the margins of old-growth stands are elevated 3.6 to 28.8°F (2 to 16°C) relative to interior temperatures. Riparian buffer widths of 100 to 300 ft may be necessary to provide full ambient temperature regulation (AFS and SER 2000; Brosofske et al. 1997).

7.4.2.2.1 Direct and Indirect Effects

The removal of riparian vegetation may affect the suitability of available habitat for fish and invertebrates by altering in-water and in-air temperature regimes and physical habitat characteristics, as well as by disrupting important ecological linkages between terrestrial and aquatic ecosystems that produce the complex, cascading trophic systems that support freshwater species. When this nutrient source is altered, the net primary production of organic matter is affected, and the abundance and availability of prey resources for HCP species could be reduced (Bisson and Bilby 1998).

This modification of the aquatic food web potentially affects invertebrates, such as the grazing giant Columbia River limpet and giant Columbia River spire snail, and the filter feeding California floater mussel. The grazing of organic material by these invertebrates and macroinvertebrates, such as caddisflies, stoneflies, and mayflies, is known to support the HCP salmon species (Hawkins et al. 1982; Murphy and Meehan 1991; Bilby and Bisson 1992), bull trout (Wydoski and Whitney 2003; Goetz et al. 2004), and sturgeon (Wydoski and Whitney 2003; Adams et al. 2002; Emmett et al. 1991). Although terrestrial and adult aquatic insects are important (Bjornn and Reiser 1991), juvenile salmon in streams have been found to be primarily supported by autochthonous organic matter (Bilby and Bisson 1992).

7.4.2.3 Altered Stream Bank and Shoreline Stability

In riverine systems, the root structure of riparian vegetation naturally resists the shear stresses created by flowing water and thus retards bank erosion, thereby stabilizing stream banks and shorelines and maintaining valuable habitat features along stream margins. By dissipating the erosive energy of flood waters, wind, and rain and by filtering sheet flows, riparian vegetation limits the amount of fine sediment entering river and stream systems (Knutson and Naef 1997; Levings and Jamieson 2001; Waters 1995; Brennan and Culverwell 2004).

Riparian vegetation in lacustrine systems plays a similar role, stabilizing shorelines against the erosive forces of wind-driven waves and boat wakes (Carrasquero 2001). The loss of riparian and emergent vegetation promotes shoreline erosion, creating an erosive cycle that further increases vegetation loss, with a resultant adverse effect on nutrient cycles. For example, loss of emergent vegetation can promote erosive cycles that preclude the recovery and reestablishment of such vegetation. Decreased emergent vegetation density results in altered sediment transport patterns. If sediments are not replenished, additional emergent vegetation loss can result, leading to additional shoreline erosion (Rolletschek and Kuhl 1997).

7.4.2.3.1 Direct and Indirect Effects

If riparian vegetation is removed as part of a marina or terminal project, stream banks and shorelines may potentially be exposed to the erosive effects of wind, rain, and current, while also potentially exposing the built structures to the effects of flooding (Brennan and Culverwell 2004). The removal of riparian trees and understory can dramatically alter stream bank stability and the filtering of sediments from overland flow (Simon and Hupp 1992; Simon 1994; Shields 1991; Shields and Gray 1992; Kondolff and Curry 1986; Waters 1995), resulting in increased erosion and increased inputs of fine sediment (Bolton and Shellberg 2001). Increased sedimentation to streams or lakes can significantly affect the spawning success of salmonids (Quinn 2005; Waters 1995; Furniss et al. 1991). Increased sedimentation may also affect other HCP fish species, directly through gill damage or indirectly through impacts on their habitat.

Increased sedimentation from destabilized banks can result in invertebrate mortality, the reduction or alteration of suitable habitat so that growth and fitness are reduced (or that the distribution of invertebrate species changes), and indirect effects associated with food web alterations.

7.4.2.4 Altered Allochthonous Input

In riverine environments, riparian detritus and other externally derived materials are the primary source of organic fodder in headwater streams, forming the basis for the food web (MacBroom 1998). This material includes terrestrial macroinvertebrates, as well as leaves and branches, the latter providing food sources for benthic macroinvertebrates (Knutson and Naef 1997; Murphy and Meehan 1991; Bisson and Bilby 1998; Cummins 1975). As rivers increase in order and grow in size, these materials are processed and recycled by an increasing diversity of organisms (Vannote et al. 1980). Without allochthonous inputs, the forage detritus available for benthic macroinvertebrates is compromised, also diminishing the habitat and species diversity of these prey items (Murphy and Meehan 1991). Lacustrine systems are similarly dependent on allochthonous inputs from riparian systems, receiving this material directly through litter fall and windblown detritus from their own riparian areas, as well as allochthonous material transported into the system by rivers and streams.

7.4.2.4.1 Direct and Indirect Effects

The removal of freshwater riparian vegetation as part marina/terminal activities would cause an incremental decrease in the input of externally derived (allochthonous) materials to the nearby aquatic environment and food web. Modification of the food web or its productivity would result in indirect effects on fish and invertebrates in the affected systems.

Riparian vegetation inputs also contribute to habitat complexity and organic matter retention, providing essential cover for fish and invertebrate species (Quinn 2005; Naiman et al. 2000; Knutson and Naef 1997; Murphy and Meehan 1991). Removal or modification of these physical elements of fish and invertebrate habitats would directly affect HCP species in these systems.

7.4.2.5 Altered Habitat Complexity

In riverine systems, by maintaining bank stability and contributing LWD to the aquatic environment, riparian vegetation forms and maintains habitat complexity in freshwater environments. Woody debris in fresh water controls channel morphology, regulates the storage and transport of sediment and particulate organic matter, and creates and maintains hydraulic complexity that contributes to fish habitat (Murphy and Meehan 1991; Naiman et al. 2002; Jennings et al. 2003; Schindler et al. 2000; Abbe and Montgomery 2003; Montgomery et al. 2003; Collins et al. 2003). Within streams, approximately 70 percent of structural diversity is derived from root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, or windthrow (Knutson and Naef 1997). In streams, LWD is a major factor influencing pool formation in plane−bed and step−pool channels. Bilby (1984) and Sedell et al. (1985) found that approximately 80 percent of the pools in several streams in southwest Washington and Idaho were associated with wood. LWD is a primary determinant of channel form in streams, creating pools and waterfalls and affecting channel width and depth (Montgomery and Buffington 1993; Keller and Swanson 1979; Bilby and Ward 1991; Bisson et al. 1987). In larger streams, the position of LWD strongly influences the size and location of pools (Naiman et al. 2002). In larger streams, LWD is typically oriented downstream due to powerful streamflow, which favors the formation of backwater pools along margins of the mainstem (Naiman et al. 2002). The hydraulic complexity created by LWD encourages the capture and sequestration of other allochthonous inputs, making these materials more available to the food web through grazing and decomposition (Quinn 2005; Naiman et al. 2002; Knutson and Naef 1997; Murphy and Meehan 1991). Although the previous discussion is primarily for streams, these impacts also occur in large river systems where marinas/terminals are more likely to be located.

Numerous studies have reported fish use of complex cover composed of riparian vegetation, such as branches, rood wads, and woody debris, which provides increased and diverse surface area and interstices for prey colonization and protection from predation. Particulate organic matter accumulated by LWD is an important food source for many stream-dwelling invertebrates. Addition of wood to channels causes increased abundance of macroinvertebrates and changes the species composition in that stream. Pools formed by LWD in streams are an important habitat for many species of stream fishes.

Sediment accumulated by woody debris in streams also provides substrate for the establishment of early successional plant species that can mature into riparian vegetation. In the Pacific Northwest, LWD in riparian areas provides an important germination site for several conifer species.

The quantity of woody debris in channels in the Pacific Coastal ecoregion has decreased over time as a result of various land use practices, including the removal of wood from rivers for navigation and fish passage, splash damming, and clearing of riparian trees (Bisson and Bilby 1998; Murphy and Meehan 1991; Jennings et al. 2003; Schindler et al. 2000; Abbe and Montgomery 2003; Montgomery et al. 2003; Collins et al. 2003).

7.4.2.5.1 Direct and Indirect Effects

Dramatic increases in sediment and organic matter export occur immediately following removal or disturbance of LWD. These short-term direct impacts affect water quality parameters such as turbidity and dissolved oxygen levels, which in turn affect the viability of multiple lifestages of fish. These impact mechanisms are discussed extensively in Section 7.3 (*Water Quality Modifications*) above. These sedimentation impacts could also affect invertebrate distribution and fitness. Long-term indirect effects on fish and invertebrates associated with altered habitat complexity include a reduction or modification of prey base and related changes or reduction in foraging success, modified distribution and/or diversity of species within riverine systems, and decreased habitat suitability for various lifestages, resulting in decreased viability and reproductive success.

7.4.2.6 Altered Groundwater–Surface Water Exchange

Alteration or removal of riparian vegetation would change the interface among plants, soil, and water on and near the bank surface. Riparian vegetation acts as a filter for groundwater, filtering out sediments and taking up nutrients (Knutson and Naef 1997). In conjunction with upland vegetation, it also moderates streamflow by intercepting rainfall, contributing to water infiltration, and removing water via evapotranspiration. Plant roots increase soil porosity, and vegetation helps to trap water flowing on the surface, thereby aiding in infiltration as the water stored in the soil is later released to streams through subsurface flows. Through these processes, riparian and upland vegetation help to moderate storm−related flows and reduce the magnitude of peak flows and the frequency of flooding. Riparian vegetation, the litter layer, and silty soils absorb and store water during wet periods and release it slowly over a period of months, maintaining streamflows during rainless periods (Knutson and Naef 1997).

Marina/terminal structures that create a physical barrier between the bank and hyporheic flow prevent groundwater-surface water exchange between the bank and aquatic ecosystem. The interface between flow within the hyporheic zone and the stream channel is an important buffer for stream temperatures (Poole and Berman 2001). Thus, the alteration of groundwater flow can affect stream temperature. The magnitude of the influence depends on many factors, such as stream channel pattern and depth of the aquifer (Poole and Berman 2001).

7.4.2.6.1 Direct and Indirect Effects

Marina/terminal construction or structures that alter riparian vegetation can directly affect fish and invertebrates in the short term by influencing groundwater dynamics, which in turn can result in reduced habitat suitability or availability and changes to water quality. In the long term, changes to groundwater exchange can generate indirect effects on fish and invertebrate species by increasing the magnitude of peak flows resulting in habitat alteration, scour, and sedimentation; increasing the magnitude of periods of drought, resulting in reduced habitat availability and suitability, potential stranding, or desiccation; and negatively affecting water quality through a lack of filtration, increased sediment input, and warmer stream temperatures.

7.5 Aquatic Vegetation Modifications

Aquatic vegetation, in both marine and freshwater systems, provides important ecological functions. These functions include: (1) autochthonous production, and (2) habitat complexity.

The role of marine littoral vegetation, as well as the significance of this vegetation in providing autochthonous inputs and habitat complexity, is discussed in detail above in Section 7.2.4 (*Ambient Light Modifications*). The role of freshwater aquatic vegetation, and the significance of this vegetation in providing autochthonous inputs and habitat complexity, is also discussed in detail above in that same discussion.

7.6 Hydraulic and Geomorphic Modifications

Hydraulic and geomorphologic modifications associated with marina/terminal projects occur in riverine, marine, and lacustrine environments. This section reviews what is known about the effects of these modifications on the movement of water (i.e., flow velocity, littoral currents) and the substrates in riverine, marine, and lacustrine environments, as well as the resultant impacts on HCP species.

7.6.1 Marine Environments

Shallow nearshore marine habitats, structured by tidal currents, wind, and input from terrestrial and freshwater sources, support spawning and larval settlement substrates as well as burrowing habitats for many of the HCP species (including juvenile salmon and rockfish species, cod, hake, Pacific herring, walleye pollock, Newcomb's littorine snail, and the Olympia oyster) (Healey 1982; Simenstad et al. 1979; Couch and Hassler 1990; Bargmann 1998; Penttila 2001; Larsen et al. 1995). The controlling factors in these habitats depend upon bathymetry, substrates, circulation and mixing, and sediment transport. These underlying hydrogeomorphic variables regulate a phenomenon known as longshore transport, or littoral drift (Komar 1998). Littoral drift is an important controlling factor in the determination of habitat structure; it is the transport and deposition of sediment that supports aquatic plants. Key to understanding littoral drift is the concept of a drift cell (also known as drift sectors), which is a segment of shoreline along which the longshore transport moves sediment at noticeable rates. Each drift cell includes: (1) a sediment source, such as a feeder bluff; (2) a driftway along which these sediments move; and (3) an accretion terminal where the drift material is deposited. In this way, a drift cell allows the uninterrupted movement of beach materials (Terich and Schwartz 1990; Cox et al. 1994).

It is known that pilings, navigation dredging, and prop wash associated with the construction, operation, and repair of marinas/terminals alter both the bathymetry and littoral drift of the area around and under such structures, both in exposed (Komar 1998) and sheltered settings (NRC 2001). These activities can produce the following major mechanisms of impact on aquatic life: altered wave energy, altered current velocities, altered nearshore circulation, altered sediment supply, a reduction in groundwater input, and altered substrate composition. These physical processes are interrelated and can act in concert (Komar 1998). More importantly, modifications to littoral drift have numerous indirect results, from substrate changes (Li and Komar 1992; Frihy and Komar 1993; El-Asmar and White 2002) to modifications in the distribution and delivery of groundwater to the coastal zone (Nakayama et al. 2007).

7.6.1.1 Altered Wave Energy

Marinas have been found to attract large populations of juvenile salmon and baitfish and provide permanent habitat for a variety of other fish (Cardwell et al. 1978; Heiser and Finn 1970; Penttila and Aguero 1978; Thom et al. 1988; Weitkamp and Schadt 1982). This attraction is likely due to the low hydraulic energy similarities between a marina environment and a natural embayment (Cardwell and Koons 1981).

Marinas are specifically designed to diminish ambient wave energy so that maritime activities can be conducted. In the process of creating a shoreline that suits this purpose, ambient waves are reflected (Wurjanto and Kobayashi 1993), diffracted (Melo and Guza 1991), and refracted (Komar 1998). In addition, vessel traffic associated with the addition of a marina can interact with these artificial boundaries, causing a significant increase in wave energy even in some places inside the marina (Tarela and Menendez 2002; Isaacson et al. 1996). Numerous studies have been performed that have attempted to manipulate the incoming wave energy to reduce reflected, refracted, and diffracted wave trains from entering the port or marina; in fact, there are entire journals dedicated to this topic (e.g., *Journal of Waterway, Port, Coastal and Ocean Engineering*). These alterations typically result in the construction of a series of jetties, groins, and breakwaters (see the Shoreline Modifications white paper for more details [Herrera 2007a]). Regardless of the nature of the alterations, the modified relationship between topography and wave energy results in a shoreline that is out of equilibrium with natural shoreline processes (Komar 1998). As a result, wave energy artificially accumulates in some areas and is diminished in others.

7.6.1.1.1 Direct and Indirect Effects

This redistribution of wave energy can have a number of interrelated indirect and direct impacts on fish and invertebrates, which are grouped into two categories: those that relate to changes in substrate, and those that alter water column characteristics. Each of these impact types is discussed in detail below.

<u>Substrate Stressors</u>

Substrate is an important factor controlling the growth of aquatic vegetation in Puget Sound (Koch and Beer 2006) and conditions for fish spawning in intertidal waters (typically forage fish). Increased wave energy increases bed shear stress, and if some of the coarsest material is not mobilized, a generally coarser substrate results (Komar 1998). However, the degree to which this occurs depends on the geologic setting. For instance, on the outer coast, substrate is loose, deep, sandy, and unconsolidated. In these areas, increased or displaced wave energy associated with marina facilities creates wholesale erosion of the shoreline (Miller et al. 2001). In protected, previously glaciated areas, the basin topography is complex and the coarse nature of the substrate slows down erosion dramatically (Nordstrom 1992). In these locales, a lag deposit can easily form a near bedrock-like shoreline (e.g., Foulweather Beach [Finlayson 2006]). Typically, however, shoreline hardening manifests itself by a loss of the pebble veneer that is common throughout much of Puget Sound (Finlayson 2006). This process is similar to what has occurred on the urbanized shorelines throughout the Great Lakes (Chrzastowski and Thompson 1994). These changes have produced pronounced ecological alterations within recent years in the Great Lakes (Meadows et al. 2005), causing the elimination of native species and enabling invasives (e.g., zebra mussels) to dominate the ecosystem (Marsden and Chotkowski 2001).

Changing substrate can adversely affect the growth of aquatic vegetation. For instance, eelgrass is incapable of growing in substrates dominated by gravel (Koch and Beer 2006). Coarser substrates can provide a surface upon which other aquatic vegetation can colonize (e.g., bull kelp). This explains the transition seen in Elliot Bay (Seattle, Washington) and other urbanized embayments.

Although there have been few experimental studies of forage fishes, damage to surf smelt spawning areas has been documented in Hood Canal by shoreline hardening (i.e., bulkheads) (Penttila 1978, in Thom et al. 1994). Usual spawning substrates consist of pea-size gravel and coarse sand; typical of the pebble veneer found throughout Puget Sound (Finlayson 2006), with broken shells intermixed in some cases (Thom et al. 1994). Surf smelt make no attempt to bury their demersal, adhesive eggs but rely on wave action to cover the eggs with a fine layer of substrate (Thom et al. 1994); therefore, changing the wave environment may also change the survivability of surf smelt spawn. The importance of substrate to spawning has also been empirically demonstrated in the closely related Japanese surf smelt (Hirose and Kawaguchi 1998).

Pacific sand lance spawn in the high intertidal zone on substrates varying from sand to sandy gravel. Sand lance also rely on sandy substrates for burrowing at night. Like surf smelt, sand lance spawning is susceptible to the deleterious effects of littoral alterations because sand lance rely on a certain beach profile and specific substrate compositions (Penttila 1995).

Marinas are specifically designed to produce areas of reduced wave energy and current velocity. Reducing wave energy lowers near bed shear stress, creating an environment conducive to the settling and accumulation of fine sediments (Miller et al. 1977). Considering the large volume of fine-grained sediment supplied to western Washington waters (Downing 1983), even areas that do not participate in active littoral cells can receive a large amount of fine sediment. This suggests that marinas in state waters are likely to experience accumulations of fine sediments in excess of levels existing prior to the modification of the site.

Deposition of large amounts of silt can kill aquatic vegetation vital to HCP species that occur in nearshore areas. Recent work has shown that burying eelgrass to a depth of as little as 25 percent of the total plant height could decrease productivity (Mills and Fonseca 2003). For more information about the effects of aquatic vegetation on fish and invertebrates, see Section 7.2 (*Facility Operation and Vessel Activities*). Eelgrass can also be discouraged from colonizing new areas with a high clay content, caused by recent sediment deposition (Koch and Beer 2006).

<u>Water Column Stressors</u>

Wave energy is the dominant source of fluid mechanics in the nearshore area in most of Washington waters (Finlayson 2006), responsible for mixing the upper portion of the water column (Babanin 2006) and producing high shear stresses near the bed (Lamb et al. 2004). Shear stress is the force applied to the bed and also related to the intensity of the turbulence in the water column. If the shear stress exceeds the force securing invertebrates to the seabed, they become entrained into the water column and destroyed. Intense turbulence may also disrupt migration of fish. Alterations in the natural distribution of wave energy can prove harmful to aquatic vegetation as well as the fish and invertebrates that use and consume them (Eriksson et al. 2004; Sandstrom et al. 2005).

Attenuation of waves can increase water column stratification in marine waters and lead to dissolved oxygen reduction and temperature anomalies (Qiao et al. 2006). Surficial mixing and circulation also play an important role in primary productivity, particularly near large river mouths (e.g., Willapa Bay [Roegner et al. 2002]). Disruption of these processes may adversely affect primary productivity and, ultimately, any marine species through the disruption of food web dynamics.

Wave energy also plays a role in the distribution of aquatic vegetation used by salmonids and other nearshore fishes, particularly in energetic environments. High wave energies have been shown to inhibit the colonization and growth of some seagrasses (e.g., eelgrass [Fonseca and Bell 1998]; see Section 7.2 [*Facility Operation and Vessel Activities*] for details), although in more recent studies in Puget Sound, no correlation was found between eelgrass prevalence and wave characteristics (Finlayson 2006). High wave energy can also dislodge kelp (Kawamata 2001).

The only direct impact of extreme wave energy would be on those invertebrates that cannot tolerate extremely high shear stresses or burial. Experimental evidence of the mortality limits of large shear stresses on mollusks or other invertebrates is not available. Olympia oysters, the only marine HCP invertebrate species prone to this sort of burial, have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b). The partial and complete burial of closely related estuarine mollusks has been addressed empirically (Hinchey et al. 2006). Results of these studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Mechanical and physiological adaptations contribute to this tolerance. For instance, motile organisms are much more capable of surviving high sedimentation rates than sedentary ones (e.g., the Olympia oyster). Most shorelines in Washington do not experience the sedimentation rates that result in burial-related mortality. However, near river mouths, alterations in sedimentation rates are possible that would exceed the criteria for mortality established by Hinchey et al. (2006).

7.6.1.2 Altered Current Velocities

Marinas are specifically designed to produce areas of reduced velocity so that maritime activities can be carried out. By protecting vessels, velocities can be reduced to the point where the deposition of fine sediment (silt and clay) occurs (Miller et al. 1977), particularly near major sources (i.e., large rivers [Downing 1984]). These effects would have the same ramifications as those discussed on the preceding section, namely reduced spawning success, burial of organisms or habitats, and altered primary productivity. Despite marinas being designed to reduce currents, strong currents can result from these activities (da Silva and Duck 2001).

At the other extreme, strong currents can have significant impacts on both aquatic vegetation and the substrate within which it is embedded. The relationship between flow velocity and a change is reflected through the boundary shear stress (Miller et al. 1977). Substrate and aquatic vegetation will be removed if the critical shear stress is exceeded.

7.6.1.2.1 Direct and Indirect Effects

Nearshore currents, even those in heavily altered environments, do not exceed the threshold for adult salmonid navigation, but high velocities have been shown to exclude some small fishes from navigating nearshore waters (Michny and Deibel 1986; Schaffter et al. 1983). This would cause fragmentation of habitat for these species. Eelgrass and many other species of aquatic vegetation (e.g., bull kelp) require some water motion for survival (Fonseca and Bell 1998). The degree of sensitivity to altered current velocities is species-dependent and also dependent on other factors such as pollutant loading. It is likely, however, that the reduction in water velocity may also contribute to a lack of eelgrass. In general, alterations in current velocities can contribute to modifications or removal of suitable habitats for fish in various lifestages. This alteration of habitat can inhibit the growth, survival, and fitness of various fish species. In addition, altered current velocities may also affect the exertion levels required for fish to move throughout the habitat. These changes could reduce the fitness required for migration or maintenance of normal behavioral functions or could result in direct mortality via direct burial and loss of suitable spawning or foraging habitat or indirect mortality resulting from impacts on prey species.

The direct impact of altered currently velocity would be on those invertebrates that cannot tolerate extremely high shear stress or burial. This alteration would most likely occur adjacent to marina activities. Experimental evidence of the mortality limits of large shear stresses on mollusks or other invertebrates is unavailable. Burial of mollusks is discussed in the preceding subsection.

7.6.1.3 Altered Nearshore Circulation

Nearshore circulation is a general phrase that describes the flux of salt, water, and sediment associated with tidal and wave motion near the shoreline. In more exposed, sandy settings, nearshore circulation is dominated by the mechanics of wave breaking (Komar 1998). These effects are generally insignificant in Puget Sound (Finlayson 2006), but they can be an important process when swell is present (e.g., on the outer coast [Komar 1998]). In Puget Sound and near the mouth of large rivers (e.g., the Columbia), tidal currents and freshwater input play a more important role in nearshore currents. Because marinas require installation of fixed (hardened) shoreline elements, there can be increases in current velocity in areas adjacent to the marinas, such as in the case of the generation of rip currents around breakwaters (Bellotti 2004).

Ratte and Salo (1985) and Penttila and Doty (1990) found that pilings associated with shoreline structures changed the flow of water around the pilings and over the substrate, thereby altering the bathymetry of the substrate and the flow of water in the immediate area. Open pile structures tend to interfere less with sediment transport. Structures located in low-energy areas that block littoral drift tend to fill in with sediment and require maintenance dredging.

In Puget Sound and near the mouth of large rivers (e.g., the Columbia), tides and freshwater input play a more important role in nearshore currents. Tidal motions are rarely sufficient to mobilize sediment typical of Puget Sound beaches (material of gravel size or larger [Finlayson 2006]), but they can mobilize fine sediments (i.e., silt and clay), particularly in areas of high sediment supply (e.g., Nittrouer 1978).

7.6.1.3.1 Direct and Indirect Effects

Construction and maintenance of shipping access to marinas have been shown to both increase (da Silva and Duck 2001) and decrease (Sherwood et al. 1990) tidal prisms, depending on the characteristics of the tides and freshwater input and the nature and geometry of the alterations. The reduction of the tidal prism, as documented on the Columbia River (Sherwood et al. 1990), can eliminate entire habitats from being exposed to tidal action. In addition to stranding areas from marine influence, reduction in tidal motions can increase stratification and limit the vertical mobility of nutrients and dissolved oxygen (Mickett et al. 2004). Recent work has shown that there is a complex interplay among these phenomena and the primary productivity of nearshore waters; however, more dramatic consequences could occur in naturally mixing-limited waters of Puget Sound. Aside from the obvious impacts on inundation of adjacent landowners, increasing tidal prisms can expose aquatic species (both fish and invertebrates) to polluted sediments, such as those found at Superfund sites, potentially resulting in long-term contaminant related impacts.

Nearshore circulation patterns are a dominant characteristic that shapes the suitability of nearshore habitats for a range of HCP species. Alteration of nearshore circulation patterns can produce many of the same effects described for altered wave energy in Section 7.6.1.2 (*Altered Current Velocities*). Specifically, fish and invertebrate species that are planktonic breeders have been shown to produce spatially variable spawn that relies on the combination of wave motion, ambient currents, and circulation patterns for transport to and retention in productive nursery areas (Hernandez-Miranda et al. 2003; Rooper et al. 2006; Sinclair 1992). While specific studies on HCP species are lacking, virtually all of the purely marine HCP species have a planktonic egg and/or larval life-history stage dependent on rearing habitat transport and retention dynamics. Developing eggs or larvae that are transported into areas unfavorable for rearing face a high likelihood of starvation and predation or, in the case of schooling pelagic species, may be permanently isolated from their spawning population (Sinclair 1992).

7.6.1.4 Altered Sediment Supply

Wave energy and water transport alterations imposed by docks, bulkheads, breakwaters, ramps, and associated bank stabilization activities alter the size, distribution, and abundance of substrate and detrital materials required to maintain the nearshore food web. Alteration of sediment transport patterns can present potential barriers to the natural processes that build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning (Parametrix 1996; Penttila 2001; Thom et al. 1994; Thom and Shreffler 1996; Thom et al. 1996, 1997; Haas et al. 2002). These impacts primarily manifest as a change in substrate, the impacts of which are discussed in Section 7.6.1.1 (*Altered Wave Energy*).

7.6.1.4.1 Direct and Indirect Effects

The primary indirect impact of changing sediment supply is to change the distribution of substrate within the littoral cell within which that modification occurs (Terich 1987). As such, the loss of sediment to a drift cell results in a coarsening of the substrate, as fine-grained sediment is lost to deep portions of the basin by resuspension (Finlayson 2006) and not resupplied by freshly eroded bluff sediments. The coarsening would have the same impacts on fish and invertebrates as discussed in Section 7.6.1.1 (*Altered Wave Energy*). However, because some drift cells can be extremely long (e.g., more than 20 miles long in the drift cell that extends between Seattle and Mukilteo on the northeastern shore of the main basin of Puget Sound [Terich 1987]), the effects of a modification can extend well beyond the primary activity area.

The primary direct impact on fish and invertebrates is to alter the degree of turbidity in the nearshore environment (Au et al. 2004; Bash et al. 2001; Berry et al. 2003). See Section 7.1.4 (*Navigation/Maintenance Dredging*) and Section 7.3.1 (*Increased Suspended Solids*) for a full discussion of the effects of turbidity.

7.6.1.5 Altered Groundwater Input

Submarine groundwater discharge serves a number of ecologic functions (Gallardo and Marui 2006). Most work on the subject has focused on the nutrient load that these waters supply to the coastal ocean in sandy, exposed coastal environments (Gallardo and Marui 2006; see Section 7.3 [*Water Quality Modifications*] for the indirect and directs effects of nutrient alterations). The importance of groundwater seepage to the macroecology of the deep ocean (i.e., benthic environments) is well known (Kiel 2006). Both hydrothermal vents and cold seeps are known to be “hot spots” of biological activity, a direct result of groundwater discharge (Kelley et al. 2002; Kiel 2006). However, the direct impacts of submarine groundwater discharge on the nearshore environment are less clear.

7.6.1.5.1 Direct and Indirect Effects

One of the outcomes of hardening the shoreline (e.g., as would occur in the installation of slips, docks, and piers) is to impede or eliminate the exchange of groundwater with supratidal areas. Submarine groundwater discharge has been documented to play an important role in the circulation of fluid and nutrients on many coasts throughout the world (Johannes 1980; Michael et al. 2005; Gallardo and Marui 2006). When marinas are installed, the substructure that interrupts the free exchange of groundwater between the sea and the uplands has been shown to have adverse effects on nearshore ecosystems (Nakayama et al. 2007).

In Puget Sound, the lack of groundwater discharge has been documented to increase substrate temperatures at comparable tidal elevations (Rice 2006). Groundwater inputs also influence the seepage face on low tide (Gendron 2005). The correlation of the top of the seepage face to the presence of eelgrass beds has been anecdotally correlated in Puget Sound (Finlayson 2006). Although not demonstrated in a systematic study, the loss of the seepage face, as observed by Finlayson (2006) and Gendron (2005), would likely increase the risk of desiccation of aquatic plants and potentially limit the growth of eelgrass (Boese et al. 2005; for details see Sections 7.1 [*Construction and Maintenance Activities*] and 7.2 [*Facility Operation and Vessel Activities*]). The potential effects on fish and invertebrate species associated with loss of marine littoral vegetation are discussed in Section 7.2.4 (*Ambient Light Modifications*).

Some species (such as the Olympia oyster) are known to take advantage of freshwater seeps along marine shorelines (West 1997; Couch and Hassler 1990). For species that are reliant upon freshwater seeps in the marine environment, groundwater impacts could potentially pose direct effects; however, the specific effects on fish and invertebrates in nearshore areas are unknown.

7.6.1.6 Altered Substrate Composition

Ferry terminal pilings can alter adjacent substrates, with increased shell-hash deposition from piling communities and changes to substrate bathymetry (Haas et al. 2002; Shreffler and Moursund 1999; Blanton et al. 2001). Pilings provide surface area for encrusting communities of mussels and other sessile organisms such as seastars that prey upon the shellfish attached to the dock. The resulting shell-hash accumulated at the base of the piling alters adjacent substrates and changes the substrate bathymetry (Penttila and Doty 1990; Parametrix 1996; Blanton et al. 2001; Southard et al. 2006; Haas et al. 2002). These changes in substrate type can also change the nature of the flora and fauna native to a given site. In the case of pilings, native dominant communities typically associated with sand, gravel, mud, sand, and seagrass substrates are replaced by those communities associated with shell-hash substrates. Shell-hash is a prime settling habitat for Dungeness crab. Both crab and seastar foraging activity can disrupt eelgrass and retard recruitment. In the presence of large crab populations, crabs burrowing into the substrate to avoid predation may significantly inhibit eelgrass recruitment (Thom and Shreffler 1996). Such disturbance of seagrass meadows by animal foraging is also reported elsewhere (Camp et al. 1973; Orth 1975; Williams 1994; Baldwin and Lovvorn 1994).

Shoreline structures associated with marinas/terminals, such as breakwaters, jetties, and bank armoring, can also modify the substrate by precluding the contribution of sediments from uplands and/or interfering with drift cell sediment transport and deposition. This can have the effect of increasing substrate scour or limiting deposition of sediments that provide suitable habitat for HCP species. These impacts are discussed in Section 7.6.1.4 (*Altered Sediment Supply*) above.

One of the most profound changes produced by marinas is to change the shoreline from a dynamic, loose surface to a rigid, immobile one. Although there are distinct differences between artificial substrates placed in marina construction, over time they all behave like bedrock shorelines similar to extremely coarse-clastic beaches in Puget Sound (Finlayson 2006). The primary difference between these installations is whether they permit exchange of groundwater with the sea.

7.6.1.6.1 Direct and Indirect Effects

By inhibiting shoreline sediment sources and introducing new substrate types like shell-hash, shoreline structures can modify species assemblages in the vicinity of marinas/terminals and alter available substrates and habitat structures critical to multiple life-history stages of HCP fish and invertebrate species. In turn, these changes can directly affect the reproduction, growth, and survival of fish and invertebrate species, or result in indirect effects on the same species by affecting the viability and distribution of their prey species. The overall effects associated with habitat modification impacts include decreased growth, survival, and fitness.

Placement of fill associated with shoreline structures (such as breakwaters, jetties, and bank armoring) alters the slope and depths of intertidal habitats and may change wave action and the littoral drift, thereby affecting the geomorphology and habitats of that site. See Section 7.6.1 (*Marine Environments*) for further discussion of effects associated with littoral drift modification. Immobile substrate also fundamentally changes the mechanics of water motion on the shoreline, increasing wave reflection (Komar 1998; Finlayson 2006) and eliminating exchange of water into and out of the shoreline (Nakayama et al. 2007). For a full discussion of impacts associated with inhibited groundwater exchange, see Section 7.6.1.5 (*Altered Groundwater Inputs*). Solid concrete walls and steel piles that allow no groundwater penetration likely have increased impacts compared to more porous artificial substrates (e.g., riprap).

Placement of fill to accommodate facility structures often results in a direct loss of vegetated shallow-water, nearshore habitat. This also potentially results in reduced availability of juvenile salmonid rearing habitat and modified migration behavior. In general, the addition of immobile substrate decreases habitat suitability for juvenile salmonids and changes the character of the shoreline that was previously conducive to their use (e.g., Knudsen and Dilley 1987; Peters et al. 1998; Schaffter et al. 1983). While data indicate that habitat use of riprapped banks by yearling and older trout species may be equal to or higher than natural banks, use by subyearling trout, coho, and Chinook salmon is lower (Weitkamp and Schadt 1982; Hayman et al. 1996; Beamer and Henderson 1998; Peters et al. 1998; Schmetterling et al. 2001; Knudsen and Dilley 1987; Garland et al. 2002). In Elliott Bay, Toft et al. (2004) found similar densities of juvenile salmonids at sand/cobble beaches and riprap sites in settings where the riprap extended only into the upper intertidal zone. When riprap extended to the subtidal zone, higher densities of juvenile salmonids were found along riprap than at sand/cobble beaches. Toft et al. (2004) hypothesized that this finding may be based on the fact that the shallow-water habitats preferred by juvenile salmonids were compressed along the highly modified shorelines with steep slopes; therefore, their snorkel observations were able to record all juvenile salmonids present. In comparison, at the sand/cobble beaches, the slopes were gentler, the zone of shallow water was much wider, and densities were therefore lower because the fish were more spread out.

Placement of riprap in the nearshore also generally encourages a shift toward hard-substrate, often invasive, communities (Wasson et al. 2005). It is possible that coarser substrate could benefit some HCP species. An active debate in the scientific community is whether marinas and their protective structures are as productive and diverse as natural hard-rock shorelines, particularly in the Adriatic Sea west of Italy (Bacchiocchi and Airoldi 2003; Guidetti et al. 2005; Bulleri et al. 2006). In addition to the elimination of mobile, sandy habitats, these studies in the Adriatic Sea have shown that maritime structures caused weighted abundances in piscivores and urchins, and decreased abundances of native species that prefer more mobile substrates (e.g., Guidetti et al. 2005). Although species distributions are clearly different in Italy than in Washington State, the steep, paraglacial landscape and relatively short period and locally generated waves make hydraulic and geomorphic variables essentially identical (Finlayson 2006). Complicating the debate is that other maritime activities (i.e., fishing, vessel traffic) are difficult to disentangle from observed effects and likely limit any gain in the transition of habitat type (Blaber et al. 2000; Guidetti et al. 2005).

7.6.2 Riverine Environments

7.6.2.1 Altered Channel Geometry

Channel hydraulics refers to the flow of water in an open channel, such as a river, stream, or tidal channel, as well as the interactions between the flow and the channel boundaries. It also includes the concentrated flow of surface water across the land or the flow of water across a valley floodplain. It can also include the exchange of marine and fresh water in channels under tidal influence.

Water flowing in any open channel is subject to the external force of gravity that propels the water downslope as well as the friction between the water and channel boundaries that tends to resist the downslope movement (Leopold et al. 1964). Resistance to flow is caused by bed roughness, instream and bank vegetation, bank obstructions or irregularities, steps in the channel bed profile, and changes in channel alignment (Knighton 1998). All of these factors influence the hydraulic regime of a channel and dictate the channel morphology and the habitat characteristics of marine and freshwater ecosystems.

7.6.2.1.1 Direct and Indirect Effects

Activities that alter channel hydraulics can influence the channel morphology and in turn alter channel processes that create and sustain suitable habitats for fluvial and marine aquatic organisms. Conceptual models based on key relationships governing channel processes can be used to predict an array of possible channel responses to changes in sediment supply, transport capacity, and external influences such as changes in vegetation and woody debris loading (Gilbert 1917; Lane 1955; Schumm 1971; Montgomery and Buffington 1998; Abbe and Montgomery 2003; Brummer et al. 2006).

The range and magnitude of potential responses and how these responses are transmitted downstream in riverine environments depend on the channel type and location of the disturbed reach in the drainage basin (Schumm 1971; Montgomery and Buffington 1997). Vannote et al. (1980) proposed the river continuum concept to describe freshwater habitat and the importance of various physical, chemical, and biological processes. According to the river continuum concept the distribution of stream characteristics reflects a headwater to mouth gradient of physical conditions that affect the biological components in a river including the location, type, and abundance of food resources with a given stream size. The ecological significance of a potential channel response to channel modification depends on the species of interest. For example, salmonids (e.g., Chinook salmon and bull trout) depend on clean gravels and on hyporheic up- and downwellings for spawning, whereas shellfish depend on fine sediment for burrowing.

The reproduction, growth, and survival of HCP species depend upon particular channel hydraulics to maintain their specific habitats. Alterations to channel geometry can result in reduced growth, fitness, reproductive success, and survival.

7.6.2.2 Altered Flow Velocity

Pilings act as cylindrical flow obstructions that add hydraulic roughness to a channel. Likewise, fill placed in a channel for the construction of jetties, groins, or barbs can act as flow obstructions and add hydraulic roughness. Because flow velocity in a channel is proportional to hydraulic radius and inversely proportional to roughness (Leopold et al. 1964), pilings can alter the flow velocity, depth, and width of a channel. The net effect of artificial fill or pile groups is to confine the flow. The primary effects of flow confinement by artificial structures are increased velocity and bed scour.

Fish and invertebrates inhabiting riverine environments require certain flow velocities for spawning, rearing, and foraging. For example, optimal spatial distribution of juvenile Pacific lamprey in southwest Washington streams includes reaches with current velocities ranging from 0–0.33 ft/sec (0–10 cm/sec) (Stone and Barndt 2005).

While it is unlikely that increases in flow velocities caused by structures associated with marinas/terminals would present potential barriers to fish migration in the low-energy channels where marinas/terminals would operate, it is possible that local velocities could exceed thresholds for the lifestages of some species.

7.6.2.2.1 Direct and Indirect Effects

The placement of pilings, fill, or nonerodible materials associated with the construction, operation, and repair of marinas/terminals can alter channel hydraulics through changes in roughness, channel geometry, and flow velocity. These changes are interrelated and can act in concert to modify channel morphology and interrupt natural habitat-forming processes (Montgomery and Buffington 1998) and even create predatory fish habitat (see Carrasquero [2001] for a related literature review). Alterations to channel hydraulics that change the ability of water to transport and deposit sediment and nutrients can have direct and indirect effects on HCP species; these effects can include modifying or eradicating suitable habitats for various lifestages, as well as altering nutrient flow, prey resources, and foraging opportunities. The effects can result in reduced growth, fitness, reproductive success, and survival for both fish and invertebrates.

7.6.2.3 Altered Substrate Composition

Increased velocities can indirectly affect various species by causing bed scour at channel obstructions (such as man-made structures) and corresponding sediment deposition downstream (Richardson and Davis 2001). Bed scour into a substrate of mixed particle sizes (i.e., sand and gravel) can selectively remove finer sediment and cause the substrate to coarsen. Likewise, deposition of the finer sediment downstream can bury organisms and cause the substrate to become finer. For blunt objects, the depth and extent of bed scour depend on the water depth, approach velocity, and shape and size of the obstruction (Richardson and Davis 2001). For pile groupings, the magnitude of bed scour also depends on the pile diameter, the spacing between piles, the number of pile rows and their staggering, and the alignment of pile rows relative to the principal direction of flow (Salim and Jones 1999; Smith 1999).

The intent of nonerodible substrate (e.g., riprap) is to stabilize channels and limit natural fluvial processes. Bank armoring with nonerodible substrate can coarsen the bed by adding material coarser than the ambient bed and through the attendant effects of channel homogenization. For instance, hardened banks that replace riparian vegetation can increase the flow velocity and potential for scour and substrate coarsening through a reduction in hydraulic roughness compared to vegetated conditions (Millar and Quick 1998). Because of their stability and low hydraulic roughness, hardened banks can act as natural attractors for channels and result in a static channel form lacking habitat diversity (Dykaar and Wigington 2000).

7.6.2.3.1 Direct and Indirect Effects

The ecological effects of substrate coarsening and fining on salmonids and trout in riverine environments are well known. Far less is known about the effects of these disturbances on the life-history stages of other freshwater fish and invertebrates. Large substrates exceeding the maximum size mobilized by spawning fish are avoided during redd building (Kondolf and Wolman 1993). Field observations have shown that salmonids can build redds where the average substrate size (D_{50}) is up to 10 percent of average body length (Kondolf and Wolman 1993). Recommended average sizes for spawning gravels are listed in Table 7-7.

Table 7-7. Spawning gravel criteria for salmonids.

Gravel Bed Criteria	Small-Bodied Salmonids (<13.8 in) (<35 cm)	Large-Bodied Salmonids (>13.8 in) (>35 cm)
Dominant substrate particle size	0.3–2.5 in (8–64 mm)	0.6–5 in (16–128 mm)
Minimum gravel patch size	10.7 ft2 (1.0 m2)	21.5 ft2 (2.0 m2)

Note: Small-bodied salmonids include cutthroat trout. Large-bodied salmonids include coho and Chinook salmon and steelhead trout (after Schuett-Hames et al. 1996).

Scour and substrate coarsening are often accompanied by an increase in the interlocking strength of bed particles and the threshold force necessary for bed mobility (Lane 1955; Church et al. 1998; Konrad 2000).

Substrate fining can adversely affect salmonids and trout by clogging spawning gravel with fine sediment (Zimmermann and Lapointe 2005). Embryo mortality has been found to occur from poor water circulation and lack of oxygenation associated with the filling of intergravel pore spaces by fine sediment (Cooper 1965; Chapman 1988; Lisle and Lewis 1992; Bennett et al. 2003). In a study of spawning chum salmon in low-gradient, gravel-bed channels of Washington and Alaska, Montgomery et al. (1996) found that minor increases in the depth of scour caused by bed fining and reduction in hydraulic roughness significantly reduced embryo survival. The deposition of fine sediment can also affect invertebrates (Wantzen 2006). Fine sediment particles may clog biological retention devices such as filtering nets of caddisfly larvae, or the filtering organs of mollusks. Additionally, overburden from increased deposition has been shown in general to affect invertebrates with low motility (Hinchey et al. 2006).

The addition of large, angular rock to banks is known to affect salmonid habitat and abundance. Knudsen and Dilley (1987) found that abundance of juvenile salmonids was reduced by bank reinforcement activities due to a loss of structural diversity and that these reductions were correlated with the severity of habitat alteration, the size of the stream, and the size of the fish. In a study from California, the primary cause for the decline of salmon in the Sacramento River was linked to the loss of spawning gravels normally derived from bank erosion before riprap bank stabilization (Buer et al. 1984). A comparative study in several western Washington streams found that salmon abundance was less along banks modified with riprap compared to natural banks containing vegetation and woody debris (Peters et al. 1998). Studies comparing the abundance of fish in areas of different size riprap correlate greater fish densities with larger rock (Beamer and Henderson 1998; Lister et al. 1995; Garland et al. 2002). Lister et al. (1995) found that juvenile salmonid densities were greater along banks with riprap greater than 1 foot (30 cm) median diameter compared to natural banks composed of cobble–boulder material presumably due to the cover provided by the relatively larger interstitial spaces created by the coarser bank protection. Indirect effects on fish from bank hardening (i.e., loss of temperature moderation and potential cover) can occur due to the replacement of riparian vegetation with rock (Chapman and Knudsen 1980).

7.6.2.4 Altered Sediment Supply

Channel morphology (i.e., width, depth, bed slope, substrate size, bed forms, and pattern) is influenced by both local and downstream variation in sediment input from watershed sources (sediment supply), the ability of the channel to transmit these loads to downstream reaches (transport capacity), and the effects of instream woody debris and bank vegetation on channel processes (Montgomery and Buffington 1998). The relationship between these controlling factors is illustrated in Figure 7-2.

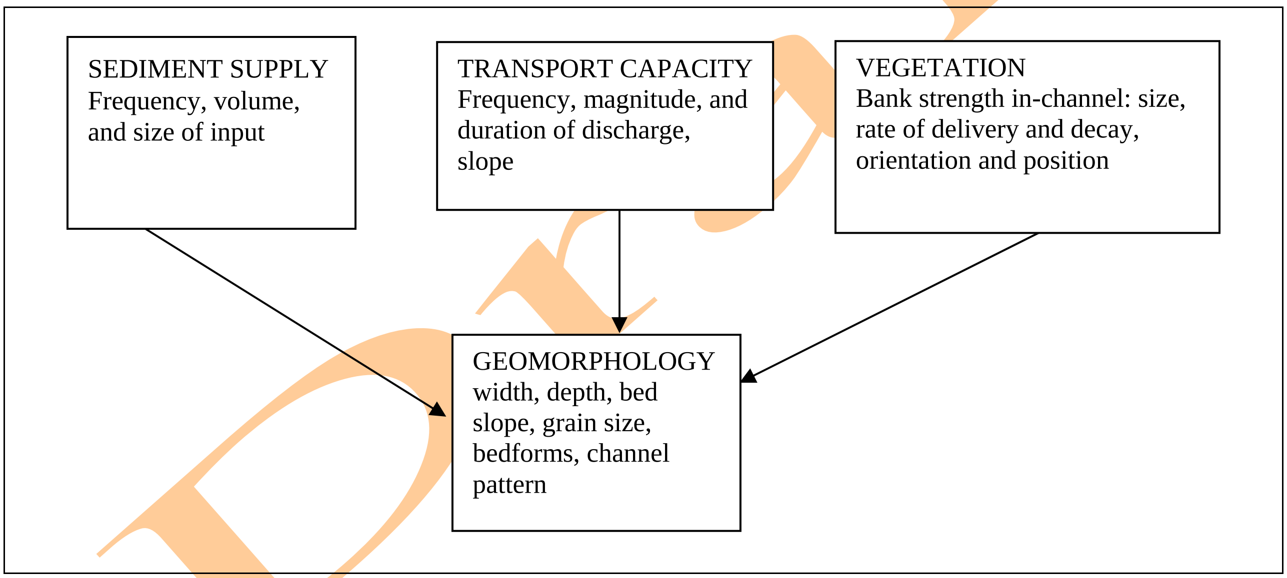

Figure 7-2. Riverine hydraulic controlling factors (adapted from Montgomery and Buffington 1998).

Because the rate and caliber of sediment supplied to a channel can influence the substrate size (Dietrich et al. 1989), changes in sediment supply can alter the composition of substrate used by HCP species.

7.6.2.4.1 Direct and Indirect Effects

Fish and invertebrates require a range of substrate conditions in riverine environments for various life-history stages. These conditions rely on the replenishment of suitably sized substrates to offset natural sediment transport processes that remove sediment. In a study in

California, the primary cause for the decline of salmon in the Sacramento River was linked to the loss of spawning gravels normally derived from bank erosion before riprap bank stabilization (Buer et al. 1984).

Excessive sediment supply can also affect fish and invertebrate species. The direct and indirect effects of increased sediment supply are discussed above in Section 7.6.2.3 (*Altered Substrate Composition*).

7.6.2.5 Groundwater–Surface Water Exchange

Ecological connectivity is essential between riverine and riparian ecosystems (Kelsey and West 1998; Stanford and Ward 1992). In riverine environments, connectivity is generally expressed in three dimensions: longitudinally (upstream–downstream), laterally (channel–floodplain), and vertically (channel–hyporheic zone [the interface between surface and groundwater]) (Edwards 1998; Stanford and Ward 1992).

The quality of habitat connectivity in one dimension may affect that in another dimension. For instance, the hyporheic zone serves as a medium across which dissolved organic matter and nutrients are exchanged between the riparian zone and surface water. A high level of substrate fines within the channel substrate may hinder the connection between surface and groundwater, limiting vertical and lateral connectivity between these two habitat types (Edwards 1998; Pusch et al. 1998). This lack of connectivity can degrade conditions for riparian zone vegetation, potentially reducing LWD recruitment to the stream channel and subsequently limiting habitat-forming and maintaining processes. Effects on ecological functions and freshwater aquatic species associated with degraded connectivity between different riverine habitat elements are well documented (Bisson and Bilby 1998; Montgomery et al. 1999; Naiman et al. 1992; Hershey and Lamberti 1992; Karr 1991; Kelsey and West 1998; Reiman and McIntyre 1993; Stanford et al. 1996; Stanford and Ward 1992).

Stream temperature is an important factor in determining the suitability of habitats for aquatic species. The interface between flow within the hyporheic zone and the stream channel is an important buffer for stream temperatures (Poole and Berman 2001), so alteration of groundwater flow can affect stream temperature. The magnitude of the influence depends on many factors, such as stream channel flow patterns and depth of the aquifer (Poole and Berman 2001).

7.6.2.5.1 Direct and Indirect Effects

Marina/terminal construction or structures that alter groundwater dynamics in riverine systems can directly affect fish and invertebrates in the short term by influencing water quality and habitat suitability or availability. In the long term, changes to groundwater exchange can generate indirect effects on fish and invertebrate species by affecting low-flow conditions (e.g., increasing the magnitude of periods of drought, resulting in reduced habitat availability and suitability, potential stranding or desiccation; and by affecting water quality through warmer stream temperatures and decreased organic and nutrient inputs).

7.6.2.6 Addition of Impervious Surfaces

The addition of impervious surfaces is known to affect the hydrologic regime through changes in the magnitude, volume, and timing of flows (Booth 1991; Konrad 2000). Hydrologic changes that affect the velocity and depth of flows are considered a hydraulic alteration.

7.6.2.6.1 Direct and Indirect Effects

Increased impervious surface area can have local effects on water quality and flow conditions in smaller streams and rivers, as well as on the cumulative effects of urbanization within a watershed. In particular, reduced infiltration can alter stream hydrology such that peak flow levels are increased and base flow levels decreased. Changes in peak flow volumes and the rates at which peak flow levels rise and fall can lead to damaging changes in channel morphology and substrate composition. Decreased base flow levels in summer months can reduce the amount of suitable habitat area available for aquatic species, as well as lead to unfavorable changes in the water temperature regime. Stormwater runoff from impervious surfaces is also likely to carry a range of pollutants known to have detrimental effects on aquatic species, including PAHs, metals, and organic compounds including pesticides, herbicides, fertilizers, and other substances.

Marinas and terminals are unlikely to produce damaging effects on peak and base flow conditions. These facilities are typically developed on larger rivers, lakes, and marine waters that are insensitive to the relatively small amount of impervious surface area created by this type of facility. These types of water bodies are considered flow control exempt by the Washington State Departments of Ecology and Transportation (WSDOT 2006c), meaning that they are considered insensitive to the effects of flow perturbation imposed by impervious surfaces. This exemption applies in ESA consultations as well (WSDOT 2006d).

Untreated stormwater runoff from impervious surfaces associated with marina and terminal projects may impose the aforementioned water quality impacts. The effects of exposure to stressors resulting from these impacts are discussed in detail in Section 7.3 (*Water Quality Modifications*). The cumulative effects of impervious surfaces are discussed in Section 8 (*Cumulative Effects*).

7.6.3 Lacustrine Environments

The impacts of shoreline modifications in lacustrine environments bear some similarity to impacts on marine environments. In both environments wave energy, and sediment recruitment and transport are altered. However, in lakes, these impacts are often exacerbated by differences in human-controlled water-level variability (in the case of reservoirs) and natural lake limnology.

7.6.3.1 Lakes

The hydraulic and geomorphic modifications in lakes have the same six mechanisms of impact as the marine environment (i.e., altered wave energy, altered current velocities, altered nearshore circulation, a loss of groundwater input, altered sediment supply, and altered substrate composition), albeit on a different suite of species. Systematic studies of impacts on the habitat in the lakes in western Washington are extremely limited (Jones & Stokes 2006). Some analysis of habitat types and species distribution has been prepared as part of the development of shoreline master programs, but these only catalog species and activity types and do not provide information about their relation to one another.

7.6.3.1.1 Direct and Indirect Effects

In the absence of literature specifically addressing marina/terminal impacts on lakes in Washington, the best course of action is to adapt the physical processes and related impacts discussed in depth in Section 7.6.1 (*Marine Environments*). To summarize, the three most important differences are:

- *Nearshore circulation*. Nearshore circulation on a lakeshore is fundamentally different than in marine settings. While wave energy is small relative to most marine beaches (see 3rd bullet below); wind plays an important role in driving the circulation (Rao and Schwab 2007). Unlike in the marine environment, where salinity is typically the most important water column constituent, temperature is the dominant factor in maintaining stratification in lakes. Finally, the absence of tides means that water level on the time scale of hours to days is stable, and any terraces that are formed are much more pronounced and discrete. Stratification and isolation of low dissolved oxygen zones are more easily achieved near lakeshores than marine shorelines, affecting all HCP species prone to low dissolved oxygen.

- *Groundwater input*. Because lakes are fundamentally more connected to upland environments, the limiting nutrients in a lake are different than in a marine setting. However, just as in marine environments, benthic productivity and diversity have been linked to groundwater effluent (Hagerthey and Kerfoot 2005; Hunt et al. 2006). Unlike marine environments, lacustrine seeps have high productivity but low species diversity (Hagerthey and Kerfoot 2005; Hunt et al. 2006). Therefore, lacustrine deepwater species such as pygmy whitefish are less likely to be affected by groundwater alteration than marine pelagic species (e.g., rockfish) to the same alterations.

- *Short-period waves*. Because lakes are confined, all of their wave energy must be generated from local winds. This makes all of the waves fetch-limited (Komar 1998). Fetch-limited waves have extremely short periods and small wave heights, compared to their open, marine counterparts. In this sense, lacustrine littoral processes are more similar to those found in Puget Sound (Finlayson 2006). Therefore, alterations to shorelines will not be felt as far from project activities as if they were to occur in the marine environment. The size of area affected by lakeshore development has relevance for sockeye spawning habitat (WDNR 2006a).

Impacts on fish species associated with marina/terminal structures include decreased growth and survival, decreased developmental and migratory fitness, and direct mortality. Migration timing may also be affected for some fish species, ultimately affecting reproductive success.

7.6.3.2 Reservoirs

Human-operated reservoirs present special issues. Reservoirs are morphologically, biologically, and hydrologically dissimilar from natural lakes. Morphologically, lakes are often deepest near the middle, whilst reservoirs are typically deepest at the downstream end. This difference has implications for current strength and direction. The planview of reservoirs can be quite variable, depending on the degree of confinement, but the length of the shoreline is often longer than that of a natural lake. Also, the extent of shoreline development is much greater than in natural lakes because annual drawdown exposes a larger area to shore processes by expanding the area alongshore exposed to wave breaking (Baxter 1977). The location and nature of depositional forms are highly variable with reservoir morphometry, incoming sediment load, and reservoir operation. Reservoirs are also subject to density or turbidity currents resulting from differences in temperature or sediment concentration between inflows and reservoir waters (Snyder et al. 2006). Mixing zones between the water sources influence the usage of reservoir areas by fishes.

Reservoir environments can lack natural habitat due to loss of riparian forest because of flooding, siltation of rocky shorelines, and a paucity of aquatic vegetation resulting from fluctuating water levels (Prince and Maughan 1978). Dependent on reservoir operations, drawdown and filling cycles can re-entrain silty deposits in littoral areas. When jetties, barbs, or breakwaters are constructed, the combined footprint of fill materials and pilings obliterates physical habitat and can exacerbate the degradation of littoral areas.

The installation of pilings as part of marina construction also presents collateral stressors. Pilings may be comprised of steel, concrete, or treated wood. The type of construction material may influence the composition and productivity of food sources including benthic productivity. These changes may include alterations to the location and structure of aquatic communities. Treated wood may also become a source of chemical contamination from substances such as chromated copper arsenate (Kahler et al. 2000)(as discussed above in Section 7.3 [*Water Quality Modifications]*). The process of pile driving also creates a short-term acoustic stressor to fishes in the form of intense underwater sound pressure waves (NOAA Fisheries 2003)(as discussed above in Section 7.1.1 [*Pile Driving*]).

7.6.3.2.1 Direct and Indirect Effects

The presence of structures such as marinas that disrupt either the movement of fishes within the littoral zone or circulation patterns may add to the inherent temperature stressor present in a reservoir. Littoral zones separated from the larger reservoir body may become significantly warmer and exhibit larger diel temperature fluctuations (Kahler et al. 2000). Similarly, structures that extend into the mixing zone may also present a physical barrier to the movement of fishes in and out of these zones. The presence of a jetty was found to restrict circulation between a discharge stream and receiving water (Altayaran and Madany 1992).

Reservoirs are also subject to density or turbidity currents resulting from differences in temperature or sediment concentrations between inflows and reservoir waters (Snyder et al. 2006). Mixing zones and shallow water littoral habitat were preferred by the razorback sucker in Lake Powell, Utah (Karp and Mueller 2002); this study found that these fish primarily use shallow, vegetated habitats in side canyons, but these areas represent less than 1 percent of the available habitat in Lake Powell. However, temperature gradients in reservoirs can fragment these habitats. Mueller et al. (2000) found that temperature gradients caused the razorback sucker to abandon preferred inshore habitat in Lake Mohave, Arizona.

It is likely that HCP species may also be affected by preferred habitat fragmentation induced by temperature gradients. For example, bull trout in reservoirs behave like adfluvial fish and prefer littoral areas (Block 1955; Chisholm et al. 1989). However, bull trout have low upper thermal limits, and the formation of thermal barriers may prevent movement (Selong et al. 2001). Rinne et al. (1981) observed that "fishes introduced into western reservoirs are intrinsically shallow-water, littoral inhabitants," and any structure in this zone may introduce a physical or thermal stressor.

The footprint of a marina also displaces substrate and aquatic vegetation. Littoral areas characterized by submerged and emergent macrophytes are preferred by juvenile fishes (Bryan and Scarnecchia 1992; Meals and Miranda 1991), compared to areas where aquatic vegetation had been removed due to shoreline development. The placement of construction materials can also modify shoreline and substrate erosion rates, circulation and current patterns, and the rate and extent of mixing of dissolved and suspended loads in the water column (NMFS 1998).

Fish also respond to habitat characteristics resulting from the association of shoreline and riparian zone modification. In a study of Wisconsin lakes, the habitat characteristics most influenced by this association were depth, substrate size and embeddedness, and amount of woody vegetation and macrophytes (Jennings et al. 1999). Species richness was greatest where there was complexity in this suite of factors.

8.0 Cumulative Effects

Evidence is increasing that indicates the most devastating environmental effects are most likely not the direct effects of a particular action, but the combination of individually minor effects of multiple actions over time (CEQ 1997).

In general, as marina/terminal structures interact with other development in a given area, impacts will accrue producing a net loss in vegetation production and a concomitant reduction in epibenthic and benthic nearshore habitat. The type and extent of each of these alterations depends on specific site characteristics and structure types. The bathymetry of Washington's inland Puget Sound, as a fjord surrounded by a narrow strip of shallow, vegetated habitat, magnifies the need to protect the integrity and continuity of this limited area of nearshore habitat. Marinas and large terminal structures produce cumulative effects by virtue of the fact that marinas have multiple docks and terminals serving large vessels. They also produce cumulative effects due to the incremental nature of the facilities and the associated development that takes place along the shoreline.

8.1 Construction and Maintenance Activities

Based on lease authorization data, the Washington Department of Natural Resources (WDNR) reported that: (1) of the total of 390 marinas in Washington State, 133 are in freshwater environments; (2) of the 59 total terminals and shipyards, 26 are in fresh water; and (3) of 44 leases for ferry terminals, five are in fresh water (WDNR 2005b). However, not all marinas require WDNR leases. The WDNR Shorezone Inventory (2001) reports a total of 716 large marinas (i.e., over 100-foot slips) along Washington's marine shoreline. Several of the ferry terminals are currently slated for expansion or improvements, including: Anacortes, Bainbridge Island, Eagle Harbor, Edmonds, Mukilteo, Port Townsend, Keystone, and Seattle (Coleman Dock) (WSDOT 2007). It is also reasonable to assume that most of the other facilities in state waters will require at least some maintenance activities if not more substantial improvement activities in order to maintain operations.

Of the four submechanisms associated with construction and maintenance activities, the two that present the greatest risk of cumulative effects are navigation/maintenance dredging and channel/work area dewatering. These submechanisms are discussed in greater detail below.

Analysis of cumulative effects of landscape-scale bathymetry modifications and changes to habitat structure should include the overall scope of dredging activities undertaken in the region. Understanding the scope of current dredging activities requires a breakdown and comparison of the aerial extent of maintenance dredging undertaken annually compared to new project dredging, as well as the extent to which this dredging alters the nature of existing habitats in marine, riverine, and lacustrine environments. An analysis of the scope and nature of current dredging activities can lay the groundwork for assessing the long-term, cumulative effects that dredging activities can pose on existing ecosystem dynamics and the effects such changes may have on a variety of species.

The scope of such an assessment will vary depending on the environment type. For example, in marine environments an assessment might focus on the aerial extent of dredging activities within each of the oceanographically distinct basins in Puget Sound, differentiating habitat impacts in terms of the depth, substrate composition, and bathymetric profile of the affected areas. In lacustrine habitats, the analysis might have a similar focus but would be limited to the individual lake. In riverine environments, a watershed-scale approach or a more targeted approach differentiating estuarine impacts may be appropriate.

Although there are no available studies on the cumulative effects of temporary activities associated with channel dewatering, cumulative effects could result from the permitting of numerous dewatering activities within a watershed over a relatively short period of time. The cumulative impacts on a particular species' population would depend on the number of concurrent projects at a watershed scale, as well as the population size of a given species. The threshold for watershed and population size and the number of activities that must occur within a particular watershed to have a measurable cumulative impact are not yet established in the literature.

8.2 Facility Operation and Vessel Activities

Empirical findings support the notion that marinas/terminals can have measurable effects on the distribution and abundance of riverine, lake, and marine resources. Fish feeding and migration abilities are closely linked to the ambient light environment. To the extent that under-dock environments block light transmission, they pose the risk of diminishing prey resources and triggering behavioral changes of HCP species. As these structures are typically in the shallow nearshore, the impacts on fish would likely be to the juvenile life-history stage. Following a study of ferry terminals in Puget Sound, Haas et al. (2002) reported that large overwater structures pose serious impacts on intertidal and subtidal nearshore habitats. These impacts include reduced benthic vegetation and decreased densities of epibenthic prey. Haas et al. (2002) concluded that the cumulative effects in densely population areas, such as Puget Sound, may be large. The extent to which this impact on prey availability is limiting to juvenile salmon is unknown. Haas et al. (2002) also identified extensive impacts of ferry terminals that pose habitat fragmentation effects.

Cumulative impacts of vessel activities are not known; however, vessel activities associated with marinas and terminals are known to produce erosion-inducing waves, prop wash-induced scouring of aquatic vegetation, and prop wash-induced turbidity. Therefore, cumulative effects would be expected based on projections of future growth. In 1980, total ridership of Washington State Ferries was 16.7 million; by 2002, it increased by 50 percent to 25.1 million. These volumes are projected to continue to increase to 43.4 million riders by 2020 (WSDOT 2006b). Recreational vessel numbers and commercial vessel traffic have also increased, and this trend is expected to continue. Areas repeatedly passed by boats are likely to have accelerated erosion (Bauer et al. 2002). Sandstrom et al. (2005) found that vessel activities had a profound effect on species composition of aquatic plants, and Eriksson et al. (2004) found similar effects on fish species in areas of marinas and ferry boat routes compared to those areas without such boating traffic. Vessel type affects the potential impacts generated by boat traffic. WSDOT is currently in the process of evaluating the feasibility of several different vessel types to replace existing ferries at the Port Townsend and Keystone ferry terminals (WSDOT 2007).

Similarly, because marinas serve multiple vessels, the underwater noise generated by boating activities (i.e., outboard motors) is cumulatively higher than at a single dock. If the marina is surrounded by a breakwater, the noise effect may be limited to the area of the marina. However, as a hub for boats traveling in and out, it would add to the total noise levels in the surrounding area. For shipping and ferry terminals, the potential for increased ambient noise levels, benthic disturbance, ambient light modifications, and water quality degradation is even greater due to year-round boat traffic and the size of the vessels using these facilities.

8.3 Water Quality Modifications

Water quality impacts, such as those discussed in Section 7.3 (*Water Quality Modifications*), are dependent upon the level of use and design of the marina and, in marine environments, the level of tidal exchange within the marina, as well as proximity of the marina to other affected habitat. Studies have shown that marinas with poor tidal exchange are characterized by higher concentrations of pathogens and PAHs than marinas with elevated water circulation. These water quality impacts also apply to marinas/terminals in freshwater environment areas with poor water circulation.

Ferry terminals do not affect water circulation to the degree that marinas do, but both marinas and ferry terminals are associated with docks, shoreline protection structures, and elevated vessel activity. The cumulative impact of these facilities may be manifest through the increased occurrence and degree of usage of individual facilities. Increased dock usage levels can pose risks to water quality through the introduction of sloughing bottom paints, vessel engine exhausts, fuel spillage, overboard sewage discharge, paint and cleaning product contamination, and introduction of contaminants from automobile traffic and asphalted parking lots adjacent to a marina via stormwater (USEPA 2001).

8.4 Riparian Vegetation Modifications

Substantial loss and fragmentation of riparian habitat has occurred in the Puget Sound region over the last 100 years. Although, empirical data are lacking to quantify the extent and quality of riparian habitat, existing data suggest that riparian areas within urbanized shoreline areas such as King County have been significantly altered (up to 100 percent) with upland development and increasing levels of urbanization (Brennan and Culverwell 2004). McClain et al. (1998)

described the process of urbanization in the Pacific Northwest as a trend that moves toward deforestation without replanting.

Naiman et al. (2000) reports that although riparian communities are being managed for a wider-than-ever variety of ecological functions, riparian communities in heavily urbanized environments constrained by pavement are precluded from the full restoration of natural functions. Marinas/terminals, as transportation hubs and pathways for the movement of passengers and freight, require substantial impervious surface and contribute to this general trend.

The Seattle-Tacoma area is an area of intense urbanization. The WDNR Shorezone Inventory (2001) reports that out of a total of 716 large marinas (i.e., over 100-foot slips) along Washington's marine shoreline, 41 percent are in this Seattle-Tacoma area. In contrast, out of the total of 3,000 miles of marine shoreline in Washington State, the Seattle-Tacoma shorelines represent less than 5 percent. In this particular area, marinas and ferry and terminal areas are typically denuded of riparian and shoreline vegetation. A major finding in a study of the cumulative effects of urbanization on 22 Puget Sound streams found that mature forested riparian corridors were effective in mitigating some of the cumulative effects of adjacent development. In riparian corridors found in highly urbanized areas, poor stream quality is common (May 1998).

Site-specific habitat functions are determined by whether an existing shoreline is in a relatively natural state or whether it is affected by urban development; cumulative effects from additional overwater structures also influence habitat functions. A natural environment that supports fish and shellfish spawning, rearing, and refugia is highly valuable from a biological perspective. Any alteration to that specific environment could influence the recruitment of fish and shellfish stocks in the larger ecosystem. As a result, the cumulative impact of additional marina or terminal structures along an ecologically intact shoreline could generate potentially significant cumulative effects.

In contrast, an urban, industrialized shoreline area may have, over a long period of time, lost its native vegetation and suffered major changes to its historical substrates. In that scenario, the addition of a new structure may pose a qualitatively different set of cumulative effects than the effects of the same new structure in a more natural environment.

Biological impacts due to shipping/ferry terminals or the various structures within marinas vary depending on the type of structures, the design of the structures, construction materials, and site location.

8.5 Aquatic Vegetation Modifications

The projected increases in marine ferry traffic and recreational vessel use and size described above will likely result in increased benthic disturbance, turbidity, and eelgrass and macroalgae disturbance. These potential effects, which are primarily associated with grounding, anchoring, and/or prop wash, are described in detail in Section 7.2.1 (*Grounding, Anchoring, and/or Prop Wash*). In freshwater environments, boat use will likely increase as the state population increases, resulting in similar disturbance of bottom substrates and vegetation generated by prop wash.

Existing structures will continue to modify ambient light conditions and subsequently aquatic vegetation via shading and turbidity. An increase in facilities or facility capacity and an overall increase in vessel traffic will likely magnify these impacts. Future construction of new facilities could result in the removal of existing aquatic vegetation, further affecting these resources.

8.6 Hydraulic and Geomorphic Modifications

Numerous studies throughout the world have documented the cumulative impact of shoreline hardening and maritime activities on the coastal ecological communities (Byrnes and Hiland 1995; Guidetti 2004; Meadows et al. 2005; Penland et al. 2005; Wijnberg 2002). The primary impacts addressed by these studies include the disruption of littoral processes as well as hardening of the shoreline and consequent coarsening of the substrate, although other maritime activities likely play a role as well (e.g., fishing) (Blaber et al. 2000; Guidetti et al. 2005). Although the notion of cumulative environmental impacts has been hypothesized to be important in the marine environment in Washington State (e.g., in Puget Sound [Gelfenbaum et al. 2006]), there have been no systematic, peer-reviewed studies that have investigated the phenomenon in Washington waters. Despite this lack of local data, the sum of work performed outside of Washington State documents a general pattern of ecological change due to the construction of shoreline protection structures. In particular, the switch from biological communities preferring soft substrates and relatively quiescent conditions to those preferring higher wave-energies and harder substrates is almost always identified (Meadows et al. 2005; Guidetti 2004; Guidetti et al. 2005). For the outer coast of Washington, the coast of California provides a relevant analog of patterns of ecological changes due to the construction of shoreline protection structures. Although development has been more recent, there has been some documentation of the general hardening of shorelines in California. For instance, Wasson et al. (2005) described the increased prevalence of coarse substrate-dependent (invasive) communities on shoreline works.

Although many of these locales are superficially different from Washington State, some of these studies are particularly germane to anthropogenic environmental degradation. In particular, the paraglacial landscape of the Great Lakes and the Adriatic Sea provide similar templates to the geomorphic variables responsible for nearshore change in the Puget Sound, the Strait of Juan de Fuca, and the large lakes of western Washington (Finlayson 2006). These areas have also been developed for a much longer time (in the case of the Great Lakes, hundreds of years; in northern Italy, millennia), such that the cumulative effect has been made much clearer. For instance, Bearzi et al. (2004) documented the historical loss of marine mammals in the Adriatic and attributed the loss to human activities (in general).

Although there are no known studies specific to the cumulative effects of channel modifications associated with the construction and operation of marinas or terminals, a few studies have documented the cumulative effects of bank hardening on the riverine ecology of large navigable channels where marinas/terminals would be sited. For instance, riprap stabilization of one 15.5-mile (25-km) reach of the Sacramento River was cited as the primary cause of salmon decline in this river due to the loss of spawning gravels previously supplied from bank erosion (Buer et al. 1984; Shields 1991). In a comprehensive study of the historical decline of coho salmon smolt production in the lower Skagit River, Washington, Beechie et al. (1994) found that hydraulic modification from the combined effects of levee construction, bank hardening, and dredging accounted for 73 percent of summer habitat losses and 91 percent of winter habitat losses. Bank stabilization along 25 percent of the 99-mile (160-km) Garrison Reach of the Missouri River in North Dakota nearly eliminated the positive effect of riparian forest on the density of instream woody debris (Angradi et al. 2004).

Previous studies on the cumulative effects of increased impervious areas have focused on the effects of urbanization on the ecology of urban streams. The condition of urban streams is controlled by the altered timing and volume of water, sediment, nutrients, and contaminants resulting from the urbanized catchment (Bernhardt and Palmer 2007). The most noticeable determinant of channel change in urban watersheds was the increase in streamflow discharges (Booth and Henshaw 2001). Increased peak streamflows from urban development cause streams to incise deeper and wider channels (Hammer 1972; Booth 1990; Leopold et al. 2005). The consequence of this channelization is local bank failure, increase in sediment supply, and sediment deposition in lower gradient, downstream reaches (Booth 1990). Konrad (2000) examined urban watersheds in the Puget Lowland and found that urban development increased peak discharge magnitudes and decreased storm flow recession rates, causing “flashy” runoff conditions. Consequently, substrate reworking by flow was more frequent and extensive in urban streams than in suburban streams draining less-developed watersheds. Summer base flow was also suppressed relative to suburban streams. The ecological effects of urbanization on urban streams include species-poor assemblages of fish and invertebrates (Freeman and Schorr 2004).

Although the previous discussion is primarily for urban systems, these cumulative impacts also occur in large river systems where marinas/terminals are more likely to occur.

9.0 Potential Risk of Take

This section provides an assessment of the risk of take resulting from the impact mechanisms associated with marina/terminal construction, operation, and repair.

The following context is used as a basis for the risk of take assessment. First, it is clear that development of marinas/terminals will result in significant modification of the project site and the surrounding area, resulting in a fundamental alteration of the environmental characteristics. The impact mechanisms produced by facility development and operation create environmental stressors. The risk of take resulting from stressor exposure will vary by species depending on the nature of stressor exposure, as well as the sensitivity of the species in question to the stressor. The magnitude, timing, duration, and frequency of each impact mechanism will vary widely with project scale. As such, the assessment of take risk associated with each impact mechanism is necessarily broad and applies a “worst-case scenario” standard, conditioned by the species occurrence and life-history specific uses of habitats suitable for the development of these types of facilities.

The risk of take is rated by impact mechanism for each species using the criteria presented in Table 6-3. As noted, the risk of take rating criteria are defined as follows:

- **High risk of take (H)** ratings are associated with:
  - Stressor exposure is likely to occur with high likelihood of individual take in the form of direct mortality, injury, and/or direct or indirect effects on long-term survival, growth, and fitness potential due to long-term or permanent alteration of habitat capacity or characteristics. Likely to equate to a Likely to Adversely Affect (LTAA) finding.
- **Moderate risk of take (M)** ratings are associated with:
  - Stressor exposure is likely to occur causing take in the form of direct or indirect effects potentially leading to reductions in individual survival, growth, and fitness due to short-term to intermediate-term alteration of habitat characteristics. May equate to an LTAA or a Not Likely to Adversely Affect (NLTAA) finding depending on specific circumstances.
- **Low risk of take (L)** ratings are associated with:
  - Stressor exposure is likely to occur, causing take in the form of temporary disturbance and minor behavioral alteration. Likely to equate to an NLTAA finding.
- **Insignificant or discountable risk of take (I)** ratings apply to:

- ▪ Stressor exposure may potentially occur, but the likelihood is discountable and/or the effects of stressor exposure are insignificant. Likely to equate to an NLTAA finding.

- **No risk of take (N)** ratings apply to species with no likelihood of stressor exposure because they do not occur in habitats that are suitable for the subactivity type in question, or the impact mechanisms caused by the subactivity type will not produce environmental stressors.

- **Unknown risk of take (?)** ratings apply to cases where insufficient data are available to determine the probability of exposure or to assess stressor response.

The risk of take assessment is organized by impact mechanism category and environment type. In cases where the physical effects and related risk of take are similar between environment types, the risk of take discussion is grouped to avoid redundancy. Each of the following subsections provides a general description of the risk of take associated with each impact mechanism. The differences between marina/terminal activity types in terms of the magnitude of impact mechanisms and related stressors are also described. The general description is supported by species-specific risk of take for that mechanism in an accompanying risk evaluation matrix.

9.1 Construction and Maintenance Activities

Construction and maintenance of marinas/terminals involves a diverse array of activities, including driving pilings to secure overwater structures, construction vessel operation, maintenance dredging, and work area dewatering. The majority of these activities are temporary in nature, lasting from a few days to several weeks, depending on the size of the facility in question. The risk of take associated with construction activity varies by impact mechanism and is dependent on the project-specific magnitude of that impact mechanism. As discussed below, some mechanisms may produce a high risk of individual take due to their intensity, while others may result in a moderate risk of take due to limited magnitude and duration. The risk of take associated with this category of impact mechanisms is presented by species in Table 9-1 (presented at the end of the narrative). (Note: the information presented in Tables 9-1 through 9-6 focuses on risk of take; more detailed information for each species—including mechanism of impact, stressor, response to stressor, and resulting effects of an action—is presented in Appendix A.)

In general, impact mechanisms imposed by marinas/terminals will vary only in terms of magnitude, and to a certain extent in the frequency of disturbance associated with construction and maintenance. Specific differences between these subactivity types are described below by impact mechanism.

9.1.1 Pile Driving

Pile driving is an activity with a high potential for direct individual take. As detailed in Section 7.1.1 (*Pile Driving*), sound pressure from pile driving has the potential to cause injury and mortality of aquatic receptors, particularly fish. The potential for injury or mortality varies depending on piling size and composition, pile driving methods, and site-specific environmental characteristics such as bathymetry, intervening land masses, and substrate composition.

Until recently, NOAA Fisheries and USFWS recently recognized underwater noise levels of 150 dB_{RMS} and 180 dB_{peak} as thresholds for disturbance and injury, respectively, of federally listed salmonid species (Stadler 2007; Teachout 2007). While the disturbance threshold still stands, on April 30, 2007, NOAA Fisheries established the following dual criteria to evaluate the onset of physical injury to fishes exposed to underwater noise from impact hammer pile driving (NMFS 2007b):

> ***SEL:*** *A fish receiving an accumulated Sound Exposure Level (SEL) at or above 187 dB re: one micropascal squared-second during the driving of piles likely results in the onset of physical injury; a simple accumulation method shall be used to sum the energy produced during multiple hammer strikes.*

> ***Peak SPL:*** *A fish receiving a peak sound pressure level (SPL) at or above 208 dB re: one micropascal from a single hammer strike likely results in the onset of physical injury.*

Exceedance of either criterion equates to injury. While these new criteria accommodate a more comprehensive evaluation of the effects of sound exposure, it is difficult to compare the SEL threshold to established reference values, which are typically reported in dB_{RMS} or dB_{peak} units. In general, pile driving activities with the greatest potential to cause injury involve large diameter steel piles placed with an impact hammer. Smaller diameter wooden piles placed with a vibratory hammer present the lowest potential for injury and are likely to result in risk of take only in the form temporary disturbance.

During ESA consultation, the criteria listed above would be used in conjunction with the practical spreading loss model (see Section 7.1.1 [*Pile Driving*]) to determine the distance from the source required to attenuate underwater noise to levels below injury and disturbance thresholds. In combination with project scheduling, this information can be used to determine the magnitude, timing, and duration of potential stressor exposure, as well as the dimensions of underwater habitat where stressor exposure may occur.

By virtue of their scale, shipping and ferry terminals are more likely to incorporate large diameter pilings, often steel or concrete, in their designs. In contrast, marinas typically involve smaller scale infrastructure for which lower intensity construction methods using materials such as wood may be appropriate. Underwater construction noise associated with these facilities may not reach sufficient magnitude to cause injury, resulting only in temporary disturbance. Again, however, it is important to recognize that material selection, pile driving methods, and site characteristics are all important determinants governing the potential for take resulting from this impact mechanism.

The risk of take associated with pile driving is presented by species in Table 9-1. The ratings shown apply a "worst-case scenario" perspective to potential exposure (i.e., installation of metal piles using an impact hammer). As shown, available data support estimation of a high risk of take for most fish species. Insufficient data on stressor response are available to estimate risk of take for invertebrate species.

9.1.2 Construction Vessel Operation

Construction vessel operation will result in increased ambient noise levels in and around the project vicinity. In general, vessel noise is usually of insufficient magnitude to cause direct injury to fish. Although this would presumably also apply to invertebrates, insufficient data are available to support this conclusion. As stated in Section 7.1.3 (*Channel/Work Area Dewatering*), increased ambient noise levels can result in auditory masking or can even cause short-term decreases in fish hearing sensitivity, potentially decreasing their ability to sense predators and prey. Increased ambient noise may also result in habitat avoidance, leading to increased stress and competition as displaced individuals seek out other suitable habitats. Increased predation exposure, increased competition, and decreased foraging success can lead to decreased survival, growth, and fitness.

Impacts of construction vessel operation also include the effects associated with deployed anchors, shading cast by the vessels (if they stay in the same place over a longer period of time), and grounding of construction vessels.

In addition, operational discharges from construction vessels result in water quality degradation through the introduction of potentially toxic substances into the marine environment. Risk of take associated with introduction of toxic substances is discussed under Section 9.3 (*Water Quality Modifications*).

In general, effects of construction vessel operation constitute potential for take; however, the overall risk of take associated with this activity is considered moderate because of its limited duration and timing restrictions that will limit the duration of effects on many HCP species (Table 9-1).

9.1.3 Channel/Work Area Dewatering

This construction and maintenance related activity poses a relatively high risk of take. Well-designed protocols and trained personnel are necessary to avoid high levels of mortality. Even with appropriate protocols and experienced field crews, high levels of mortality can result. For example, NOAA Fisheries evaluated take associated with dewatering and fish handling in a recent biological opinion and estimated that salmonid mortality rates as high as 8 percent may occur even when trained personnel are used (NOAA Fisheries 2006).

Mortality rates may be even higher in areas with complex substrate and bathymetry. During the egg, larval, or juvenile life-history stage of many species, individuals may be too small or too cryptic to collect and relocate effectively (e.g., river lamprey ammocoetes that rear buried in fine sediments), meaning that mortality is likely for any individuals trapped within the exclusion area. Even in the absence of mortality, fish handling and relocation may result in stress and injury, as well as increased competition for forage and refuge in the relocation habitat. Even in the absence of these effects, the act of capturing and handling an ESA-listed species constitutes harassment, which is considered a form of take. As such, the permitting of channel and work area dewatering poses a high risk of take of varying levels of severity depending on habitat and species-specific factors (Table 9-1).

9.1.4 Navigation/Maintenance Dredging

Marina/terminal development often involves dredging to establish and maintain approach and navigation channels. Dredging activities are typically temporary to short term in duration, lasting from days to weeks, and recur at interannual to decadal frequencies. Stressors associated with dredging include disturbance and the potential for direct injury or mortality from physical entrainment. The potential for take associated with this stressor varies by species and life-history stage, ranging from low to moderate risk of take (e.g., from limited exposure to disturbance and displacement effects) and high risk of take for non-motile organisms (e.g., exposure to entrainment resulting in injury and/or mortality) (Table 9-1). Generally, many juvenile and most adult fish are sufficiently mobile to avoid entrainment and injury. In combination with timing restrictions, this will limit exposure so that only moderate risk of take will result from activity-related disturbance and temporary or permanent displacement. In contrast, eggs and demersal or planktonic larvae are not mobile and therefore are vulnerable to entrainment, and timing restrictions may not provide protection for all HCP species in all environments. As such, permitted dredging activities associated with marina and shipping/ferry terminal development is likely to result in varying degrees of risk of take.

Dredging will produce associated stressors related to water quality modification that create the potential for take. Specifically, dredging causes increased suspended solids (turbidity), altered substrate composition, and changes in bathymetry leading to alteration in wave energy and current and circulation patterns. In specific cases, dredging may also result in the resuspension of contaminated sediments. Risk of take associated with these impact mechanisms is discussed below under Section 9.3 (*Water Quality Modifications*) and Section 9.6 (*Hydraulic and Geomorphic Modifications*).

9.2 Facility Operation and Vessel Activities

Once a marina or terminal is constructed, the operation of the facility and related vessel activities will impose a suite of ongoing impact mechanisms on the aquatic environment. Stressors associated with these impact mechanisms vary in nature and severity, but are similar in that they will be essentially permanent in duration and common to continuous in frequency.

On the whole, facility and vessel operation at terminals would be expected to produce impact mechanisms of greater magnitude and frequency than marinas. This is not universally true, however, because these types of facilities can vary broadly in scale and activity frequency, and the related impact mechanisms will vary accordingly. For example, a high-volume marine terminal frequented by cargo vessels will clearly produce disturbance at greater magnitude and frequency than a small recreational marina on a lake. In contrast, a low-volume ferry terminal serving a lightly populated area will produce less operational and vessel-related disturbance than a large marina supporting a mix of commercial and recreational vessels. Therefore, it is not practicable to discriminate the risk of take based on facility type alone. It is more pragmatic to estimate risk of take based on receptor life history, which dictates the scale of facility that the species will likely be exposed to. Species occurring in larger rivers, estuaries of large rivers, and the marine environment are more likely to be exposed to larger, higher activity facilities because these environments are more suitable for this type of development. Species occurring only in lakes or smaller rivers will not receive the same type of exposure, as these environments are more suitable for smaller-scale facilities supporting predominantly recreational uses. The risk of take associated with this category of impact mechanisms is presented by species in Table 9-2 (presented at the end of the narrative).

9.2.1 Grounding, Anchoring, and Prop Wash

Grounding, anchoring, and prop wash are forms of direct disturbance from vessel activity associated with marinas/terminals. The species-specific risk of take rating associated with this mechanism (Table 9-2) incorporate a "worst-case scenario" perspective regarding stressor exposure. As shown in the table, the risk of take for receptors exposed to this stressor is variable, with likelihood of adverse effects dependent on project-specific considerations. In general, the risk of take from stressors associated with this impact mechanism is low to moderate for species and life-history stages that do not utilize the affected habitat extensively and are mobile and can avoid the stressor with minor behavioral alteration. In contrast, species that are less mobile or have less mobile life-history stages that are exposed to this stressor may experience a moderate to high potential for take from this impact mechanism.

Even in the absence of direct risk of take, repeated exposure to grounding, anchoring, and prop wash is likely to cause effectively permanent alteration of substrate characteristics and the aquatic vegetation community. These effects will also lead to potential for take, as described in Sections 9.5 (*Aquatic Vegetation Modifications*) and 9.6 (*Hydraulic and Geomorphic Modifications*).

9.2.2 Vessel Maintenance and Operational Discharges

Vessel maintenance and operational discharges result in water quality degradation through the introduction of potentially toxic substances into the marine environment. Risk of take associated with introduction of toxic substances is discussed in Section 9.3.3 (*Introduction of Toxic Substances*). The ratings of species-specific risk of take associated with this stressor (Table 9-2) are based on a combination of the general effects of receptor exposure to toxic substances and the duration and frequency of potential exposure resulting from facility operation. Because the associated stressors are likely to occur at a greater frequency over the long term, this submechanism is generally associated with a high risk of take.

9.2.3 Increased or Altered Ambient Noise Levels

The effects of facility and vessel operation on ambient noise levels are similar to those described above in Section 9.1.2 (*Construction Vessel Operation*); but unlike construction activities, the duration of stressor exposure is essentially permanent at frequencies ranging from intermittent to continuous depending on the type of facility involved. As such, this impact mechanism essentially results in permanent alteration of the habitat characteristics within the marina or terminal site and the surrounding area. Stressor response is also similar, but the risks of take associated with this mechanism are greater because of the longer duration and higher frequency of exposure.

The risk of take associated with this impact mechanism will vary broadly across the marina/terminal activity types, and is largely dependent on the scale of the facility. In general, shipping or ferry terminals frequented by large vessels capable of producing high levels of underwater noise would be expected to produce a higher level of risk of take, as the potential for auditory masking and hearing threshold effects are greater; in addition, the higher level of ambient noise may encourage avoidance behavior. However, large marinas frequented by numerous commercial and recreational vessels may also produce considerable ambient noise and related risk of take that are comparable to or exceed smaller shipping terminals. In contrast, smaller marinas serving recreational vessels may produce less pronounced effects on ambient noise levels overall, with seasonal peaks in activity punctuated by long periods of decreased stressor exposure.

The species-specific risk of take rating associated with this mechanism (Table 9-2) incorporate a “worst-case scenario” perspective regarding stressor exposure. As shown, receptors exposed to this stressor are generally likely to experience a high risk of take, with likelihood of adverse effects dependent on project-specific considerations.

9.2.4 Ambient Light Modifications

Marinas/terminals clearly alter ambient light conditions in the nearshore environment. Ambient light modification produces stressors that predominantly affect fish species. For example, daytime shading produced by overwater structures and vessels and nighttime lighting both modify the ambient light environment, forcing behavioral adaptations by exposed fish. Structural shading can also lead to alteration of submerged aquatic vegetation, producing additional impact mechanisms. In marine environments, the diffusion of small bubbles from cavitation and prop wash can also modify the ambient light environment by diminishing light penetration, again resulting in additional impact mechanisms caused by alteration of submerged aquatic vegetation. Risk of take ratings associated with this impact mechanism address only the effects on receptors resulting from direct exposure to shading and the behavioral adaptations that result. Risk of take ratings resulting from shading-induced alteration of aquatic vegetation are addressed in Section 9.5 (*Aquatic Vegetation Modifications*).

Risk of take associated with this stressor varies by species and affected environment types. In general, fish species that are exposed to this stressor, particularly in lacustrine and nearshore marine environments, will alter their behavior, with variable effects on survival, growth, and fitness. In contrast, the sensitivity of invertebrates to this stressor is less understood. The species-specific risk of take rating associated with this mechanism (Table 9-2) incorporate a "worst-case scenario" perspective regarding stressor exposure. As shown, receptors exposed to this stressor are generally likely to experience a high risk of take because the habitat alterations associated with this stressor, and resulting effects on survival, growth, and fitness, are long term in nature.

9.3 Water Quality Modifications

Water quality modification is a broad category covering a number of impact mechanisms and related stressors. These impact mechanisms can be produced by a variety of activities associated with the development and operation of marinas/terminals. The severity of individual stressors will vary depending on the nature of the effect; its magnitude, duration, and frequency; and the sensitivity of the species and life-history stage exposed.

As described previously for facility operation and vessel activities, it is not practicable to clearly delineate a difference between marinas/terminals in the magnitude of water quality related impact mechanisms they produce. The size of the facility, its operation and maintenance requirements, and the intensity of vessel traffic will determine stressor intensity. Again, for the purpose of assessing risk of take associated with these facilities, a "worst-case scenario" approach is taken with consideration of the scale of facility that a given species is likely exposed to in each environment type. Species-specific risk of take ratings by impact mechanism are shown in Table 9-3 (presented at the end of the narrative).

9.3.1 Increased Suspended Solids

Increased suspended solids can result from several different impact mechanisms. The severity of this stressor will vary depending on its magnitude, duration, and frequency, as well as the sensitivity of the species and life-history stage exposed. In general, mobile species and life-history stages exposed to temporary sediment impacts at low occurrence frequency will experience only temporary disturbance and behavioral alteration and low risk of take (Table 9-3). In contrast, sessile invertebrates or relatively immobile life-history stages (e.g., demersal larvae) exposed to the same stressor may experience decreased survival and reduced foraging opportunities, leading to a moderate risk of take. More frequent or longer duration sediment impacts will have more pronounced effects on even mobile species. Such exposure can cause behavioral alteration for longer periods, potentially increasing stress, exertion and predation exposure, decreasing foraging opportunities, or even causing injury in extreme events.

9.3.2 Resuspension of Contaminated Sediments

Dredging, grounding and anchoring, pile driving, and other activities can result in the resuspension of previously contaminated sediments. Depending on the nature and concentration of the contaminant and the duration of exposure, the toxic substances in contaminated sediments can cause a range of adverse effects in exposed species. These effects may include physiological injury and/or contaminant bioaccumulation leading to decreased survival, growth, and fitness. This presents a moderate risk of take to species potentially exposed to this stressor (Table 9-3).

9.3.3 Introduction of Toxic Substances

Construction and operation of marinas/terminals presents multiple pathways for the introduction of a range of toxic substances to the aquatic environment. Depending on the nature and concentration of the contaminant, toxic substance exposure can cause a range of adverse effects in exposed species. In extreme cases, these effects can include direct mortality. More commonly, chronic, low-level exposure to a variety of contaminants is likely to cause physiological injury and/or contaminant bioaccumulation leading to decreased survival, growth, and fitness. This presents a moderate risk of take to species potentially exposed to this stressor (Table 9-3).

9.3.4 Altered Dissolved Oxygen Levels

There are limited pathways through which marina/terminal projects can lead to alterations in surface water dissolved oxygen levels that are not implicitly addressed by other impact mechanisms. In extreme circumstances, nutrient-rich discharge from shipboard sanitary systems or ballast water may cause temporary or short-term decreases in dissolved oxygen levels. A large decrease in aquatic vegetation may limit photosynthetic production of oxygen, but the likelihood of this effect substantially decreasing dissolved oxygen levels is quite limited. In general, the likelihood of this stressor occurring as a direct or indirect result of marina/terminal development is low. Fish species that are highly mobile will generally be able to avoid adverse effects through behavioral avoidance, translating to a low risk of take. In contrast, sessile invertebrates and less mobile life-history stages could experience direct mortality as a result of exposure, equating to moderate or even high risk of take depending on species-specific life history. However, because of the low likelihood of occurrence, the overall risk of take associated with this stressor is considered low for all species.

9.3.5 Altered pH Levels

There are limited pathways through which marina/terminal projects can lead to alterations in surface water pH. A primary pathway is the in-water curing of concrete and discharge of concrete leachate to surface waters. Concrete, cement, mortars, grouts, and other portland cement or lime-containing construction materials are alkaline in nature and are capable of measurably raising pH. Operational discharges and accidental spills of acidic or caustic materials may also lead to alteration of normal pH levels.

Increases or decreases in pH that exceed the normal tolerance thresholds of fish and invertebrates are highly toxic and can rapidly cause acute mortality. Risk of take from this impact mechanism is generally higher in fresh water than in marine waters. Salt water has an inherent buffering capacity that limits the changes in alkalinity. In general, this stressor will be limited to low-frequency events that are temporary to short term in duration. Fish species that are highly mobile will generally be able to avoid adverse effects through behavioral avoidance, translating to a low risk of take. In contrast, sessile invertebrates and less mobile life-history stages could experience direct mortality as a result of exposure, equating to high risk of take where sensitive life-history stages occur in environments suitable for marina/terminal development (Table 9-3).

9.3.6 Use of Creosote-treated Wood

Creosote-treated wood was often used historically in pilings, docks and piers, bulkheads, and other structures associated with marina/terminal development. This substance is still permitted in some circumstances. Creosote is a wood preservative with a complex formula composed of more than 150 toxic chemical substances. These toxic substances are expected to produce the same risk of take as described above in Section 9.3.3 (*Introduction of Toxic Substances*) (i.e., a moderate risk of take to species potentially exposed to this stressor). WACs 220-110-060 and -224 prohibit the use of creosote- and pentachlorophenol-treated wood in lakes; therefore, exposure to this stressor will not occur in most lacustrine habitats for new projects. There is some uncertainty about potential exposure in lacustrine environments because the applicability of this statute to reservoirs (which are functionally similar to lacustrine environments) is not clear.

9.3.7 Use of ACZA and CCA Type C Treated Wood

Prohibitions on the use of creosote, pentachlorophenol, and other wood preservatives employed in marina/terminal development have prompted the development of alternatives. ACZA and CCA type C are alternative wood preservatives that are less toxic than prohibited materials, but are still effective against undesirable invertebrates. These substances, which slowly leach out of treated wood over time, have incidental toxicity to other forms of aquatic life as well as the potential to bioaccumulate. These toxic substances are expected to produce the same risk of take as described above in Section 9.3.3 (*Introduction of Toxic Substances*) (i.e., a high risk of take to species potentially exposed to this stressor) (Table 9-3).

9.3.8 Increased Stormwater and Nonpoint Source Pollution

Permitting of marinas/terminals will implicitly authorize the development of some amount of associated impervious surface. Runoff from these surfaces that is not detained and treated or infiltrated will transport toxic substances and contaminated sediments to the aquatic environment, creating a new permanent stressor of temporary to short-term duration, occurring at common frequencies with seasonal peaks. Depending on the nature and concentration of the transported contaminants, stormwater-related toxic substances can cause a range of adverse effects on exposed species. In extreme cases, these effects can include direct mortality. More commonly, chronic, low-level exposure to a variety of contaminants is likely to cause physiological injury and/or contaminant bioaccumulation leading to decreased survival, growth, and fitness. This presents a high risk of take for species potentially exposed to these stressors.

9.4 Riparian Vegetation Modifications

The development of marina/terminal projects will inherently involve the modification of riparian vegetation in the project area, as well as the subsequent imposition of a number of impact mechanisms and related stressors on the aquatic environment. The nature of these mechanisms and stressors varies slightly between riverine, marine, and lacustrine environments. As such, the risk of take in these different environment types is discussed separately. Species-specific risk of take ratings for the impact mechanisms resulting from riparian vegetation modifications are presented by environment type in Table 9-4 (presented at the end of the narrative).

As with the other categories of impact mechanisms addressed in this white paper, the nature and scale of riparian vegetation modifications cannot readily be distinguished between marina/terminal project types. Rather, they depend on the size and design of the individual project in combination with site-specific conditions. It is also important to note that the majority of riparian vegetation modifications associated with these types of projects involves permanent conversion to an armored shoreline using bulkheads or some similar structure. These types of shoreline modifications impose a separate group of effects on the aquatic environment. The impact mechanisms and risk of take associated with shoreline modifications are discussed in a separate white paper (Shoreline Modifications White Paper [Herrera 2007a]).

9.4.1 Marine Environments

Marina/terminal projects in the marine environment will unavoidably affect marine riparian vegetation, resulting in the imposition of several impact mechanisms and related stressors on the nearshore environment. Risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment and, where supported by available science, the demonstrated dependence of the species in question on riparian functions. For many species, the risk of take associated with marine riparian impact mechanisms is unknown because scientific understanding of the related ecological processes is in its infancy, and the extent to which many marine or anadromous species rely on the nearshore environment during their life history is unclear.

9.4.1.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

The influence of riparian shading on water temperatures in the nearshore marine environment is limited in most circumstances. However, specific microhabitats (e.g., upper intertidal beaches used as spawning habitat by various fish species, pocket estuaries that are isolated during tidal exchange) can experience significant changes in microclimatic conditions when riparian vegetation is altered. This equates to high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness, and these effects will be long term in nature (Table 9-4).

9.4.1.2 Altered Shoreline and Bluff Stability

Depending on site-specific conditions, modification of marine riparian vegetation can lead to clear alteration of shoreline and bluff stability. In the context of marina/terminal projects, this effect can be variable depending on specific design elements. Most riparian modification associated with these projects will involve the permanent conversion of the shoreline with bulkheads and other forms of armoring, increasing shoreline and bluff stability locally, as well as possibly decreased stability elsewhere through alteration of wave energy. In other cases, unmitigated vegetation alteration may decrease stability. The effects of this stressor on receptors can be similarly variable. In general, however, this stressor would be expected to alter shoreline habitat conditions and habitat suitability for species dependent on the nearshore environment during some portion of their life history. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness, and these effects will be long term in nature (Table 9-4).

9.4.1.3 Altered Allochthonous Inputs

Allochthonous inputs to the nearshore environment from marine riparian vegetation include leaf litter, and terrestrial insect-fall, as well as inputs of LWD. These inputs clearly contribute to aquatic food web productivity, but the science regarding the significance of these inputs in the marine environment is relatively limited. LWD recruitment is an important contributor to habitat structure. Because this stressor has the potential to alter food web productivity and habitat complexity, it is likely to affect the survival, growth, and fitness of species dependent on the nearshore environment for foraging and rearing during some portion of their life history. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in food web productivity caused by these impact mechanisms will lead to reduced survival, growth, and fitness, and these effects will be long term in nature (Table 9-4).

9.4.1.4 Altered Habitat Complexity

The physical structure of marine riparian vegetation, allochthonous inputs of LWD, shoreline stability, and effects on localized microhabitat conditions all contribute to habitat structure and complexity of the nearshore environment. Alteration of habitat complexity can have demonstrable effects on the productivity of aquatic species dependent on the nearshore environment, particularly fish species that spawn and rear in these areas, through effects on survival, growth, and fitness. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness, and these effects will be long term in nature (Table 9-4).

9.4.1.5 Altered Freshwater Inputs

Freshwater inputs to the nearshore environment are demonstrably linked to a number of important habitat parameters such as temperatures in forage fish spawning substrates, eelgrass distribution, and habitat selection by certain fish species. Alteration of groundwater inputs would be expected to cause a corresponding alteration in the distribution of desirable habitat features and availability for species dependent on the nearshore environment. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness, and these effects will be intermediate term to long term in duration (Table 9-4).

9.4.2 Riverine Environments

Marina/terminal projects in riverine environments will in almost all cases be limited to higher order (i.e., large) river environments or the lower reaches and estuaries of medium-sized rivers that are suitable for this type of development. As such, the effects of riparian vegetation modification will be limited to specific segments of the river continuum where the influence of riparian vegetation on the aquatic environment is less pronounced than it is in lower order stream systems. This factor strongly influences the risk of take associated with specific impact mechanisms resulting from riparian vegetation modification.

9.4.2.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

Removal of riparian vegetation can demonstrably affect the temperatures of streams and lower order river environments, producing a range of potential effects on fish and wildlife species. In higher order river environments suitable for marina/terminal development, this effect will be far less pronounced. Water temperatures in systems of this nature are less influenced by localized shading and ambient air temperature than by the combined effects of basin conditions in upstream areas of the watershed, hydromodification (e.g., dam and reservoir development), and other factors that influence water temperatures flowing through the affected area.

On this basis, the risk of take associated with this impact mechanism is viewed to be insignificant and the localized effects discountable in the vast majority of environments suitable for marina/terminal development (Table 9-4).

9.4.2.2 Altered Stream Bank Stability

Removal of riparian vegetation can affect shoreline stability through the reduction in root cohesion and the loss of large woody debris (LWD) inputs that affect localized erosion and scour conditions. It is important to note that in the majority of marina/terminal projects, modification of riparian habitat usually involves permanent conversion of the habitat using bulkheads and other forms of shoreline armoring intended to stabilize banks. As discussed in Herrera (2007a), these activities impose a multitude of stressors on the aquatic environment and their own risk of take.

In the worst-case scenario, however, riparian vegetation modification associated with a permitted project could result in decreased stream bank and shoreline stability, as well as increased erosion and turbidity. These effects will be localized and predominant during seasonal high-flow conditions. Risk of take associated with this stressor varies depending on species-specific sensitivity to increased turbidity. In general, more mobile fish species will experience only temporary behavioral alteration and low risk of take. In contrast, less mobile fish life-history stages or sessile invertebrates could experience high risk of take from decreased survival due to long-term substrate sedimentation and burial, as well as decreased growth and fitness due to the effects of high turbidity on foraging success (Table 9-4).

9.4.2.3 Altered Allochthonous Inputs

Riparian vegetation is an important source of nutrient input to the aquatic environment, strongly influencing the productivity of the aquatic food chain. Allochthonous nutrient inputs include sources such as insect-fall, leaf litter and other organic debris, and LWD inputs that contribute both organic material and habitat complexity. The importance of allochthonous inputs to riverine food web productivity decreases along a downstream gradient, however, as rivers grow in size and the contributions of autochthonous production and nutrient cycling to the food web increase.

Marina/terminal projects are limited to the lower reaches of larger river systems in virtually all circumstances, meaning that they are located in a position on the river continuum where allochthonous inputs are less important to overall food web productivity. On this basis, the loss of allochthonous production from riparian vegetation modification at the scale of a typical terminal or marina project is likely to have an insignificant effect on food web productivity and foraging opportunities as a whole (Table 9-4).

In a worst-case scenario, a large marina shipping terminal project could alter a large amount of riparian area, leading to a localized reduction in allochthonous inputs in a relatively enclosed circulation environment. However, these effects are not expected to be significant relative to the broader effects on habitat suitability imposed by the activity.

9.4.2.4 Altered Habitat Complexity

The influence of riparian vegetation on riverine habitat complexity is broadly recognized. Modification of riparian vegetation alters habitat complexity in a number of ways, primarily through the loss of undercut banks, root structure, and LWD inputs to the channel. The hydraulic and geomorphic effects of riparian vegetation modification can lead to further alterations in habitat complexity. This impact mechanism presents potential risk of take for a broad range of species dependent on riverine aquatic ecosystems through a variety of species-specific stressors. Depending on the particular life history of the affected species, alteration in habitat complexity may limit the availability of suitable spawning, resting, and rearing habitat, and may alter foraging opportunities and predation exposure. In general, fish species that are dependent on habitats potentially affected through this mechanism of impact by marina/terminal development are likely to experience decreased spawning success and/or decreased survival, growth, and fitness due to an overall reduction in suitable habitat area. Because these effects are long term in nature, they equate to a high risk of take, which applies broadly across all species (Table 9-4).

9.4.2.5 Altered Groundwater-Surface Water Exchange

The influence of riparian vegetation on hyporheic exchange is well documented as an important component of ecosystem health. Alteration of riparian vegetation can in turn lead to alteration of surface water and groundwater exchange, with important effects on the riverine ecosystem. This impact mechanism will be expressed predominantly in the lower reaches of higher order river systems suitable for marina/terminal development. This distribution of impacts limits the potential exposure of related stressors to a narrower range of species and species life-history stages, but the potential risk of take caused by this mechanism is nonetheless significant. For example, some salmonid populations that spawn in the mainstems of large river systems are dependent on groundwater inflow to maintain spawning habitat quality. For rearing salmonids and other temperature-sensitive species, groundwater inflow may provide thermal refuges important for survival during summer rearing periods. Hyporheic connectivity is also an important component of food web productivity. As such, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. Therefore, this mechanism is generally equated with a high risk of take for species exposed to this stressor, depending on species-specific life-history characteristics (Table 9-4).

9.4.3 Lacustrine Environments

Marina/terminal projects in the lacustrine environment will unavoidably affect riparian vegetation, resulting in the imposition of several impact mechanisms and related stressors on the nearshore environment. Risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment and, where supported by available science, the demonstrated dependence of the species in question on riparian functions.

9.4.3.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

Riparian shading in lacustrine environments can have a pronounced effect on nearshore water temperatures. The effect of riparian modification on the ambient air temperature regime is less clear and is dependent on a range of site-specific environmental factors. In general, water temperatures in lacustrine environments are predominantly driven by solar radiation exposure, seasonal stratification, turnover rate, and the temperature of source water. However, specific microhabitats such as shallow waters in protected embayments may be sensitive to temperature effects if shading and ambient air temperatures are altered by riparian modification. Such temperature effects may alter the suitability of these habitats for species that utilize them during some portion of their life history. These effects would be long term in duration and seasonal in frequency, meaning that these habitats may be unavailable or unsuitable for rearing for a significant segment of a population's life history. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness (Table 9-4).

9.4.3.2 Altered Shoreline Stability

Depending on site-specific conditions, modification of lacustrine riparian vegetation can lead to alteration of shoreline stability conditions. In the context of marina/terminal projects, this effect can be variable depending on specific design elements. Most riparian modification associated with these projects will involve the permanent conversion of the shoreline with bulkheads and other forms of armoring, leading to locally increased shoreline stability, and possibly decreased stability elsewhere through the alteration of short-period wave energy patterns. In other cases, unmitigated vegetation alteration may lead to decreased stability and cyclical shoreline erosion. In general, however, this stressor would be expected to alter shoreline habitat conditions and habitat suitability for species dependent on the nearshore environment during some portion of their life history. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness (Table 9-4).

9.4.3.3 Altered Allochthonous Inputs

Allochthonous inputs to the lacustrine environment from riparian vegetation include leaf litter, other organic debris, and terrestrial insect-fall, as well as inputs of LWD. These inputs clearly contribute to aquatic food web productivity, and LWD recruitment is also an important contributor to habitat structure. Because this stressor has the potential to alter food web productivity and habitat complexity, it is likely to affect the survival, growth, and fitness of species dependent on the nearshore environment for foraging and rearing during some portion of their life history. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in food web productivity caused by these impact mechanisms will lead to reduced survival, growth, and fitness (Table 9-4).

9.4.3.4 Altered Habitat Complexity

The physical structure of lacustrine riparian vegetation, allochthonous inputs of LWD, shoreline stability, and effects on localized microhabitat conditions all contribute to habitat structure and complexity of the nearshore environment. Alteration of habitat complexity can have demonstrable effects on the productivity of aquatic species dependent on the nearshore environment, particularly fish species that spawn and rear in these areas, through effects on survival, growth, and fitness. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness (Table 9-4).

9.4.3.5 Altered Groundwater-Surface Water Exchange

Groundwater inputs to the lacustrine nearshore environment provide beneficial microhabitat conditions for a range of species. For example, beach spawning sockeye salmon populations are dependent on groundwater-fed beaches for spawning habitat. Juvenile salmonids rearing in nearshore environments may also depend on thermal refugia provided by groundwater inflow. Alteration of groundwater inputs would be expected to cause a corresponding alteration in the distribution of desirable habitat features and availability for species dependent on the nearshore environment. This equates to a high risk of take for species with demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness (Table 9-4).

9.5 Aquatic Vegetation Modifications

Both the construction and operation of marinas/terminals can result in aquatic vegetation modifications. During construction, vegetation in the structural footprint of the project will be eradicated or buried by the placement of fill or structural material. After construction, vegetation growth and persistence can be affected by changes in ambient light conditions caused by vessel and structural shading. Changes in wave energy, flow and/or current velocities, and substrate composition can also lead to alteration of the vegetation community.

Alteration of aquatic vegetation imposes impact mechanisms on the nearshore environment in the form of changes in autochthonous production and altered habitat complexity. The nature of these mechanisms and related stressors varies slightly between riverine and lacustrine habitats versus marine habitats, primarily because the role of aquatic vegetation differs between these systems. As such, the risk of take in these different environment types is discussed separately. Species-specific risk of take ratings for the impact mechanisms resulting from aquatic vegetation modifications are presented by environment type in Table 9-5 (presented at the end of the narrative).

As with the other categories of impact mechanisms addressed in this white paper, the nature and scale of aquatic vegetation modifications cannot readily be distinguished between marina/terminal project types. Rather, they depend on the size and design of the individual project in combination with site-specific conditions. One effect, however, appears to be more prevalent in association with ferry terminals in marine waters; ferries create a profusion of small bubbles by propeller cavitation when they decelerate quickly as they approach the terminals. These bubbles are so abundant they can affect light penetration. When vessel operation occurs at sufficient frequency, the reduction in light penetration may be sufficient to affect vegetation growth and persistence.

9.5.1 Marine Littoral Environments

Submerged aquatic vegetation (including eelgrass, kelp, and other forms of marine algae) is an important component of the marine littoral ecosystem, relied upon by many species during critical life-history stages.

9.5.1.1 Altered Autochthonous Production

Autochthonous production by submerged aquatic vegetation is a source of primary and secondary production in the aquatic food web of the marine littoral zone. A diversity of species feed directly on live and fragmented submerged aquatic vegetation, forming the basis of the food web for a number of other species. Alteration of marine littoral vegetation caused by marina/terminal projects may in some cases lead to localized shifts in food web productivity, possibly affecting foraging opportunities for dependent species and life-history stages. This translates to a high risk of take resulting from decreased growth and fitness (Table 9-5).

9.5.1.2 Altered Habitat Complexity

The contribution of submerged aquatic vegetation to habitat structure in nearshore marine environments is well recognized. Numerous species use these habitats for cover and rearing during larval and juvenile life-history stages. Submerged aquatic vegetation also provides spawning habitat for Pacific herring. Alterations of the submerged aquatic vegetation community through reduction in aerial extent or conversion to other habitat types (e.g., conversion of eelgrass habitat to algae and kelp) can reduce the productivity of these habitats for dependent life-history stages. This translates to a high risk of take for species dependent on these habitats through reduced survival, spawning success, or growth and fitness (Table 9-5).

9.5.2 Riverine and Lacustrine Environments

Aquatic vegetation is a relatively minor component of the ecological structure of riverine and lacustrine systems in Washington State. Aside from native emergent vegetation confined to a relatively narrow range of depths, the majority of aquatic vegetation species in lake systems are invasive exotic species.

9.5.2.1 Altered Autochthonous Production

Modification of the submerged aquatic vegetation community in lakes and rivers can lead to decreased primary and secondary productivity, which in turn may affect overall food web productivity in the nearshore environment. Risk of take associated with this submechanism varies, depending on the degree to which the affected species relies on the productivity of the freshwater environment. For example, species such as chum and pink salmon would be expected to face an insignificant risk of take from this submechanism in riverine environments because their residence time is short and they are not functionally feeding. In contrast, species such as mountain sucker, dace, and other species that forage in and around aquatic vegetation may face high risk of take due to indirect effects on foraging success, growth, and fitness of species (Table 9-5).

9.5.2.2 Altered Habitat Complexity

Submerged aquatic vegetation (SAV) provides habitat structure in nearshore environments, creating vertical dimension and overhead cover. Alteration of habitat complexity can decrease the availability of suitable rearing habitat for species and life-history stages dependent on the nearshore environment, leading to increased predation risk and increased competition for suitable space, leading to effects on survival, growth, and fitness. Marinas/terminals are likely to lead to effectively permanent modification of the aquatic vegetation community. This translates to a high risk of take for species dependent on aquatic vegetation functions in these environments (Table 9-5).

9.6 Hydraulic and Geomorphic Modifications

The development of marina/terminal projects will inherently involve modification of hydraulic and geomorphic conditions in the project vicinity, as well as the subsequent imposition of a number of impact mechanisms and related stressors on the aquatic environment. The nature of these mechanisms and stressors varies slightly between riverine, marine, and lacustrine environments. As such, the risk of take in these different environment types is discussed separately here. Species specific risk of take ratings for the impact mechanisms resulting from modification of hydraulic and geomorphic conditions are presented by habitat type in Table 9-6 (presented at the end of the narrative).

As with the other categories of impact mechanisms addressed in this white paper, the nature and scale of these modifications cannot readily be distinguished between marina/terminal project types. Rather, it is dependent on the size and design of the individual project in combination with site-specific conditions. It is also important to note that these impact mechanisms will largely be caused through permanent reconfiguration of the shoreline and nearshore environment using shoreline armoring, jetties, and other hard structures. The impact mechanisms and risk of take associated with the construction of these specific project activity types are discussed in Herrera (2007a), the Shoreline Modifications white paper. The impact mechanisms associated with hydraulic and geomorphic modifications are discussed here.

9.6.1 Marine Environments

Marina/terminal projects in the marine environment will unavoidably modify hydraulic and geomorphic conditions in the nearshore marine environment, resulting in the imposition of several impact mechanisms and related stressors. Risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment.

9.6.1.1 Altered Wave Energy, Altered Current Velocities, and Altered Nearshore Circulation Patterns

Wave energy, current velocities, and circulation patterns are all important determinants governing nearshore marine habitat characteristics. These factors determine habitat suitability for a number of species-specific life history processes. For example, wave energy conditions, currents, and circulation patterns will have a strong influence on nearshore water temperatures and on the sorting and transport of sediments. Many fish species selectively spawn in locations where current and circulation patterns promote settling of planktonic larvae in favorable environments for rearing. Alteration of these patterns can cause larvae to be transported to unfavorable environments. Similarly, juvenile fish rearing in nearshore environments selectively choose environments with suitable wave energy and current conditions. These impact mechanisms can fundamentally alter habitat suitability for these uses, leading to decreased survival, growth, and fitness. This translates to a high risk of take for species that are dependent on these habitats during some phase of their life history, due to the long-term duration of these effects (Table 9-6).

9.6.1.2 Altered Sediment Supply and Altered Substrate Composition

Sediment supply and substrate composition are fundamental components of nearshore ecosystem structure. The physical alteration of the shoreline environment that accompanies marina/terminal development can lead to alterations in sediment supply and substrate conditions through fragmentation of the shoreline environment from sources of sediment recruitment, as well as the interruption or alteration of longshore sediment transport. In conjunction with altered wave energy, this can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the nearshore environment, these habitat changes can fundamentally alter community structure and habitat suitability for species dependent on the original habitat condition. This translates to a high risk of take for species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed lifestages (Table 9-6).

9.6.1.3 Altered Freshwater Inputs

Freshwater inputs to the nearshore environment are demonstrably linked to a number of important habitat parameters such as temperatures in forage fish spawning substrates, eelgrass distribution, and habitat selection by certain fish species. Alteration of groundwater inputs would be expected to cause a corresponding alteration in the distribution of desirable habitat features and availability for species dependent on the nearshore environment. This equates to a high risk of take for species with demonstrable dependence on these habitats (Table 9-6) because freshwater inputs will likely still occur; however, they will be modified, resulting in a potential reduction in suitable habitat area which in turn will lead to reduced survival, growth, and fitness.

9.6.1.4 Addition of Impervious Surface

Marinas and terminals are unlikely to produce damaging effects on peak and base flow conditions in marine waters. Marine water bodies (as well as the larger rivers and lakes suitable for marina and terminal development) are insensitive to the relatively small amount of impervious surface area created by this type of facility. These types of water bodies are considered flow control exempt by the Washington State Departments of Ecology and Transportation (WSDOT 2006c), meaning that for regulatory purposes they are considered insensitive to the effects of flow perturbation imposed by impervious surfaces. Flow effects in flow control exempt water bodies are not considered a source of take for ESA consultation purposes (WSDOT 2006d), meaning that the risk of take is considered insignificant and discountable (Table 9-6). However, water quality related effects may still occur. Risk of take from water quality related stressor exposure is discussed in Section 9.3.8 (*Increased Stormwater and Nonopoint Source Pollution*).

9.6.2 Riverine Environments

Marina/terminal projects in riverine environments will in almost all cases be limited to higher order (i.e., large) river environments or the lower reaches and estuaries of medium-sized rivers that are suitable for this type of development. As such, the effects of hydraulic and geomorphic modification will be limited to specific segments of the river continuum, and the resulting risk of take will be dependent on the sensitivity of the species and life-history stages that utilize the affected habitats.

9.6.2.1 Altered Channel Geometry, Altered Flow Velocity, and Altered Substrate Composition

Channel geometry, flow conditions, and substrate composition are all dominant factors determining aquatic habitat structure in riverine environments. Alteration of any of these habitat components can change the suitability of the habitat for various life-history stages of HCP species. These habitat alterations will be essentially permanent and continuous, and can lead to changes in the productivity of the habitat for spawning, forage, rearing, and refuge. In a worst-case scenario, these effects are in turn likely to lead to reduced spawning success, as well as reduced survival, growth, and fitness for species and life-history stages dependent on the affected habitat. This equates to a high risk of take for species with exposure to these impact mechanisms (see Table 9-6).

9.6.2.2 Altered Groundwater-Surface Water Exchange

Hydraulic and geomorphic modifications can influence and alter groundwater and surface water exchange in the vicinity of the modification. As discussed in Section 9.4.1 (*Marine Environments*), this hyporheic exchange is an important component of ecosystem function in riverine environments. As such, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. This mechanism is generally equated with a high risk of take for species exposed to this stressor, depending on species-specific life-history characteristics (Table 9-6).

9.6.2.3 Addition of Impervious Surface

Permitting of marinas/terminals will implicitly authorize the development of some amount of associated impervious surface. Runoff from these surfaces that is not detained or infiltrated will alter peak flows entering the receiving body and, in theory, could result in localized alteration of hydraulic conditions. In reality, however, the larger rivers suitable for marina and terminal development are insensitive to the relatively small amount of impervious surface area created by this type of facility. These types of water bodies are considered flow control exempt by the Washington State Departments of Ecology and Transportation (WSDOT 2006c), meaning that for regulatory purposes they are considered insensitive to the effects of flow perturbation imposed by impervious surfaces. Flow effects in flow control exempt water bodies are not considered a source of take for ESA consultation purposes (WSDOT 2006d), meaning that the risk of take is considered insignificant and discountable. Therefore, the risk of take resulting from this stressor will be insignificant (Table 9-6).

9.6.3 Lacustrine Environments

Marina/terminal projects in the marine environment will unavoidably modify hydraulic and geomorphic conditions in the lacustrine environment, resulting in the imposition of several impact mechanisms and related stressors. Risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment.

9.6.3.1 Altered Wave Energy, Altered Current Velocities, and Altered Nearshore Circulation Patterns

Wave energy, current velocities, and circulation patterns are all important determinants governing nearshore lacustrine habitat characteristics. These processes strongly influence nearshore water temperatures and other water quality parameters, shoreline stability, and the accumulation of allochthonous and autochthonous materials. Alteration of these parameters can fundamentally alter the suitability of nearshore habitats for species dependent on these habitats, leading to decreased survival, growth, and fitness. This translates to a high risk of take for species that are dependent on these habitats during some phase of their life history (Table 9-6).

9.6.3.2 Altered Sediment Supply and Altered Substrate Composition

Sediment supply and substrate composition are also fundamental components of nearshore ecosystem structure. The physical alteration of the shoreline environment that accompanies marina/terminal development can lead to alterations in sediment supply and substrate conditions through fragmentation of the shoreline environment from sources of sediment recruitment, as well as the interruption or alteration of longshore sediment transport. In conjunction with altered wave energy, this can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the lacustrine environment, these habitat changes can fundamentally alter community structure and habitat suitability for species dependent on the original habitat condition. This translates to a high risk of take for species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed lifestages (Table 9-6).

9.6.3.3 Altered Groundwater–Surface Water Exchange

Hydraulic and geomorphic modifications can influence and alter groundwater and surface water exchange in the vicinity of the modifications. As discussed in Section 9.4.3 (*Lacustrine Environments*), groundwater and surface water exchange is an important component of ecosystem function in lacustrine environments. As such, this impact mechanism has the potential to affect survival, growth, fitness, and (in some cases) the spawning productivity of a range of species. Therefore, this mechanism is generally equated with a risk of take ranging from low to high for species exposed to this stressor, depending on species-specific life-history characteristics and habitat requirements (Table 9-6).

9.6.3.4 Addition of Impervious Surface

Risk of take associated with this stressor in lacustrine environments will be the same as described in Section 9.6.1 (*Marine Environments*) (i.e., insignificant risk of take), because the larger lakes suitable for marina and terminal development are considered flow control exempt (WSDOT 2006c).

Table 9-1. Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal construction and maintenance activities.

Species	Pile Driving			Construction Vessel Operation			Channel/Work Area Dewatering			Navigation/ Maintenance Dredging			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	H	H	M	M	M	H	H	H	M	M	M	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors.
Coho salmon	H	H	H	M	M	M	H	H	H	M	L	M	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Chum salmon	H	H	I	M	M	I	H	H	I	M	M	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum may spawn in the lower reaches of large river environments (e.g., the Columbia River) and may therefore be subject to temporary effects of maintenance dredging on spawning habitat, as well as juvenile and adult exposure during migration. Juvenile chum salmon are dependent on nearshore marine habitats and are therefore subject to stressor exposure from marina/terminal development in these environments.
Pink salmon	H	H	I	M	M	I	H	H	I	M	M	I	Pink salmon in Washington State do not use lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure.
Sockeye salmon	H	H	H	M	M	M	H	H	H	M	L	M	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. However, some populations spawn in nearshore lacustrine habitats, creating increased risk of stressor exposure at sensitive egg and alevin life-history stages. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor. Avoidance of impacts on juvenile sockeye in lacustrine environments is difficult due to year-round residence.
Steelhead	H	L	H	L	L	M	H	L	H	M	L	M	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these habitat types is unknown.
Coastal cutthroat trout	H	H	H	L	L	M	H	H	H	M	M	M	This species is prevalent in estuaries and large rivers and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Westslope cutthroat trout	I	N	H	I	N	M	I	N	H	I	N	M	These species occur primarily in coldwater streams and small to medium sized rivers, and in lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.
Redband trout	I	N	H	I	N	M	I	N	H	I	N	M	
Bull trout	H	H	H	M	M	M	H	H	H	M	M	M	Spawning by these species occurs in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, as well as riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults.
Dolly Varden	H	H	H	M	M	M	H	H	H	M	M	M	
Pygmy whitefish	N	N	H	N	N	M	N	N	H	N	N	M	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development; therefore, stressor exposure will only occur in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	H	N	H	L	N	M	H	N	H	M	N	M	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development.
Lake chub	I	N	I	N	N	I	I	N	I	I	N	I	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development. Therefore, the likelihood of stressor exposure is considered discountable.
Leopard dace	H	N	H	M	N	M	H	N	H	M	N	M	This species has been reported in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Umatilla dace	H	N	H	M	N	M	H	N	H	M	N	M	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal construction and maintenance activities.

Species	Pile Driving			Construction Vessel Operation			Channel/Work Area Dewatering			Navigation/ Maintenance Dredging			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
River lamprey	H	H	H	?	?	?	H	H	H	H	M	H	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of larger rivers to rear for extended periods, potentially years. In their saltwater phase, river lamprey remain close to shore for periods of 10 to 16 weeks from spring through fall. They are therefore susceptible to dredging and dewatering impacts. Sound sensitivity of primitive fishes such as lamprey is currently a data gap, so the potential effects of this stressor are unknown. This life-history makes this species particularly sensitive to dredging and dewatering in lakes and rivers, as well as in the nearshore marine environment. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Pacific lamprey	H	H	H	?	I	?	H	I	H	H	L	H	Pacific lamprey are anadromous with migratory corridors that cross estuaries and mainstems of larger river systems suitable for marina/terminal development. Ammocoetes burrow into riverine sediments to rear for extended periods. They are therefore susceptible to dredging and dewatering impacts in freshwater environments. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6 to 40 months. Sound sensitivity of primitive fishes such as lamprey is currently a data gap, so the potential effects of this stressor are unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Green sturgeon	N	H	N	N	?	N	N	L	N	N	M	N	In Washington, white sturgeon are found in the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. Although this species is considered anadromous, some populations in the Columbia River may be reproducing successfully in some impoundments. Sturgeon eggs are demersal and adhesive. Larval sturgeon are essentially planktonic and rear in quiet backwaters of the large rivers and lakes where they are transported by currents following emergence. These life-history stages are therefore sensitive to dewatering, dredging, and other direct impacts. Green sturgeon fisheries occur in the Columbia River below Bonneville Dam, Willapa Bay, and Grays Harbor. Individuals are also occasionally caught incidentally in small coastal bays and the Puget Sound. Sturgeon are wide ranging in marine waters. Dependence on nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in nearshore habitats.
White sturgeon	H	H	H	L	?	L	H	L	H	M	M	M	
Longfin smelt	H	H	N	M	M	N	H	H	H	H	H	H	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. Demersal adhesive eggs are vulnerable to short-term dewatering and dredging impacts. Adults, eggs, and larvae are vulnerable to impacts from pile driving. Planktonic larvae and juveniles of these species may also be vulnerable to stressor exposure in the nearshore marine environment during early rearing. Mature juveniles and adults are found in offshore environments.
Eulachon	H	H	N	M	M	N	H	H	N	H	H	N	
Pacific sand lance	N	H	N	N	M	N	N	H	N	N	H	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high.
Surf smelt	N	H	N	N	M	N	N	H	N	N	H	N	
Pacific herring	N	H	N	N	M	N	N	H	N	N	H	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure is high.
Lingcod	N	H	N	N	M	N	N	H	N	N	H	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are subject to impacts from dewatering and dredging. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Temporary disturbance while brooding may increase risk of egg predation. Low mobility larvae settle in nearshore areas, increasing risk of take from dredging and dewatering.
Pacific hake	N	H	N	N	M	N	N	H	N	N	H	N	Hake, cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Larvae and smaller juveniles of all three species may be at higher risk of dredging entrainment due to limited mobility.
Pacific cod	N	H	N	N	M	N	N	H	N	N	H	N	
Walleye pollock	N	H	N	N	M	N	N	H	N	N	H	N	

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal construction and maintenance activities.

Species	Pile Driving			Construction Vessel Operation			Channel/Work Area Dewatering			Navigation/ Maintenance Dredging			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Brown rockfish	N	H	N	N	M	N	N	H	N	N	H	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Planktonic larvae and demersal juveniles are particularly vulnerable to dewatering and fish handling, as well as dredging activities.
Copper rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Greenstriped rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Widow rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Yellowtail rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Quillback rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Black rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
China rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Tiger rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Bocaccio rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Canary rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Redstripe rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Yelloweye rockfish	N	H	N	N	M	N	N	H	N	N	H	N	
Olympia oyster	N	?	N	N	M	N	N	H	N	N	H	N	Olympia oysters are found in intertidal and subtidal environments potentially subject to dredging and dewatering impacts. Exposure to these impact mechanisms could lead to direct mortality or injury. Sound sensitivity of this species is currently a data gap, and the effects of related stressors are unknown.
Northern abalone	N	?	N	N	M	N	N	H	N	N	H	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. This distribution increases risk of stressor exposure and potential for take from dewatering and dredging activities. Effects of underwater noise on mollusks is a data gap so the potential for take related to this stressor is unknown.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	This species inhabits a narrow band of upper littoral zone habitat above MHHW and is therefore not exposed to stressors resulting from in-water construction activities.
Giant Columbia River limpet	?	N	N	?	N	?	?	N	N	I	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. This distribution likely limits exposure to navigational dredging. Exposure to work area dewatering is possible, but sensitivity to this stressor is a data gap so the potential for take is unknown. The effects of underwater noise on mollusks are currently a data gap so the potential for take related to this stressor is unknown.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	
California floater (mussel)	?	N	?	?	N	?	H	N	H	H	N	H	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. This distribution presents risk of stressor exposure and potential for take, particularly from dewatering and dredging activities. Exposure to dewatering can cause mortality in both species. The effects of underwater noise on mollusks is currently a data gap so the potential for take related to this stressor is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	?	N	N	?	N	N	H	N	N	H	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-2. Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal facility operation and vessel activities.

Species	Grounding, Anchoring, and/or Prop Wash			Vessel Maintenance and Operational Discharges			Increased or Altered Ambient Noise Levels			Ambient Light Modifications			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	H	H	H	H	H	L	L	L	L	H	H	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Ambient light modification is a recognized stressor for this species in nearshore marine and lacustrine environments.
Coho salmon	H	H	H	H	M	H	L	L	L	L	?	H	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Ambient light modification is a likely source of risk of take for this species in nearshore lacustrine environments and may also pose risk of take in marine environments. However, as juvenile coho salmon are more typically found farther from shore, the effects of shading are less clear; therefore, the risk of take in the marine environment is uncertain.
Chum salmon	H	H	I	H	H	I	L	L	I	L	H	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum may spawn in the lower reaches of large river environments (e.g., the Columbia River) and may therefore be subject to facility and vessel operational effects dredging on spawning habitat, in addition to juvenile and adult exposure during migration. Juvenile chum salmon are dependent on nearshore marine habitats, and are therefore subject to stressor exposure from marina/terminal development in these environments. Ambient light modification is a recognized stressor for this species, resulting in a moderate risk of take from chronic behavioral alteration.
Pink salmon	H	H	I	H	H	I	L	L	I	L	H	I	Pink salmon in Washington State do not use lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure.
Sockeye salmon	H	L	H	H	H	H	L	L	L	L	?	H	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. However, some populations spawn in nearshore lacustrine habitats, creating increased risk of stressor exposure at sensitive egg and alevin life-history stages. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor. Avoidance of impacts on juvenile sockeye in lacustrine environments is difficult due to year-round residence. Ambient light modification is a likely source of risk of take for this species in nearshore lacustrine environments and may also pose risk of take in marine environments. However, as juvenile sockeye salmon are more typically found farther from shore, the effects of shading are less clear; therefore, the risk of take in the marine environment is uncertain.
Steelhead	H	L	H	H	H	H	L	L	L	L	?	H	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these habitat types is unknown. Ambient light modification is a potential source of take for this species in nearshore lacustrine environments and may also pose risk of take in marine environments. However, as juvenile steelhead are more typically found farther from shore, the effects of shading are less clear; therefore, the risk of take in the marine environment is uncertain.
Coastal cutthroat trout	H	H	H	H	H	H	L	L	L	H	H	H	This species is prevalent in estuaries and large rivers and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable. Spawning and juvenile rearing activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Ambient light modification is a likely source of risk of take for this species in nearshore marine environments, based on similar sensitivity of other salmonid species in these environments.
Westslope cutthroat trout	I	N	H	I	N	H	I	N	L	I	N	H	These species occur primarily in coldwater streams, small to medium-sized rivers, and in lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely. Ambient light modification is a likely source of risk of take for these species in nearshore lacustrine environments, based on similar sensitivity of other salmonid species in these environments.
Redband trout	I	N	H	I	N	H	I	N	L	I	N	H	
Bull trout	H	H	H	H	H	H	L	L	L	?	?	?	Spawning by these species occurs in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, as well as riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults. Sensitivity to this stressor in lacustrine environments is a data gap. However, char in lakes are typically found in deeper water.
Dolly Varden	H	H	H	H	H	H	L	L	L	?	?	?	
Pygmy whitefish	N	N	H	N	N	H	N	N	L	N	N	?	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development; therefore, stressor exposure will only occur in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	H	N	H	H	N	H	M	N	M	?	N	?	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development. Sensitivity of this species to ambient light modification is currently a data gap; therefore, the potential for take resulting from this stressor is unknown.
Lake chub	N	N	N	N	N	N	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development.

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal facility operation and vessel activities.

Species	Grounding, Anchoring, and/or Prop Wash			Vessel Maintenance and Operational Discharges			Increased or Altered Ambient Noise Levels			Ambient Light Modifications			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Leopard dace	H	N	H	H	N	H	M	N	M	?	N	?	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Umatilla dace	H	N	H	H	N	H	M	N	M	?	N	?	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.
River lamprey	H	H	H	H	H	H	?	?	?	?	I	?	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of larger rivers to rear for extended periods, potentially years. In their saltwater phase, river lamprey remain close to shore for periods of 10 to 16 weeks from spring through fall. They are therefore susceptible to injury or mortality from grounding, anchoring, and prop wash. Sensitivity to ambient noise and light modification in lamprey is currently a data gap so the potential effects of these stressors are unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Pacific lamprey	H	I	H	H	L	H	?	?	?	?	?	?	Pacific lamprey are anadromous, with migratory corridors that cross estuaries and mainstems of larger river systems suitable for marina/terminal development. Ammocoetes burrow into riverine sediments to rear for extended periods. They are therefore susceptible to injury or mortality from grounding, anchoring, and prop wash. Sensitivity to ambient noise and light modification in lamprey is currently a data gap so the potential effects of these stressors are unknown. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6 to 40 months. Sound sensitivity of primitive fishes such as lamprey is currently a data gap so the potential effects of this stressor are unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Green sturgeon	N	L	N	N	H	N	N	?	N	N	?	N	In Washington, white sturgeon are found in the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. Although this species is considered anadromous, some populations in the Columbia River may be reproducing successfully in some impoundments. Sturgeon eggs are demersal and adhesive. Larval sturgeon are essentially planktonic and rear in quiet backwaters of the large rivers and lakes where they are transported by currents following emergence. These life-history stages are therefore sensitive to grounding, anchoring, and other direct impacts. Individuals are occasionally caught incidentally in small coastal bays and the Puget Sound. Sturgeon are wide ranging in marine waters. Green sturgeon fisheries occur in the Columbia River below Bonneville Dam, Willapa Bay, and Grays Harbor. Dependence on nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in nearshore habitats. Sensitivity to ambient noise and light modification in primitive fishes like sturgeon is currently a data gap so the potential effects of these stressors are unknown.
White sturgeon	H	L	H	H	H	H	?	?	?	?	?	?	
Longfin smelt	H	L	H	H	H	H	L	H	H	?	?	?	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. Adults, eggs, and larvae are vulnerable to impacts from vessel anchoring and grounding, and other operational impacts. Planktonic larvae and juveniles of these species may also be vulnerable to stressor exposure in the nearshore marine environment during early rearing. Mature juveniles and adults occupy offshore environments and are therefore not at risk of take from marina/terminal related impact mechanisms until they return to nearshore and riverine environments for spawning. Smelt sensitivity to ambient light modification is a data gap; therefore, the risk of take from this stressor is uncertain.
Eulachon	H	L	N	H	H	N	L	H	N	?	?	N	
Pacific sand lance	N	H	N	N	H	N	N	L	N	N	?	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high. Smelt and sand lance sensitivity to ambient light modification is a data gap; therefore, the risk of take resulting from this stressor is uncertain.
Surf smelt	N	H	N	N	H	N	N	L	N	N	?	N	
Pacific herring	N	H	N	N	H	N	N	H	N	N	H	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure is high. Sensitivity of spawning habitat and incubating eggs from vessel grounding, anchoring, and prop wash is high, meaning that there is high risk of take resulting from this stressor. Herring display demonstrable sensitivity to vessel noise, meaning that risk of take from ambient noise modification is likely.
Lingcod	N	H	N	N	H	N	N	H	N	N	H	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are subject to impacts from vessel ground, anchoring and prop wash, and other operational impact mechanisms. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Temporary disturbance while brooding may increase risk of egg predation. Low-mobility larvae settle in nearshore areas, increasing risk of take from grounding, anchoring, and prop wash. Lingcod sensitivity to ambient light modification is a data gap, meaning the risk of take resulting from this stressor is unknown.
Pacific hake	N	H	N	N	H	N	N	H	N	N	?	N	Hake, cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Low-mobility larvae settle in nearshore areas, increasing risk of take from grounding, anchoring, and prop wash. The sensitivity of these species to ambient light modification is a data gap, meaning the risk of take resulting from this stressor is unknown.
Pacific cod	N	H	N	N	H	N	N	H	N	N	?	N	
Walleye pollock	N	H	N	N	H	N	N	H	N	N	?	N	

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with marina/terminal facility operation and vessel activities.

Species	Grounding, Anchoring, and/or Prop Wash			Vessel Maintenance and Operational Discharges			Increased or Altered Ambient Noise Levels			Ambient Light Modifications			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Brown rockfish	N	H	N	N	H	N	N	H	N	N	?	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Demersal larvae are vulnerable to injury and mortality from grounding, anchoring, and prop wash. The sensitivity of these species to ambient light modification is a data gap, meaning the risk of take resulting from this stressor is unknown.
Copper rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Greenstriped rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Widow rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Yellowtail rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Quillback rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Black rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
China rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Tiger rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Bocaccio rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Canary rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Redstripe rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Yelloweye rockfish	N	H	N	N	H	N	N	H	N	N	?	N	
Olympia oyster	N	H	N	N	H	N	N	H	N	N	?	N	This species occurs commonly in shallow nearshore habitats. This distribution increases risk of stressor exposure and potential for take from grounding and anchoring activities. The effect of underwater noise and ambient light modification on mollusks is a data gap; therefore, the related risk of take is unknown.
Northern abalone	N	H	N	N	H	N	N	H	N	N	?	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. This distribution increases risk of stressor exposure and potential for take from grounding and anchoring activities. The effect of underwater noise and ambient light modification on mollusks is a data gap; therefore, the related risk of take is unknown.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	This species inhabits a narrow band of upper littoral zone habitat above MHHW and is therefore not exposed to stressors resulting from marina/terminal operation.
Giant Columbia River limpet	H	N	N	H	N	N	?	N	?	?	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. This distribution may increase exposure to anchoring and prop wash. The effect of ambient light and noise modification on mollusks is currently a data gap so the potential for take related to this stressor is unknown.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	
California floater (mussel)	H	N	H	H	N	H	?	N	?	?	N	?	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. This distribution presents risk of stressor exposure and potential for take, particularly from grounding, anchoring, and prop wash. The effect of ambient light and noise modification on mollusks is currently a data gap so the potential for take related to this stressor is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	H	N	N	H	N	N	?	N	N	?	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-3. Species- and habitat-specific risk of take for mechanisms of impact associated with water quality modifications caused by marinas/terminals.

Species	Increased Suspended Solids			Resuspension of Contaminated Sediments			Introduction of Toxic Substances			Altered pH			Altered Dissolved Oxygen			Use of Creosote-Treated Wood			Use of ACZA and CCA Type C Treated Wood			Increased Stormwater and Nonpoint Source Pollution			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	M	M	M	M	M	M	M	M	M	L	L	L	L	L	L	M	H	N	M	M	M	M	M	M	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors.
Coho salmon	M	M	M	M	M	M	M	M	M	L	L	L	L	L	L	M	H	N	M	M	M	M	M	M	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Chum salmon	M	M	I	M	M	I	M	M	I	L	L	I	L	L	I	M	H	N	M	M	I	M	M	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum may spawn in the lower reaches of large river environments (e.g., the Columbia River). As such, in addition to migratory juveniles and adults, spawning habitats may therefore be exposed to water quality related stressors. Juvenile chum salmon are dependent on nearshore marine habitats and are therefore subject to stressor exposure from marina/terminal development in these environments.
Pink salmon	M	M	I	M	M	I	M	M	I	L	L	I	L	L	I	M	H	N	M	M	I	M	M	I	Pink salmon in Washington State do not use lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure.
Sockeye salmon	M	M	M	M	M	M	M	M	M	L	L	M	L	L	L	M	H	N	M	M	M	M	M	M	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. However, some populations spawn in nearshore lacustrine habitats, creating increased risk of stressor exposure at sensitive egg and alevin life-history stages. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor. Avoidance of impacts on juvenile sockeye in lacustrine environments is difficult due to year-round residence.
Steelhead	M	M	M	L	M	M	M	M	M	L	L	L	L	L	L	M	M	N	M	M	M	M	M	M	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these habitat types is unknown. As juvenile steelhead are more typically found farther from shore, the effects of shading are less clear; therefore, the risk of take in the marine environment is uncertain.
Coastal cutthroat trout	M	M	M	M	M	M	M	M	M	L	L	L	L	L	L	M	M	N	M	M	M	M	M	M	This species is prevalent in estuaries and large rivers and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Westslope cutthroat trout	I	N	M	I	N	M	I	N	M	I	N	L	I	N	L	I	N	N	I	N	L	I	N	M	These species occur primarily in coldwater streams, small to medium-sized rivers, and lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.
Redband trout	I	N	M	I	N	M	I	N	M	I	N	L	I	N	L	I	N	N	I	N	L	I	N	M	

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with water quality modifications caused by marinas/terminals.

	Increased Suspended Solids			Resuspension of Contaminated Sediments			Introduction of Toxic Substances			Altered pH			Altered Dissolved Oxygen			Use of Creosote-Treated Wood			Use of ACZA and CCA Type C Treated Wood			Increased Stormwater and Nonpoint Source Pollution			
Species	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	**Comments**
Bull trout	M	M	M	L	M	M	M	M	M	L	L	L	L	L	L	M	M	N	M	M	M	M	M	M	Spawning by these species occurs in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, as well as in riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults. However, char in lakes are typically found in deeper water.
Dolly Varden	M	M	M	L	M	M	M	M	M	L	L	L	L	L	L	M	M	N	M	M	M	M	M	M	
Pygmy whitefish	N	N	M	N	N	M	N	N	M	N	N	L	N	N	L	N	N	N	N	N	M	N	N	M	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development; therefore, stressor exposure will only occur in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	M	N	M	M	N	M	M	N	M	M	N	M	L	N	L	M	N	N	M	N	N	M	N	M	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development.
Lake chub	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development.
Leopard dace	M	N	M	M	N	M	M	N	M	M	N	M	L	N	L	M	N	N	M	N	M	M	N	M	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Umatilla dace	M	N	M	M	N	M	M	N	M	M	N	M	L	N	L	M	N	N	M	N	M	M	N	M	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development at sensitive life-history stages, including egg incubation.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.
River lamprey	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	N	M	M	M	M	M	M	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of larger rivers to rear for extended periods, potentially years. This nonmobile life-history stage is more susceptible to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. In their saltwater phase, river lamprey remain close to shore for periods of 10 to 16 weeks from spring through fall, increasing exposure to stressors in the nearshore environment. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with water quality modifications caused by marinas/terminals.

Species	Increased Suspended Solids			Resuspension of Contaminated Sediments			Introduction of Toxic Substances			Altered pH			Altered Dissolved Oxygen			Use of Creosote-Treated Wood			Use of ACZA and CCA Type C Treated Wood			Increased Stormwater and Nonpoint Source Pollution			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Pacific lamprey	M	L	M	M	L	M	M	L	M	M	L	M	M	L	M	M	L	N	M	L	M	M	L	M	Pacific lamprey are anadromous with migratory corridors that cross estuaries and mainstems of larger river systems suitable for marina/terminal development. Ammocoetes burrow into riverine sediments to rear for extended periods. This nonmobile life-history stage is more susceptible to acute transient water quality impacts, such as reduced dissolved oxygen or altered pH. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6 to 40 months and are therefore less likely to be exposed to project-related stressors in the nearshore marine environment. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Green sturgeon	N	L	N	N	M	N	N	M	N	N	L	N	N	L	N	N	M	N	N	M	N	N	M	N	In Washington, white sturgeon are found in the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. Although this species is considered to be anadromous, populations in the Columbia River may be reproducing successfully in some impoundments. Sturgeon eggs are demersal and adhesive. Larval sturgeon are essentially planktonic and rear in quiet backwaters of the large rivers and lakes where they are transported by currents following emergence. These life-history stages are therefore potentially exposed to water quality related impact mechanisms from marinas/terminals. Their relative lack of mobility increases sensitivity to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Sturgeon are wide ranging in marine waters. Green sturgeon fisheries occur in Columbia River below Bonneville Dam, Willapa Bay, and Grays Harbor. Individuals are also occasionally caught incidentally in small coastal bays and the Puget Sound. Dependence on nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in nearshore habitats.
White sturgeon	H	L	H	M	M	M	M	M	M	H	L	H	H	L	H	M	M	M	M	M	M	M	M	M	
Longfin smelt	H	L	H	M	M	M	M	M	M	H	L	H	M	L	M	M	M	M	M	M	N	M	M	M	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. Demersal adhesive eggs are vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Planktonic larvae and juveniles of these species may also be vulnerable to stressor exposure in the nearshore marine environment during early rearing. Mature juveniles and adults occupy offshore environments and are therefore at less risk of take from these stressors.
Eulachon	H	L	N	M	M	N	M	M	N	M	L	N	M	L	N	M	M	N	M	M	N	M	M	N	
Pacific sand lance	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high. Larvae of both species disperse in nearshore waters for early rearing. Because they are essentially planktonic, larvae are vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Larvae are also visual feeders. Increased turbidity can reduce foraging success, leading to decreased growth and productivity.
Surf smelt	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with water quality modifications caused by marinas/terminals.

Species	Increased Suspended Solids			Resuspension of Contaminated Sediments			Introduction of Toxic Substances			Altered pH			Altered Dissolved Oxygen			Use of Creosote-Treated Wood			Use of ACZA and CCA Type C Treated Wood			Increased Stormwater and Nonpoint Source Pollution			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Pacific herring	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure is high. Larvae disperse in nearshore waters for early rearing. Because they are essentially planktonic, larvae are vulnerable to acute transient water quality impacts such as reduced dissolved or altered pH. Larvae are also visual feeders. Increased turbidity can reduce foraging success, leading to decreased growth and productivity.
Lingcod	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are potentially exposed to water quality related impact mechanisms from marinas/terminals. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Temporary disturbance while brooding may increase risk of egg predation. Larvae disperse and settle in nearshore waters for early rearing. Because they are demersal and relatively immobile, larvae are vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Larvae are also visual feeders. Increased turbidity can reduce foraging success, leading to decreased growth and productivity.
Pacific hake	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	Hake, cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Because they are demersal and relatively immobile, larvae are vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Larvae are visual feeders. Increased turbidity can reduce foraging success, leading to decreased growth and productivity.
Pacific cod	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	
Walleye pollock	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	M	N	N	M	N	
Brown rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Because they are demersal and relatively immobile, larvae are vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Larvae are also visual feeders. Increased turbidity can reduce foraging success, leading to decreased growth and productivity.
Copper rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Greenstriped rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Widow rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Yellowtail rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Quillback rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Black rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
China rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Tiger rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Bocaccio rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Canary rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Redstripe rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	
Yelloweye rockfish	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	M	N	

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with water quality modifications caused by marinas/terminals.

Species	Increased Suspended Solids			Resuspension of Contaminated Sediments			Introduction of Toxic Substances			Altered pH			Altered Dissolved Oxygen			Use of Creosote-Treated Wood			Use of ACZA and CCA Type C Treated Wood			Increased Stormwater and Nonpoint Source Pollution			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Olympia oyster	N	H	N	N	H	N	N	H	N	N	M	N	N	L	N	N	M	N	N	M	N	N	M	N	This species occurs commonly in shallow water nearshore habitats. This distribution increases risk of stressor exposure and potential for take resulting from water quality modification in the nearshore environment. Because this species is sessile at all live-history stages, it is vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Increased turbidity may reduce foraging success of this filter feeding species, leading to decreased growth and productivity.
Northern abalone	N	H	N	N	H	N	N	H	N	N	M	N	N	L	N	N	M	N	N	M	N	N	M	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. Because this species is sessile at all life-history stages, it is vulnerable to acute transient water quality impacts such as reduced dissolved oxygen or altered pH. Increased turbidity may affect algal growth, reducing available forage.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This species inhabits a narrow band of upper littoral zone habitat above MHHW and is therefore not directly exposed to water quality-related stressors resulting from marina/terminal operation.
Giant Columbia River limpet	M	N	M	M	N	M	H	N	H	H	N	H	L	N	L	M	N	M	M	N	M	M	N	M	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. The distribution of this species presents the possibility of stressor exposure. However, because it lives in lotic habitats, water quality effects will by nature be transitory, meaning that exposure to acute events will be temporary. Their sessile nature makes behavioral avoidance impossible, however, increasing the duration of acute exposure and potential for physiological injury.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
California floater (mussel)	H	N	H	M	N	M	H	N	H	H	N	H	M	N	M	H	N	N	H	N	M	H	N	H	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. Because they occur primarily in lotic habitats, water quality effects will by nature be transitory, meaning that exposure to acute events will be temporary. Their sessile nature makes behavioral avoidance impossible, however, increasing the duration of acute exposure and potential for physiological injury. Toxicity of copper, ammonia, and chlorine has been demonstrated in closely related species. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	H	N	N	H	N	N	M	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-4. Species- and habitat-specific risk of take for mechanisms of impact associated with riparian vegetation modifications caused by marina/terminal development.

	Altered Riparian Shading and Ambient Air Temperature Regime			Altered Stream Bank and Shoreline Stability			Altered Allochthonous Inputs			Altered Habitat Complexity			Altered Surface Water-Groundwater Exchange, or Freshwater Input			
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Comments**
Chinook salmon	I	H	H	H	H	H	I	H	H	H	H	H	H	H	H	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Marinas/terminals in riverine environments will be developed in habitats where modification of riparian vegetation will have little influence on water temperatures or food web productivity as a whole. Modification of riparian habitat will also most likely involve permanent conversion to an armored state, meaning that effects on bank stability will be minimal.
Coho salmon	I	H	H	H	H	H	I	H	H	H	H	H	H	H	H	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Chum salmon	I	H	I	H	H	I	I	H	I	H	H	I	H	H	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum may spawn in the lower reaches of large river environments (e.g., the Columbia River) and may therefore be subject to temporary effects of riparian modification on spawning habitat, in addition to juvenile and adult exposure during migration. Juvenile chum salmon are dependent on nearshore marine habitats and are therefore subject to stressor exposure from marina/terminal development in these environments.
Pink salmon	I	H	I	H	H	I	I	H	I	H	H	I	H	H	I	Pink salmon in Washington State do not utilize lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure.
Sockeye salmon	I	H	H	H	H	H	I	H	H	H	H	H	H	H	H	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. However, some populations spawn in nearshore lacustrine habitats, creating increased risk of stressor exposure at sensitive egg and alevin life-history stages. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor. Avoidance of impacts on juvenile sockeye in lacustrine environments is difficult due to year-round residence.
Steelhead	I	?	H	H	?	H	I	?	H	H	?	H	H	L	H	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these habitat types is unknown.
Coastal cutthroat trout	I	H	H	H	H	H	I	H	H	H	H	H	H	H	H	This species is prevalent in estuaries and large rivers and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Westslope cutthroat trout	I	N	H	I	N	H	I	N	H	I	N	H	I	N	H	These species occur primarily in coldwater streams, small to medium-sized rivers, and lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.
Redband trout	I	N	H	I	N	H	I	N	H	I	N	H	I	N	H	
Bull trout	I	H	H	H	H	H	I	H	H	H	H	H	H	?	H	These species spawn in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, as well as in riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults.
Dolly Varden	I	H	H	H	H	H	I	H	H	H	H	H	H	?	H	
Pygmy whitefish	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development; therefore, stressor exposure will only occur in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	I	N	H	I	N	H	H	N	H	H	N	H	H	N	H	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development.
Lake chub	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development.
Leopard dace	I	N	H	H	N	H	I	N	H	H	N	H	?	N	?	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development.
Umatilla dace	I	N	H	H	N	H	I	N	H	H	N	H	?	N	?	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development.

Table 9-4 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with riparian vegetation modifications caused by marina/terminal development.

Species	Altered Riparian Shading and Ambient Air Temperature Regime			Altered Stream Bank and Shoreline Stability			Altered Allochthonous Inputs			Altered Habitat Complexity			Altered Surface Water-Groundwater Exchange, or Freshwater Input			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.
River lamprey	I	?	?	H	H	H	I	?	?	H	H	H	?	?	?	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of larger rivers to rear for extended periods, potentially years. They are therefore susceptible to changes in stream bank stability with the potential to affect bottom sediments. In their saltwater phase, river lamprey remain close to shore for periods of 10 to 16 weeks from spring through fall. The dependence of this species on riparian vegetation and freshwater inflow in lacustrine and marine environments is a data gap, so the potential risk of take associated with these stressors is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Pacific lamprey	I	I	?	H	I	H	I	I	H	H	I	H	?	?	?	Pacific lamprey are anadromous, with migratory corridors that cross estuaries and mainstems of larger river systems suitable for marina/terminal development. Ammocoetes burrow into riverine sediments to rear for extended periods. They are therefore susceptible to changes in stream bank stability with the potential to affect bottom sediments. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6 to 40 months. The dependence of this species on riparian vegetation and freshwater inflow in lacustrine and marine environments is a data gap, so the potential risk of take associated with these stressors is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Green sturgeon	N	I	N	N	H	N	N	I	N	N	L	N	N	?	N	In Washington, white sturgeon are found in the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. Although this species is considered anadromous, populations in the Columbia River may be reproducing successfully in some impoundments. Larval sturgeon are essentially planktonic and rear in quiet backwaters of the large rivers and lakes where they are transported by currents following emergence. Green sturgeon fisheries occur in Columbia River below Bonneville Dam, Willapa Bay, and Grays Harbor. Sturgeon eggs are demersal and adhesive. These life-history stages are therefore potentially exposed to riparian modification impact mechanisms. Adults are occasionally caught incidentally in small coastal bays and Puget Sound. Sturgeon are wide ranging in marine waters. Dependence on nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in nearshore habitats.
White sturgeon	I	I	H	H	H	H	I	I	H	H	L	H	H	?	H	
Longfin smelt	I	I	N	H	I	H	I	I	H	H	I	H	?	?	?	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. Demersal adhesive eggs are vulnerable to short-term dewatering and dredging impacts. Adults, eggs, and larvae may be exposed to riparian modification impact mechanisms in marine and riverine environments. Planktonic larvae and juveniles of these species may also be vulnerable to stressor exposure in the nearshore marine environment during early rearing, particularly suspended sediments from decreased bank stability, which may decrease foraging success for these visual feeders. Dependence on freshwater inflow is a data gap, so the related risk of take resulting from this stressor is unknown. Mature juveniles and adults are found in offshore environments and are not exposed to these stressors.
Eulachon	I	I	N	H	I	N	I	I	N	H	I	N	?	?	N	
Pacific sand lance	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high. Egg survival is demonstrably affected by modification of riparian shading and ambient temperature regime, and by alteration of freshwater inflow. Larvae and juveniles are highly dependent on the habitat complexity and productivity of the nearshore environment for rearing, and changes in habitat complexity and allochthonous inputs affecting food web productivity are likely to affect growth and fitness. Changes in stream bank and shoreline stability may affect the suitability of spawning substrate, and increased suspended sediments may affect foraging success of visual feeding larvae.
Surf smelt	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	
Pacific herring	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure is high. Larvae and juveniles are highly dependent on the habitat complexity and productivity of the nearshore environment for rearing, and changes in habitat complexity and allochthonous inputs affecting food web productivity are likely to affect growth and fitness. Changes in stream bank and shoreline stability may increase suspended sediments, affecting egg incubation and the foraging success of visual feeding larvae.
Lingcod	N	I	N	N	H	N	N	H	N	N	H	N	N	H	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are therefore potentially exposed to riparian modification impact mechanisms. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Larvae and juveniles are highly dependent on the habitat complexity and productivity of the nearshore environment for rearing, and changes in habitat complexity and allochthonous inputs affecting food web productivity are likely to affect growth and fitness. Changes in stream bank and shoreline stability may increase suspended sediments, affecting egg incubation and the foraging success of visual feeding larvae.
Pacific hake	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	Hake, Pacific cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae and juveniles may experience stressor exposure. Larvae and juveniles are highly dependent on the habitat complexity and productivity of the nearshore environment for rearing, and changes in habitat complexity and allochthonous inputs affecting food web productivity are likely to affect growth and fitness. Changes in stream bank and shoreline stability may increase suspended sediments, affecting egg incubation and the foraging success of visual feeding larvae.
Pacific cod	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Walleye pollock	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	

Table 9-4 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with riparian vegetation modifications caused by marina/terminal development.

Species	Altered Riparian Shading and Ambient Air Temperature Regime			Altered Stream Bank and Shoreline Stability			Altered Allochthonous Inputs			Altered Habitat Complexity			Altered Surface Water-Groundwater Exchange, or Freshwater Input			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Brown rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Larvae and juveniles are highly dependent on the habitat complexity and productivity of the nearshore environment for rearing, and changes in habitat complexity and allochthonous inputs affecting food web productivity are likely to affect growth and fitness. Changes in shoreline stability may increase suspended sediments, affecting egg incubation and the foraging success of visual feeding larvae.
Copper rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Greenstriped rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Widow rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Yellowtail rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Quillback rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Black rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
China rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Tiger rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Bocaccio rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Canary rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Redstripe rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Yelloweye rockfish	N	I	N	N	H	N	N	H	N	N	H	N	N	?	N	
Olympia oyster	N	L	N	N	H	N	N	L	N	N	H	N	N	H	N	While the influence of shading and buffer on lower intertidal zone is limited, Olympia oyster growth and fitness may benefit from thermal extremes in some cases. In contrast, sedimentation demonstrably affects survival, growth and fitness in this species. Dependence on allochthonous inputs is currently a data gap. Habitat complexity and groundwater inflow affect habitat suitability for larval settlement and development, as well as juvenile and adult survival.
Northern abalone	N	I	N	N	H	N	N	I	N	N	I	N	N	I	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. Subtidal distribution generally limits exposure to riparian modification impact mechanisms and related stressors. For example, riparian shading will have effectively no influence on this species. In contrast, sedimentation resulting from decreased shoreline stability may extend into the subtidal zone, affecting foraging success. Exposure to other stressors resulting from these impact mechanisms are insignificant, given the subtidal distribution of this species. Therefore, these impact mechanisms are expected to have no effect.
Newcomb's littorine snail	N	H	N	N	H	N	N	N	N	N	H	N	N	?	N	This species inhabits a narrow band of upper littoral zone vegetation above MHHW and is therefore directly exposed to riparian vegetation modification where it is known to occur. Because this species is largely terrestrial, it is unaffected by alteration in allochthonous inputs and groundwater inputs.
Giant Columbia River limpet	I	N	I	I	N	I	L	N	L	H	N	H	?	N	?	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Dependence of this species on groundwater inputs is a data gap, so the risk of take from this stressor is unknown.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
California floater (mussel)	I	N	I	H	N	H	I	N	I	H	N	H	H	N	H	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. The localized influence of riparian vegetation on temperature conditions in these larger river systems is limited. Dependence of these species on groundwater inputs is a data gap, so the risk of take from this stressor is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	I	N	N	H	N	N	I	N	N	H	N	N	H	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-5. Species- and habitat-specific risk of take for mechanisms of impact associated with aquatic vegetation modifications caused by marinas and terminal development and operation.

Species	Altered Autochthonous Production			Altered Habitat Complexity			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	L	H	H	L	H	H	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors.
Coho salmon	L	H	H	L	H	H	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure.
Chum salmon	I	H	I	I	H	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum migrate through and in some cases may spawn in the lower reaches of large river environments and may therefore be exposed to aquatic vegetation modification impact mechanisms. Juvenile chum salmon are dependent on nearshore marine habitats and are therefore subject to stressor exposure from marina/terminal development in these environments.
Pink salmon	I	H	I	I	H	I	Pink salmon in Washington State do not use lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing, and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure.
Sockeye salmon	I	?	H	L	?	H	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. Alteration of lacustrine aquatic vegetation may affect survival, growth and fitness of rearing juveniles. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor.
Steelhead	L	?	H	L	?	H	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these habitat types is unknown.
Coastal cutthroat trout	L	H	H	L	H	H	This species is prevalent in estuaries and large rivers, and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable.
Westslope cutthroat trout	I	N	H	I	N	H	These species occur primarily in coldwater streams, small to medium-sized rivers, and lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.
Redband trout	I	N	H	I	N	H	
Bull trout	L	H	H	L	H	H	Spawning by these species occurs in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, and in riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults. Predominant riverine habitats do not support extensive aquatic vegetation.
Dolly Varden	L	H	H	L	H	H	
Pygmy whitefish	N	N	H	N	N	H	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development, therefore stressor exposure will only occur in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	M	N	M	H	N	H	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development.
Lake chub	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development.
Leopard dace	H	N	H	H	N	H	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development.
Umatilla dace	H	N	H	H	N	H	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development.
Western brook lamprey	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.
River lamprey	?	?	?	?	?	?	Dependence of this species on aquatic vegetation is a data gap; therefore, the risk of take associated with these stressors is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Pacific lamprey	?	?	?	?	?	?	Dependence of this species on aquatic vegetation is a data gap; therefore, the risk of take associated with these stressors is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Green sturgeon	N	?	N	N	?	N	Dependence on aquatic vegetation in freshwater environments and nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in nearshore habitats.
White sturgeon	H	?	H	H	?	H	
Longfin smelt	I	I	H	I	I	H	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. This species has limited freshwater residence time and is not dependent on aquatic vegetation during adult, egg, and larval life-history stages. Rearing larvae in nearshore marine areas may be dependent on habitat complexity and food web productivity.
Eulachon	I	I	N	I	I	N	

Table 9-5 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with aquatic vegetation modifications caused by marinas and terminal development and operation.

Species	Altered Autochthonous Production			Altered Habitat Complexity			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Pacific sand lance	N	H	N	N	H	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high. Planktonic larvae rear in nearshore areas and are dependent on food web productivity and habitat complexity of these environments.
Surf smelt	N	H	N	N	H	N	
Pacific herring	N	H	N	N	H	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on aquatic vegetation in nearshore habitats for spawning, and egg incubation, meaning that the likelihood of stressor exposure is high. Planktonic larvae rear in nearshore areas and are dependent on food web productivity and habitat complexity of these environments.
Lingcod	N	H	N	N	H	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are therefore potentially exposed to aquatic vegetation modification impact mechanisms. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Planktonic larvae and demersal juveniles rear in nearshore areas and are dependent on food web productivity and habitat complexity of these environments.
Pacific hake	N	H	N	N	H	N	Hake, cod, and Pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Planktonic larvae and demersal juveniles rear in nearshore areas and are dependent on food web productivity and habitat complexity of these environments.
Pacific cod	N	H	N	N	H	N	
Walleye pollock	N	H	N	N	H	N	
Brown rockfish	N	H	N	N	H	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Planktonic larvae and demersal juveniles rear in nearshore areas and are dependent on food web productivity and habitat complexity of these environments.
Copper rockfish	N	H	N	N	H	N	
Greenstriped rockfish	N	H	N	N	H	N	
Widow rockfish	N	H	N	N	H	N	
Yellowtail rockfish	N	H	N	N	H	N	
Quillback rockfish	N	H	N	N	H	N	
Black rockfish	N	H	N	N	H	N	
China rockfish	N	H	N	N	H	N	
Tiger rockfish	N	H	N	N	H	N	
Bocaccio rockfish	N	H	N	N	H	N	
Canary rockfish	N	H	N	N	H	N	
Redstripe rockfish	N	H	N	N	H	N	
Yelloweye rockfish	N	H	N	N	H	N	
Olympia oyster	N	H	N	N	H	N	Alteration of aquatic vegetation may affect the productivity of the nearshore food web, leading to reduced growth and fitness of larval, juvenile and adult Olympia oyster.
Northern abalone	N	?	N	N	I	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. While this species feeds on intertidal and subtidal algal biomass and could be affected by altered autochthonous production, but the level of dependence is a data gap and effects are unknown. Alteration of habitat complexity may alter the suitability and productivity of larval settlement habitat, leading to effects on survival, growth, and fitness of this species.
Newcomb's littorine snail	N	N	N	N	N	N	This species inhabits a narrow band of upper littoral zone habitat above MHHW and is therefore not exposed to stressors resulting from these impact mechanisms.
Giant Columbia River limpet	H	N	H	?	N	?	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. The dependence of this species on allochthonous inputs from riparian vegetation is unknown. However, being substrate feeding species dependent on functional nutrient cycling, activities that affect allochthonous production may cause at least some risk of take. The effect of diminished habitat complexity due to aquatic vegetation modification on this species is a data gap; therefore, the associated risk of take is unknown.
Great Columbia River spire snail	N	N	N	N	N	N	
California floater (mussel)	H	N	H	?	N	?	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. However, being filter feeding species dependent on functional nutrient cycling, activities that affect autochthonous production may cause at least some risk of take. The effect of diminished habitat complexity due to aquatic vegetation modification on this species is a data gap; therefore, the associated risk of take is unknown. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	H	N	N	?	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-6. Species- and habitat-specific risk of take for mechanisms of impact associated with hydraulic and geomorphic modifications caused by marinas/terminals.

Species	Altered Channel Geometry	Altered Flow Velocity	Altered Wave Velocities		Altered Current Velocities		Altered Nearshore Circulation Patterns		Altered Sediment Supply		Altered Substrate Composition			Altered Surface Water Groundwater Exchange, or Freshwater Input			Addition of Impervious Surface			Comments
	Riverine	Riverine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	This species has a complex and variable life history depending on race. In general, Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Coho salmon	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	This species has a complex and variable life history depending on race. In general, coho salmon occur in riverine, lacustrine, and nearshore marine habitats suitable for marina/terminal development and may experience exposure to related stressors. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Chum salmon	H	H	H	I	H	I	H	I	H	I	H	H	I	H	?	I	I	I	I	Chum salmon in Washington State do not use lacustrine habitats suitable for marina/terminal development. Therefore, stressor exposure will not occur in lacustrine environments. Chum may spawn in the lower reaches of large river environments (e.g., the Columbia River) and may therefore be exposed to impact mechanisms from hydraulic and geomorphic modification during spawning as well as during juvenile and adult migration. Juvenile chum salmon are dependent on nearshore marine habitats, and are therefore subject to stressor exposure from marina/terminal development in these environments. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Pink salmon	H	H	H	I	H	I	H	I	H	I	H	H	I	H	?	I	I	I	I	Pink salmon in Washington State do not use lacustrine habitats. Therefore, stressor exposure will not occur in lacustrine environments. This species is dependent on nearshore marine habitats for juvenile rearing, and migrates through the mainstems and estuaries of larger river systems potentially suitable for marina/terminal development. As such, this species may potentially experience related stressor exposure. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Sockeye salmon	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	This species is highly dependent on lacustrine environments for juvenile rearing. Most spawning behavior occurs in smaller rivers and streams that are not suitable for marina development. However, some populations spawn in nearshore lacustrine habitats, creating increased risk of stressor exposure at sensitive egg and alevin life-history stages. Migrating juveniles and adults may experience stressor exposure in larger rivers and reservoirs along their migratory corridor. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Steelhead	H	H	?	H	?	H	?	H	?	H	H	?	H	H	?	H	I	I	I	Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Steelhead have a lesser but uncertain level of dependence on nearshore marine habitats, so the risk of take associated with activities in these environment types is unknown. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Coastal cutthroat trout	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	This species is prevalent in estuaries and large rivers, and is highly dependent on nearshore marine areas for foraging. These habitats are suitable for marina/terminal development. Migratory behavior and residence timing are variable. Spawning activity typically occurs in habitats that are not suitable for terminal and marina development; therefore, eggs and alevins will not experience stressor exposure. Migrating adults and migrating and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Westslope cutthroat trout	I	I	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	These species occur primarily in coldwater streams, small to medium-sized rivers, and lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.
Redband trout	I	I	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	These species occur primarily in coldwater streams, small to medium-sized rivers, and in lakes. Occurrence in larger rivers suitable for marina/terminal development is unlikely.

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with hydraulic and geomorphic modifications caused by marinas/terminals.

Species	Altered Channel Geometry	Altered Flow Velocity	Altered Wave Velocities		Altered Current Velocities		Altered Nearshore Circulation Patterns		Altered Sediment Supply		Altered Substrate Composition			Altered Surface Water Groundwater Exchange, or Freshwater Input			Addition of Impervious Surface			Comments
	Riverine	Riverine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Bull trout	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	Spawning by these species occurs in habitats that are generally unsuitable for marina/terminal development. Therefore, spawning, egg incubation, and early rearing will not be directly affected by these activities. Most effects will occur from development in riverine migratory corridors, as well as in riverine, lacustrine, and marine foraging habitats used by mature juveniles and adults. Migrating adults, migrating and rearing juveniles, and foraging adults in marine habitats are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased juvenile growth and fitness.
Dolly Varden	H	H	H	H	H	H	H	H	H	H	H	H	H	H	?	H	I	I	I	
Pygmy whitefish	N	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	H	N	I	Lakes and smaller lake tributaries are primary habitats used by this species. Whitefish do not occur in larger rivers suitable for marina/terminal development; therefore, stressor exposure will only occur in lacustrine environments. This species is sensitive to alteration of hydraulic and geomorphic conditions in lacustrine environments.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. Species does not occur in larger rivers or lakes suitable for marina/terminal development.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for marina/terminal development.
Mountain sucker	H	H	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	This species is commonly found in large rivers and lakes suitable for marina and potentially terminal development. Adults and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased growth and fitness.
Lake chub	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens Counties that are generally unsuitable for marina/terminal development.
Leopard dace	H	H	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. As such, this species occurs in habitats potentially suitable for marina/terminal development. Adults and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased growth and fitness.
Umatilla dace	H	H	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake Rivers (including reservoirs within the Columbia and Snake River systems). As such, this species occurs in habitats potentially suitable for marina/terminal development. Adults and rearing juveniles are sensitive to alterations in hydraulic and geomorphic conditions in all environment types, experiencing decreased survival, decreased spawning fitness, and decreased growth and fitness.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This species is characterized by isolated breeding populations favoring small streams and brooks, which are unsuitable environments for marina development. Therefore, marina/terminal development will have no-effect on this species.
River lamprey	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	I	I	I	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of larger rivers to rear for extended periods, potentially years. In their saltwater phase, river lamprey remain close to shore for periods of 10 to 16 weeks from spring through fall. They are therefore susceptible to alteration of riverine, lacustrine, and nearshore marine environments caused by hydraulic and geomorphic modification. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Pacific lamprey	H	H	L	H	L	H	L	H	L	H	H	L	H	H	L	H	I	I	I	Pacific lamprey are anadromous, with migratory corridors that cross estuaries and mainstems of larger river systems suitable for marina/terminal development. Ammocoetes burrow into riverine sediments to rear for extended periods. They are therefore susceptible to hydraulic and geomorphic modifications in riverine and lacustrine environments. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6 to 40 months. While some exposure to nearshore habitat conditions altered by hydraulic and geomorphic modification is possible, the dependence on these habitats is low so the associated risk of take is also believed to be low. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with hydraulic and geomorphic modifications caused by marinas/terminals.

Species	Altered Channel Geometry	Altered Flow Velocity	Altered Wave Velocities		Altered Current Velocities		Altered Nearshore Circulation Patterns		Altered Sediment Supply		Altered Substrate Composition			Altered Surface Water Groundwater Exchange, or Freshwater Input			Addition of Impervious Surface			Comments
	Riverine	Riverine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Green sturgeon	N	N	?	N	?	N	?	N	?	N	N	?	N	N	?	N	N	I	N	In Washington, white sturgeon are found in the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. Although this species is considered anadromous, populations in the Columbia River may be reproducing successfully in some impoundments. Sturgeon eggs are demersal and adhesive. Larval sturgeon are essentially planktonic and rear in quiet backwaters of the large rivers and lakes where they are transported by currents following emergence. These life-history stages are therefore sensitive to altered riverine and lacustrine habitat conditions caused by hydraulic and geomorphic modification. Green sturgeon fisheries occur in Columbia River below Bonneville Dam, Willapa Bay, and Grays Harbor. Individuals are also occasionally caught incidentally in small coastal bays and Puget Sound. Sturgeon are wide ranging in marine waters. Dependence on nearshore marine habitats is unknown, as is the potential for exposure to stressors occurring in these habitats.
White sturgeon	H	H	?	H	?	H	?	H	?	H	H	?	H	H	?	H	I	I	I	
Longfin smelt	H	H	H	H	H	H	H	H	I	H	H	I	N	?	?	?	I	I	N	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems, which are preferred areas for marina development. Demersal adhesive eggs are sensitive to altered riverine habitat conditions caused by hydraulic and geomorphic modification. Planktonic larvae and juveniles of these species may also be vulnerable to stressor exposure in the nearshore marine environment during early rearing. These life-history requirements translate to risk of take resulting from riverine and marine habitat alteration caused by hydraulic and geomorphic modification. Mature juveniles and adults are found in offshore environments.
Eulachon	H	H	H	N	H	N	H	N	I	N	H	I	N	?	?	N	I	I	N	
Pacific sand lance	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure is high. Dependence on shoreline and nearshore habitats for spawning and rearing means that these species are sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Surf smelt	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Pacific herring	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure is high. Dependence on nearshore habitats for spawning and rearing means that this species is sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Lingcod	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are therefore exposed to impact mechanisms associated with hydraulic and geomorphic modification. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 to 150 m) and therefore have less exposure potential. Temporary disturbance while brooding may increase risk of egg predation. Dependence on nearshore habitats for rearing means that this species is sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Pacific hake	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Hake, cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. As such, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Dependence on nearshore habitats for rearing means that these species are sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Pacific cod	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Walleye pollock	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impact associated with hydraulic and geomorphic modifications caused by marinas/terminals.

Species	Altered Channel Geometry	Altered Flow Velocity	Altered Wave Velocities		Altered Current Velocities		Altered Nearshore Circulation Patterns		Altered Sediment Supply		Altered Substrate Composition			Altered Surface Water Groundwater Exchange, or Freshwater Input			Addition of Impervious Surface			Comments
	Riverine	Riverine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Brown rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. As such, rockfish can experience stressor exposure across all life-history stages. Dependence on nearshore habitats for rearing means that these species are sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Copper rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Greenstriped rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Widow rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Yellowtail rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Quillback rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Black rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
China rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Tiger rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Bocaccio rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Canary rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Redstripe rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Yelloweye rockfish	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	
Olympia oyster	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	Dependence on nearshore habitats throughout this species' life history means that it is sensitive to habitat alterations caused by hydraulic and geomorphic modification. These impact mechanisms are likely to result in effects on survival, growth, and productivity across veliger, juvenile, and adult life-history stages.
Northern abalone	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) depth. Dependence on nearshore habitats throughout much of this species' life history means that it is sensitive to habitat alterations caused by hydraulic and geomorphic modification.
Newcomb's littorine snail	N	N	H	N	H	N	H	N	H	N	N	H	N	N	H	N	N	I	N	This species inhabits a narrow band of upper littoral zone habitat above MHHW. Hydraulic and geomorphic modification of nearshore habitats can result in alteration of upper intertidal habitat characteristics, leading to indirect risk of take on this species.
Giant Columbia River limpet	H	H	N	H	N	H	N	H	N	H	H	N	H	?	N	?	I	N	I	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for marina/terminal development. As such, there is essentially no likelihood of stressor exposure and therefore no potential for take resulting from these activities. The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. This species is sensitive to alterations in hydraulic and geomorphic conditions in riverine and lacustrine habitats, leading to decreased survival, growth, and fitness.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
California floater (mussel)	H	H	N	H	N	H	N	H	N	H	H	N	H	H	N	H	I	N	I	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake River and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. As such, both species may occur in habitats suitable for marina/terminal development. These species are sensitive to alterations in hydraulic and geomorphic conditions in riverine and lacustrine habitats, leading to decreased survival, growth, and fitness. Impact mechanism effects affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults.
Western ridged mussel	H	H	N	N	N	N	N	N	N	N	M	N	N	M	N	N	I	N	N	

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

10.0 Data Gaps

This section identifies data gaps, as well as what information is needed to fill those gaps, for each of the impact mechanisms associated with the construction, operation, and repair of marinas/terminals. In general, the thresholds for watershed and population size and the number of activities that must occur within a particular watershed to have a measurable cumulative impact are not yet established in the literature. These are needed to assess the effects of marinas/terminals on HCP species in a holistic approach.

10.1 Construction and Maintenance Activities

10.1.1 Pile Driving

The following data gaps were identified in relation to the effects of pile driving on HCP species in marine, lacustrine, and riverine environments:

- The sound sensitivity of primitive fishes (such as lamprey) is currently unknown.
- The sound sensitivity of the Olympia oyster is currently a data gap, and the effects of related sound stressors are unknown.
- Effect of underwater noise on mollusks is a data gap.

10.1.2 Construction Vessel Operations

Exposure of the giant Columbia River limpet and great Columbia River spire snail to work area dewatering related to construction vessel operations is possible, but sensitivity to this stressor is a data gap so the potential for take is unknown. The effects of underwater noise (associated with construction vessel operations) on mollusks are also unknown.

10.1.3 Channel Dewatering

Few studies have compared the susceptibility of various fish and macroinvertebrate species to different types of handling techniques. More information comparing the susceptibility to injuries associated with these types of techniques is needed to identify potential take for these species. Training and minimum qualifications for personnel performing fish capture and handling (particularly electrofishing) are also needed to define standard protocols that would minimize risk of take. Most of the studies on the effects of fish handling have been performed on electrofishing. Electrofishing effects have been conducted on adult fish greater than 12 inches in length (Dalbey et al. 1996). The relatively few studies that have been conducted on juvenile salmonids indicate that spinal injury rates are substantially lower than they are for large fish. Only a few recent studies have examined the long-term effects of electrofishing on salmonid survival and growth (e.g., Ainslie et al. 1998, Dalbey et al. 1996). Little research has been conducted on the effects of dewatering and fish capture and handling on nonsalmonid HCP species. More directed research is necessary to understand the risk of take resulting from this submechanism for these species.

10.1.4 Navigation/Maintenance Dredging

There are numerous studies of impacts on aquatic species from dredging activities (Cooper et al. 2007; Erftemeijer and Lewis 2006; Newell et al. 2004). However, these impacts have been shown to be site- and species-specific (Byrnes et al. 2004), with “opportunistic” species (e.g., mollusks) being much less affected than those that have long life histories (e.g., rockfish) (Newell et al. 2004). Considering the diversity of environments present in Washington, a number of data gaps exist with respect to specific HCP species, most particularly with the effects on rockfish adjacent dredging operations. While dredging is already prohibited in rockfish nursery areas by WAC 220-110-320, adjacent areas potentially exposed to heightened turbidity are not covered by this legislation. Turbidity thresholds similar to those use in monitoring programs that have been successful elsewhere to limit effects on aquatic species (Thorkilsen and Dynesen 2001) are needed for HCP species.

Although the physics of turbidity generation can be calculated, adequate data do not exist to quantify the biological response in terms of threshold sediment dosages and exposure durations that can be tolerated by each of the HCP species. Numerical modeling simulations of dredging-related suspended sediment plume dynamics need to be correlated with field and laboratory studies to further identify information needs on each of the HCP species. Studies on East Coast species have identified lethal suspended concentration levels, and Newcombe and Jensen (1996) developed a predictive model for defining lethal and sublethal fish injury threshold levels for suspended sediment concentrations. However, threshold studies (single event as well as cumulatively) for the temporary impacts of suspended sediment levels specific to dredging in Pacific Northwest marine, lacustrine, and riverine environments are lacking (Nightingale and Simenstad 2001a).

Data gaps also include the following information needs:

- Comprehensive data on the spatial and temporal distribution of spawning, rearing, and migration behaviors of HCP species to determine and assign dredging work windows on a site-specific basis have not been compiled.

- Cumulative thresholds associated with dredge-induced changes in salinity intrusion and other critical physicochemical processes in marine environments have not been identified.

- Recovery capability for HCP species that may be at risk of impacts from temporary exposure, chronic exposure, and cumulative thresholds associated with dredging in marine, lacustrine, and riverine environments in early life-history as well as adult stages is not fully understood for many HCP species.

- Recolonization capacities, after temporary, chronic, or cumulative thresholds are reached, of HCP species and the species endemic to those habitats (in marine, lacustrine, and riverine environments) that are important to their growth and survival are not yet understood.

- Temporary, chronic, and cumulative effects associated with nighttime lighting from dredge equipment (during construction as well as during operations following construction) have not been comprehensively investigated. The role of lighting in attracting predator species to affected sites is not fully understood.

- The magnitude and duration of noise associated with dredging operations have not been evaluated. Additional research on fish responses to noise is needed. This information is needed to evaluate potential noise impacts on HCP species.

- Fish behavior responses to dredging-related turbidity plumes of different extents are not yet understood.

10.2 Facility Operation and Vessel Activities

Information specific to facility operation and vessel activities is needed to address temporary, chronic, and cumulative impacts on HCP species. Although significant data gaps exist pertaining to the impacts of marinas/terminals on HCP species, recent work specific to identifying the impacts of such structures on migrating juvenile salmon along marine and lake shorelines has begun to address these information needs. Previous white papers prepared in conjunction with WDFW, WSDOT, and Ecology on overwater structures (Nightingale and Simenstad 2001a; Carrasquero 2001) identified significant gaps on the subject of ambient light modifications and effects on habitat along marine shorelines. Specifically, these gaps included further exploration to: (1) determine the conditions for and the significance of avoidance of shoreline structures by migrating juvenile salmon; (2) measure the effects of using artificial lights in under-pier environments to avoid interference with natural ambient light patterns in shallow nearshore habitats**; (**3) further quantify the effects of overwater structures on salmonid prey resource abundance; and (4) develop a scientifically based approach to determine cumulative impact thresholds.

Since 2001, Toft et al. (2004), studying fish distribution, abundance, and behavior at nearshore habitats, reported on fish behavior along the urban marine shorelines of Seattle. This observational work (with an emphasis on juvenile salmonids) has helped to identify fish behavioral responses to overwater structures on these urban shorelines. Haas et al. (2002) added information on the impacts of terminals and vessel activities on shading and the response of epifaunal biota to these changes. Southard et al. (2006) further studied the conditions and responses of juvenile salmon to ferry terminals. These studies have supported the previous findings of salmonid avoidance of docks identified in (Nightingale and Simenstad 2001a; Weitkamp and Schadt 1982; Pentec 1997; Shreffler and Moursund 1999; Simenstad et al. 1999).

The question of cumulative effects of docks, marinas, and terminals has yet to be addressed. There is still a need for a scientifically based cumulative assessment tool to guide the design and placement of marinas/terminals. This assessment should include steps to: (1) develop a landscape-scale model of shoreline processes that create and maintain biological habitats; (2) develop assessment indices for identifying ecological responses to marina/terminal structures within the context of the model; (3) identify landscape-level subunits, such as shoreline drift cells (sectors); and (4) identify landscape elements in terms of connectivity and homogeneity using the fundamental definitions of corridors, matrices, patches, and other landscape attributes. Although marina, dock, and terminal shade effects on the behavior of salmonids and their prey resources have been studied, similar effects on other HCP species can only be inferred from these findings, as the majority of these species have not been the focus of the studies to date.

In addition to the above cumulative assessment gaps, significant gaps still exist as to the effect of marinas/terminals on littoral vegetation. As Jones & Stokes (2006) identified, the following significant data gaps still exist for eelgrass: (1) factors governing and affecting the local and large-scale coverage of eelgrass (Dowty et al. 2005); (2) understanding how the variation of large-scale eelgrass coverage in response to shoreline structures also varies in response to climatic variability; (3) understanding the causes behind observed local declines in eelgrass coverage (Dowty et al. 2005); (4) understanding the dependence of the full suite of HCP species on eelgrass and other littoral vegetation species; (5) understanding the carrying capacity of Puget Sound for juvenile salmon, including food limitation thresholds; (6) understanding the minimum patch size and connectivity elements needed for littoral vegetation to function as a prey source for HCP species; and (7) understanding how habitat fragmentation affects HCP species.

10.2.1 Grounding, Anchoring, and Prop Wash

Grounding, anchoring, and prop wash are forms of direct disturbance from vessel activity associated with marinas/terminals in marine, riverine, and lacustrine environments. Grounding, anchoring, and prop wash are likely to cause effectively permanent alteration of substrate characteristics and the aquatic vegetation community. Numerous studies have documented the effects of grounding, anchoring, and prop wash on habitat (see Section 7.2.1 [*Grounding, Anchoring, and/or Prop Wash*] for specific studies on impacts), which is an indirect way to assess impacts on HCP species. However, the effects of grounding, anchoring, and prop wash have not been studied for most HCP species and remain a data gap. These include temporary, chronic, and cumulative impacts on HCP species in marine, riverine, and lacustrine environments. Despite the lack of specific studies, some conclusions can be drawn regarding risk of take for many species. Specifically, this submechanism is likely to result in long-term effects on habitat complexity, which is generally equated with a high risk of take for those species that use the affected habitat. In addition, non-motile benthic species or life history stages such as lamprey ammocoetes, larval rockfish, or HCP invertebrate species are susceptible to direct injury or mortality, which also meet the high risk of take criterion.

10.2.2 Vessel Maintenance and Operational Discharges

Given the large numbers of vessels typically associated with a marina and the large-sized vessels using terminals, the potential effects on fish and invertebrate growth, survival, and fitness in the vicinity of these maritime structures from these types of discharges could be significant. Information is needed on the temporary, chronic, and cumulative impacts of vessel maintenance and operational discharges on HCP species in marine, riverine, and lacustrine environments.

10.2.3 Vessel Activities

Little is known about the impacts of marina/terminal vessel activities on HCP species. Although some work has examined the effects of vessel waves, sediment resuspension, and turbidity, these studies addressed salmonid species or cetaceans and not the other HCP species. Measurements incorporating the elements of repetitious exposure over time, effects resulting from numerous vessels, and large vessels idling and approaching and leaving terminal docks are needed to understand the potential effects on the HCP species occupying those habitats in marine, riverine, and lacustrine environments. In addition, information is needed on temporary, chronic, and cumulative impacts on HCP species in marine, riverine, and lacustrine environments.

10.2.4 Ambient Light Modifications

Species-specific sensitivity to ambient light modification is a data gap for most HCP species. For example, ambient light modification is a likely stressor for many species in nearshore lacustrine environments and may also pose risk in marine environments. However, as juvenile sockeye salmon and steelhead are more typically found farther from shore, the effects of shading are less clear; therefore, the impact potential in the marine environment is uncertain. In addition, information is needed on the temporary, chronic, and cumulative impacts of ambient light modification on HCP species in marine, riverine, and lacustrine environments.

10.2.5 Underwater Noise

Exposure to pile driving noise is likely the primary source of underwater noise that is known to cause mortality and injury to some HCP species; however, the effects of underwater noise on invertebrates is limited, and the effects on mollusks are currently a data gap. Additional research is needed on this topic to evaluate noise impacts generated by various equipment types on a diversity of species, including shellfish. Data gaps on the hearing capacities of HCP species and the effects of increased underwater noise on hearing as well as the heart, kidneys, and other highly vascular tissue due to marina/terminal vessel use remain. Although studies have identified elevated hearing thresholds in response to engine and other white noises for cyprinid fishes (which are hearing specialists), data are needed on hearing (as well as the heart, kidneys, and other highly vascular tissue) thresholds and effects on HCP species. In addition, data gaps exist on the temporary, chronic, and cumulative effects of underwater noise induced by marinas/terminals in marine, riverine, and lacustrine environments.

10.3 Water Quality Modifications

In general, additional information is needed regarding how cumulative impacts related to water quality degradation may affect HCP species. In addition, information is needed regarding creosote-treated wood effects on fish and shellfish in riverine and lacustrine environments. Also, the chronic and cumulative effects of copper-treated wood in marine, riverine, and lacustrine environments are a data gap.

As indicated in Jones & Stokes (2006), information is needed to identify the impacts of suspended sediments on HCP species. Bash et al. (2001) filled many data gaps for freshwater habitats, but additional information is needed to evaluate effects of turbidity and suspended sediment on freshwater HCP species, and more data are required to evaluate impacts on marine habitats and species. A particular data gap, pertinent to terminal and marina structures and activities, is how HCP species are affected by resuspension and transport of contaminated sediments (Michelsen et al. 1999). Another data gap requiring analysis and modeling effort is the issue of leaching and food web effects related to treated wood products.

In addition, it is currently unknown what behavioral mechanisms are triggered as various fish species encounter patches of increased turbidity, such as dredging plumes. Also unknown is what threshold of turbidity might be a cue to fish to avoid light-reducing turbidity.

10.4 Riparian Vegetation Modifications

Although the functions of freshwater riparian vegetation have been identified for riverine systems, exploring and defining the functions of marine riparian vegetation are ongoing. There is reason to believe that marine riparian vegetation provides similar functions to riparian vegetation adjacent to freshwater habitats; however, the extent and nature of those functions is not fully understood (Desbonnet et al. 1995; NRC 2001; Brennan and Culverwell 2004). The following information needs are outstanding: (1) understanding the specific nature and function of riparian habitat elements along marine shorelines; (2) the dependence of HCP species on riparian marine and freshwater habitat functions; (3) the effects on HCP species of marina/terminal modifications to those habitats; and (4) the cumulative and synergistic effects of riparian and shoreline removal.

10.5 Aquatic Vegetation Modifications

Additional information is needed regarding how temporary, chronic, and cumulative impacts related to aquatic vegetation modifications may affect HCP species in marine, riverine, and lacustrine environments.

The following species-specific data gaps were identified:

- Dependency of Pacific and river lamprey as well as northern abalone on aquatic vegetation.
- Effect of diminished habitat complexity due to aquatic vegetation modification on the giant Columbia River limpet and California floater (mussel).

10.6 Hydraulic and Geomorphic Modifications

In other regions of the United States, studies have documented the cumulative impacts on the nearshore environment (e.g., the Great Lakes [Meadows et al. 2005]; for more details see Section 8.6 [*Hydraulic and Geomorphic Modifications*]). Impacts on numerous HCP species have been documented due to hydraulic and geomorphic modifications associated with marina development (as detailed in Section 7.6 [*Hydraulic and Geomorphic Modifications*]). Data and analysis describing the ecosystem processes affected by marina/terminal activities are needed.

A large data gap exists on the effects of substrate modifications in both freshwater and marine habitats on HCP species. There are two areas where research, particularly as it relates to the protection of aquatic resources and managing future development, needs to be performed:

- **Cutting-edge technique effectiveness assessments**. Current practical knowledge exists to protect shoreline areas through the implementation of innovative (cutting-edge) engineering alternatives. These cutting-edge alternatives can provide the desired degree of infrastructure protection while restoring physical processes, habitat features, and/or ecological functions. Unfortunately, while technically feasible, the effectiveness of these techniques has not been fully tested through the implementation of prototype projects.
- **Peer-reviewed monitoring of constructed restoration efforts**. Habitat restoration activities have been undertaken in many nearshore settings throughout western Washington over the last 30 years. While some have been large and monitored (Cheney et al. 1994; Carney et al. 2005), most have a tendency to be for small properties with no monitoring. Even when monitoring has been performed, it is generally used more as a design tool,

rather than to evaluate the efficacy of the restoration activities to restore the targeted species (Carney et al. 2005).

Targeting a common technique of shore protection in the construction and maintenance of marinas, Schmetterling et al. (2001) noted four areas where research on this subject is lacking: (1) quantifying the habitat availability and quality of riprap; (2) correlation of the effects of riprap banks on salmonid density in the absence of other dependent variables such as diking, channelization, and watershed land use; (3) comparative studies on the use of riprap and alternative “soft” techniques, such as the integration of natural materials; and (4) the cumulative effects of numerous bank-hardening projects at the watershed level.

Finlayson (2006) identified five areas where additional research pertaining to physical nearshore processes is needed: (1) characterizing the role of historical morphology; (2) identifying tide-level controls on littoral phenomena; (3) further development of existing littoral transport models; (4) improved characterization of the role of extreme events in shaping low-energy, mixed-sediment beaches; and (5) further testing and adaptation of numerical wave models for fetch-limited environments. No research has been conducted to study submarine and intertidal groundwater n Puget Sound. It is clear from work elsewhere that such flows are crucial in sustaining nearshore ecosystems (Gallardo and Marui 2006); however, their role on the nearshore environment throughout Puget Sound is virtually unknown (Finlayson 2006).

Jones & Stokes (2006) reported that no data pertaining to substrate modification associated with marina/terminal structures were found on lake environments for HCP species.

11.0 Habitat Protection, Conservation, Mitigation, and Management Strategies

The Endangered Species Act requires that impacts on listed species or designated critical habitat be avoided or, if unavoidable, minimized to the maximum extent practicable. This analysis assumes that all marinas/terminals are conditioned under HPA authority pursuant to the Hydraulic Code (RCW 77.55) and their associated rules (WAC 220-110), as well as applicable local, state, or federal regulations.

11.1 Construction and Maintenance Activities

Construction phase recommendations have been thoroughly addressed in a recent U.S. Environmental Protection Agency (USEPA) publication (USEPA 2007). The report summarized best management practices that should be applied to hydromodification projects to reduce nonpoint source pollution. The recommendations relevant to construction phase activities include:

- Stockpile fertile topsoil for later use for plants
- Use hand equipment rather than heavy equipment
- If using heavy equipment, use wide-track or rubberized tires
- Avoid instream work, except as authorized by the local fish and wildlife authority
- Stay 100 feet away from water when refueling or adding oil
- Avoid using wood treated with creosote or copper compounds
- Protect areas exposed during construction.

Other nonconstruction-related recommendations in USEPA (2007) include:

- Incorporating monitoring and maintenance of structures
- Using adaptive management
- Conducting a watershed assessment to determine project fate and effects
- Focusing on prevention rather than mitigation
- Emphasizing simple, low-tech, and low-cost methods.

In the construction of new marina or terminal facilities, avoidance or minimization of impacts can be accomplished through site selection and facility design. For construction and maintenance activities, management strategies can be implemented to minimize underwater noise, channel dewatering, and navigational dredging impacts. The following strategies can be used to avoid and, if avoidance is not possible, to minimize and mitigate negative impacts on habitats and HCP species associated with construction and maintenance activities.

11.1.1 Site Selection

- Site marinas/terminals away from areas with littoral and aquatic freshwater vegetation, where practicable.
- Locate marinas/terminal in areas that are naturally deep enough to avoid resuspension of sediments associated with prop wash.
- Locate new shipping terminals and marinas: (1) in existing developed areas where nearshore areas have already been dredged, or (2) in areas where the natural bathymetry of the shoreline steeply drops off close to shore.
- Locate marinas/terminal in areas with low or impaired biological integrity.

11.1.2 Facility Design

- Minimize width of the structure over the water.
- When applicable and feasible, require construction of longer marina/terminal decks that keep vessels in deeper water to avoid/minimize propeller wash effects on sensitive habitat areas such as eelgrass beds.
- Residential/recreational floats should be sited in deeper water to reduce the potential impacts associated with propeller wash.
- Use the smallest number of pilings necessary to carry the load.
- Allow light transmission wherever possible along the shallowest areas of migratory corridors and over any areas near or adjacent to submerged aquatic vegetation.
- Locate the structure as high as practical to increase light transmission.
- Use light-reflecting materials on underside of docks, whenever feasible.
- Consider solar-powered artificial lighting under the dock, if light transmission is not possible.

- Construct marinas/terminals so that most of the overwater coverage is beyond the photic zone.
- Increase the distance between the dock and the water to allow greater light penetration.
- Place the potential shade-casting structures perpendicular to the arc of the sun (i.e., north–south placement) to maximize transmission of light under the structure.
- Install grating with maximum open spacing and ensure that the open space is kept uncovered or unshadowed by other pier features of gear.
- Orient grating to maximize transmission of light under the structure.
- At marinas/terminals, minimize the amount of pier area that directly contacts the shoreline to allow light penetration to the nearshore intertidal and shallow subtidal areas.
- Promote community-use docks to minimize the proliferation of single-family residential docks along shorelines.
- Site slips for smaller boats in shallow water, with slips for larger boats placed in deeper water.
- Facilities should be sited, if possible, so that dredging is not required.
- Require the use of rub strips on treated wood piles or timbers that are abraded by vessels (fender piles) or docks (guide piles) to reduce physical breakup of the piles.
- Use low-intensity artificial nighttime lighting and shield the lighting to prevent artificial light transmission to the ambient nighttime underwater light environment.

11.1.3 Pile Driving

- Maintain the integrity of the air bubble curtain; no barges, boat traffic, or other structure or equipment should be allowed to penetrate the air curtain during pile driving activities.
- To avoid attracting fishes with lights during nighttime pile driving operations, pile driving should be limited to daylight hours to the extent practicable.

- Use pile caps (wood blocks), if feasible and safe, to reduce the sound of pile driving below injury level (Laughlin 2006).

- Use vibratory hammers; the low rise in sound over a longer period of time (see Section 7.1.1 [*Pile Driving*], Figure 7-1) is less stressful to aquatic animals, and the sound is typically 10 to 20 dB lower than impact hammer pile driving (WSDOT 2006a).

- For projects with pile sizes less than 24 inches in diameter, use the smallest piling size practicable to lower sound pressure levels when driven.

- Consider using wood or concrete piles where practicable, as these also induce lower sound pressure levels.

11.1.4 Noise

To protect HCP species from the impacts of increased noise, use noise reduction devises such as:

- Air bubble curtains to create a bubble screen that can reduce peak underwater sound pressure levels by at least 15 dB_{peak} (Reyff et al. 2003; Vagle 2003).

- Maintain the integrity of the air bubble curtain; no barges, boat traffic, or other structure or equipment should be allowed to penetrate the air curtain.

- Installation of a geotube should occur during low tide to minimize the potential for entrapment and stranding of fish within the enclosed area.

- Fabric barriers and/or cofferdams to create an additional interface to buffer sound transmission into the underwater environment (WSDOT 2006a).

11.1.5 Channel Dewatering

For activities that require dewatering, impacts can be minimized by performing work during low-flow or dry conditions and by pumping sediment-laden water from the work area to an infiltration treatment site. Disturbed areas within the channel should be stabilized with a layer of sediment corresponding to the ambient bed to prevent an influx of fine sediment once water is reintroduced to the site. Science-based protocols for fish removal and exclusion activities should be adopted to track and report the number and species of fish captured, injured, or killed. Projects should also require slow dewatering and passive fish removal from the dewatered area before initiating active fish-removal protocols. During passive fish removal, fish removal by seining is recommended before resorting to electrofishing, which carries a greater risk of mortality (NMFS 2006).

Further minimize channel dewatering impacts on HCP species by taking the following precautions:

- Perform work during low-flow or dry conditions, and/or during dry weather.
- Pump sediment-laden water (from the work area that has been isolated from surrounding water) to an infiltration treatment site.
- Dispose of debris or sediment outside of the floodplain.
- Stabilize disturbed areas at the work site with sediment corresponding to the ambient bed in order to prevent an influx of fine sediment once water is reintroduced to the site.
- Adopt science-based protocols for fish removal and exclusion activities, including tracking and reporting of number and species of fish captured, fish injured, and mortality.
- Define and require qualifications for personnel performing fish capture and handling; maintain a list of qualified personnel.
- Require slow dewatering and passive fish removal from the dewatered area before initiating active fish-removal protocols.
- During passive fish removal, fish removal by seining is recommended before resorting to electrofishing, which carries a greater risk of mortality.

11.1.5.1 Electrofishing Guidelines

- Require adherence to NOAA Fisheries electrofishing guidelines.
- Use lowest power output for effective electrofishing.
- Use least damaging direct current (not alternating current).
- Watch for burns or brands or muscle spasms as these indicate harm to the fish.
- Use spherical electrodes appropriate to the water conductivity and the desired size and intensity of the field (Snyder 2003).
- Minimize fish exposure to handling by netting rapidly.

- Frequently change holding water to ensure adequate dissolved oxygen levels and avoid excessive temperature rises.

- Avoid crowding of fish in holding areas.

11.1.6 Navigational Channel and Berthing /Maintenance Dredging

General recommendations to avoid and minimize the impacts of dredging are provided in the Dredging: Marine Issues white paper (Nightingale and Simenstad 2001a) and include: (1) more extensive use of multiseason pre- and postdredge project biological surveys to assess animal community impacts; (2) incorporation of cumulative effects analysis into all dredging project plans; (3) increased use of landscape-scale planning concepts to plan for beneficial use projects most suitable to the area's landscape ecology and biotic community and food web relationships; (4) further identification of turbidity and noise thresholds to assess fish injury risks; and (5) further analysis and synthesis of the state of knowledge on what is known about the spatial and temporal distribution of fish and shellfish spawning, migration behaviors, and juvenile rearing to evaluate environmental windows for dredging on a site-specific basis.

The following recommendations are intended to reduce the effects of dredging on HCP species.

- For new marine, riverine, and lacustrine projects and significant expansions beyond general maintenance dredging, thoroughly assess the large-scale, cumulative impacts of the resulting changes in bathymetry, habitat loss, and change to estuarine/nearshore marine ecosystem dynamics (e.g., salinity intrusion).

- Require hopper dredges, scows, and barges or any other equipment used to transport dredged materials to the disposal or transfer sites to completely contain the dredged material.

- For long-term projects where continuous dredging and on-loading to barges occurs, require periodic movement of the barge to reduce unnecessary shading (for more information regarding shading impacts see white paper on *Marine Overwater Structures* [Jones & Stokes 2006]).

- Modify in-water work windows to take into consideration what is known about site-specific spatial and temporal distribution of fish and shellfish eggs, larvae, and juveniles.

- Evaluate the application of in-water work windows on a site-specific basis based upon the location and features of the site, such as sediment composition, plant and animal assemblages, and timing of seasonal and migration patterns.

- Use presampling bathymetric surveys, records from previous dredging events, and best professional judgment to estimate the volume of sediments likely to be dredged; base sampling and testing requirements on this estimated volume.

- Avoid projects and expansions that convert intertidal to subtidal habitat. If such conversion is unavoidable, employ comprehensive, large-scale risk assessment to identify the cumulative effects of site-specific changes on ecosystem dynamics.

- Select dredging equipment types according to project-specific conditions, such as sediment characteristics.

- Base turbidity threshold testing for dredging operations upon background site turbidity.

- In areas where dredging is proximal to sensitive habitats (or in projects where sediments both suitable and unsuitable for unconfined open water disposal will be dredged adjacent to each other), use the "Silent Inspector" (a computerized electronic sensor system) to monitor dredging operations. This tool can assist in operational documentation and regulatory compliance by providing record accessibility and clarity. It also offers advantages for planning, estimating, and managing dredging activities.

- Increase the use of multiseason preproject surveys of benthos to compare with post project surveys to understand dredging impacts.

- Where applicable and involving uncontaminated sediments, consider beneficial use of dredged materials that can contribute to habitat restoration, rehabilitation, and enhancement, particularly for projects that incorporate a landscape ecology approach.

- Avoid beneficial use projects that impose unnatural habitats and features on estuarine, marine, and riverine landscapes.

- Dredging should be conducted to a depth not greater than a navigation channel depth at the seaward end. If necessary, authorize dredging to depths greater than the navigation channel at the seaward end only in berthing areas and turning basins for commercial shipping purposes.

- Use hydrodynamic models to predict system-wide changes in salinity, turbidity, and other physicochemical regimes for project assessment planning that avoids or minimizes impacts on aquatic habitat.

11.2 Facility Operation and Vessel Activities

Several management strategies can be adopted to minimize impacts on aquatic habitats and species stemming from operation of marina/terminal facilities and associated vessel activities. Issues related to vessel activities include vessel grounding in sensitive habitats, the effects of propeller wash, the risk of accidental spills of fuel or other contaminants, and the risk of introducing invasive species. Management strategies to minimize these impacts are described below.

11.2.1 Facility Operation

- When applicable and feasible, require construction of longer marina/terminal decks that keep vessels in deeper water to avoid/minimize propeller wash effects on sensitive habitat areas such as eelgrass beds.
- Residential/recreational floats should be sited in deeper water to reduce the potential impacts associated with propeller wash.
- Allow light transmission wherever possible along the shallowest areas of migratory corridors and over any areas near or adjacent to submerged aquatic vegetation.
- Use light-reflecting materials on underside of docks, whenever feasible.
- Consider solar-powered artificial lighting under the dock, if light transmission is not possible. However, compared to full sunlight, grating transmits 10 times more light under a pier than, for example, acrylic prisms (Gayaldo and Nelson 2006); hence, the use of grating is always a better option than prisms.
- Use low-intensity artificial nighttime lighting and shield the lighting to prevent artificial light transmission to the ambient nighttime underwater light environment.
- Require the use of rub strips on treated wood piles or timbers that are abraded by vessels (fender piles) or docks (guide piles) to reduce physical breakup of the piles.

11.2.2 Vessel Activities

To avoid impacts on HCP species, the following measures should be implemented:

- Manage vessel operations to minimize the adverse effects of prop wash.

- Take precautions to avoid impacts from accidental spills of fuel and contaminants and post guidelines and protocols for handling spills for all personnel to view.
- Provide spill response training.
- Establish guidelines and protocols to avoid introduction of invasive species.
- If aquatic vegetation is present at or adjacent to a pier or wharf facility, establish guidelines and protocols outlining where vessel traffic should occur when entering or leaving the site.

11.3 Water Quality Modifications

Based on the findings of Bash et al. (2001) on turbidity effects on salmonids, the following measures are recommended to avoid direct and indirect effects on HCP species:

- Determine background suspended sediment concentrations, including particle size and shape, to understand the ambient turbidity to which animals have adapted.
- Review existing watershed assessments to consider pollution loads that may be from sources outside the project to evaluate the project's cumulative effects on turbidity levels.
- Upon determination of existing turbidity and sources, establish acceptable project increases to background turbidity that are similar to those set in the Implementing Agreement between WSDOT and Ecology (WSDOT and Ecology 1998). These standards allow a mixing zone for turbidity generated by in-water construction, as allowed by WAC 173-201A-1090(4) and (6) if the use of this mixing zone does not result in habitat loss, damage to the ecosystem, or adversely affect public health. A mixing zone not meeting turbidity standards is only authorized following the issuance of all other local and state permits and approvals, as well as the implementation of best management practices to avoid or minimize exceedance of turbidity criteria.
- Require that stormwater runoff be 100 percent contained. Route stormwater from the structure and adjacent impervious surfaces to a treatment system.

- Locate the structure deep enough to avoid prop wash resuspension of sediments and contaminants.

- If possible, determine a spatial limit, beyond which no water quality effects will extend. Within this limit, monitoring will be required to ensure that established water quality standards are met. If at any point during construction/dredging/demolition these standards are exceeded, construction/dredging/demolition activities will cease until water quality standards are met.

- If used, treated wood should be encased or sealed to prevent leaching of harmful chemicals.

- Sawdust, drillings, and trimmings from treated wood should be contained with tarps or other impervious materials and prevented from contact with the bed or waters of the state.

- Structures built of treated wood should incorporate features such as steel, plastic, or rubber collars, fendering, or other systems to prevent or minimize the abrasion of treated wood by floats, ramps, or vessels.

- Given the large size of terminals and the large number of pilings required for marinas, use alternatives to treated wood (e.g., materials such as metal, concrete, plastics, and composites) to avoid potential impacts for both new and/or replacement structures.

11.4 Aquatic Vegetation Modifications

The typical effects of vessels on aquatic vegetation vary with both distance and propeller speed, both of which may be important factors in loosening sediment particles and eroding the vegetation. In addition, increased propeller speed results in greater amounts of suspended matter and bubbles, which reduce light levels on the bottom, interfering with photosynthesis by aquatic plants. These impacts can be minimized or prevented altogether, for example, by locating the facility in an area that is currently devoid of native aquatic vegetation or in an area farther offshore to minimize the potential impacts of propeller wash.

To protect and restore aquatic habitat functions, management strategies and development of shoreline regulations should:

- Avoid or minimize the removal or disturbance of aquatic vegetation.

- Do not allow floats to ground out on low tides.

- Manage vessel operations and establish no-construction or no-vessel activity buffers around existing aquatic vegetation to protect this habitat and its contribution to ecological functions.
- Require the control of turbidity during construction and operation of the facility to minimize the proliferation of prop wash and bubble impacts to prevent suffocation or excessive shading of plants.
- Site and design marina/terminal facilities in deeper water to minimize shading and physical impacts (e.g., propeller wash effects) on aquatic vegetation.
- Place the potential shade-casting structures perpendicular to the arc of the sun (i.e., north–south placement) to maximize transmission of light under the structure.
- Encourage the use of upland boat storage areas and the use of slings.
- Any walkways should be 100 percent grated; floats and docks should be at least 60 percent grated.
- Orient grating to maximize transmission of light under the structure.
- At marinas/terminals, minimize the amount of pier area that directly contacts the shoreline to allow light penetration to the nearshore intertidal and shallow subtidal areas.

11.5 Riparian Vegetation Modifications

Avoid and minimize any impacts on riparian, aquatic, and shoreline vegetation by protecting the vegetation. If it is not possible to leave vegetation, prepare revegetation plans to restore the riparian vegetation. A monitoring plan should be included in any revegetation project. For projects that disturb large areas of riparian vegetation, performance bonds should also be required. Each of these measures is discussed more fully below.

For large projects with high-quality riparian habitat that require extensive access from the shoreline for construction, consider the short-term impacts of work performed in the channel rather than removing high-quality riparian habitat that would be a long-term impact due to the size and age of the stand.

Consider establishing buffers and setbacks that protect the functions of the riparian system and its contribution to the ecosystem. The term “buffer” is often loosely used as a synonym for riparian area. However, the term buffer is typically applied in a specific management context to denote an area set aside and managed to protect the natural environment from the effects of surrounding land use or human activities (May 2003; Knutson and Naef 1997). Depending on the context, buffers may be designed to perform a specific function or set of functions, such as filtering pollutants or providing shade (May 2003). The use of the term buffer in this document and the recommendations therein are directed to protect the area ("riparian protection area") needed for the ecological functions of nearshore marine habitats.

Establishing buffer areas is an important regulatory tool to both keep development activity in this habitat to a minimum, and (for developed or redeveloping sites) to trigger mitigation sequencing to deal with project impacts on riparian vegetation. May (2003) provides a review of riparian functions as a factor of buffer width. Table 11-1 provides a summary from the scientific literature of how different riparian habitat widths protect function. As indicated in May (2003), there is no consensus in the literature recommending a single buffer width for a particular function or to accommodate all functions. Knutson and Naef (1997) resolved the variability in the literature by averaging effective buffers widths reported for specific riparian functions. Table 11-2 illustrates the results of the Knutson and Naef (1997) literature review and shows that for streams, a buffer width of 147 feet is effective in providing five of the seven riparian functions including: sediment filtration, erosion control, pollutant removal, LWD, and water temperature protection.

Table 11-1. Riparian buffer functions and appropriate widths identified by May (2003).

Riparian Function	Range of Effective Buffer Widths (feet)	Minimum Recommended Widths (feet)	Notes on Function
Sediment removal/erosion control	26 – 600	98	For 80% sediment removal
Pollutant removal	13 – 860	98	For 80% nutrient removal
LWD recruitment	33 – 328	164	1 SPTH based on long-term natural levels
Water temperature	36 – 141	98	Based on adequate shade
Wildlife habitat	33 – 984	328	Coverage not inclusive
Microclimate	148 – 656	328	Optimum long-term support

SPTH = site potential tree height.

Table 11-2. Riparian functions and appropriate widths identified by Knutson and Naef (1997).

Function	Range of Effective Buffer Widths (feet)	Average of Reported Widths (feet)
Sediment filtration	26 – 300	138
Erosion control	100 – 125	112
Pollutant removal	13 – 600	78
LWD recruitment	100 – 200	147
Water temperature protection	35 – 151	90
Wildlife habitat	25 – 984	287
Microclimate	200 – 525	412

In addition, to protect and restore riparian habitat functions, management strategies should:

- Prohibit the removal or disturbance of riparian vegetation for any areas subject to erosion hazard.
- Fill data gaps through research and documentation of successful and failed riparian protection and revegetation strategies to develop effective policies that protect riparian functions that are important to HCP species.
- Establish buffers and setbacks that protect the functions of the riparian system and its contribution to ecological functions.
- Maintain and restore riparian vegetation to protect human health and safety.
- If the project removes vegetation, require that the project proponent save the large trees and root wads to place strategically in either this aquatic habitat or another restoration project in the region.
- Where riparian vegetation has been removed, isolate disturbed areas from aquatic resources using erosion control features until disturbed areas are stabilized.
- Incorporate all ecological functions into the riparian management strategy.
- Develop financial incentives for conservation programs.
- Increase public education and outreach to educate the public and decision-makers on the outcomes of project actions and decisions.

11.5.1 Revegetation Design

To protect habitat and ecological functions for HCP species, revegetation plans should only include native species endemic to the location of the project. The proximity of the vegetation to the aquatic habitat and the size of the vegetation should be such that it can restore the ecological benefits, such as temperature regulation and autochthonous and allochthonous inputs.

11.5.2 Monitoring Plan

Pursuant to WAC 220-110, revegetation should be monitored annually for 3 years to ensure 100 percent survival of all plantings at the end of the first year and 80 percent survival by the end of the 3-year monitoring period. Monitoring data should be provided to permitting agencies in detailed annual monitoring reports. After 3 years, monitoring and reporting should be completed every other year or every third year. In addition, any specific conditions provided by USACE (for project permits) or NOAA Fisheries and USFWS (for ESA Section 7 compliance) must be implemented.

11.5.3 Insurance

Require performance bonds to cover projects that disturb large areas of riparian vegetation.

11.6 Hydraulic and Geomorphic Modifications

11.6.1 Marine Environments

Construction phase recommendations have been thoroughly addressed in a recent USEPA publication (USEPA 2007). The report summarized best management practices that should be applied to hydromodification projects to reduce nonpoint source pollution.

If possible, all marina activities should include some component of on-site habitat enhancement. Types of enhancement include prototype (soft) shoreline stabilization techniques, planting, and beach nourishment. The mix of these activities should be consistent with the preactivity conditions. These activities are discussed in detail in the Habitat Modifications White Paper (Herrera 2007b).

In the design of the marina itself, a number of alterations to traditional designs can minimize the impacts associated with hydraulic and geomorphic modifications. For instance, submerged breakwaters and weir jetties should be used in place of structures that are exposed. However, both submerged and emergent breakwaters have hydraulic and geomorphic impacts on adjacent areas. Weir jetties are particularly effective at reducing the littoral disruptions associated with marina activities, especially when accompanied by a strategy of beach nourishment and sediment routing (Seabergh and Kraus 2003).

If hydraulic and geomorphic modification cannot be avoided, identify the area affected by the impacts. In addition, ascertain the number of species affected by the modification and the importance of the affected habitat to those species. For example, the area of alteration includes areas affected by embedding, scour, or deposition. For projects of this size, hydraulic modeling of potential impacts using well-established sediment transport models should be required (Miller et al. 2001).

Several additional guidelines included for specific marina construction activities are listed below. If docks are installed:

- Design pile-supported structures with maximum open space between pilings to allow waves, currents, and sediment to pass beneath; use the fewest pilings necessary to carry the load of the structure.

- Encourage the use of upland boat storage areas and the use of slings.

- Require that stormwater runoff be 100 percent contained.
- Encourage designs that create shallow-sloped pocket beach areas instead of continuous vertical bulkheads or riprap.

If pilings are installed:

- Avoid the use of continuous sheet (impermeable) piles and encourage the use of permeable geomaterials (e.g., geotubes) (Oh and Shin 2006).
- Where possible, mantle the seaward side of the pile with natural materials (i.e., sediment consistent with the environment).

If breakwaters are necessary:

- Locate them to best connect to other areas of hard-rock habitat.
- Use submerged breakwaters in place of exposed breakwaters where appropriate (i.e., in areas of small tides and large waves, on the outer coast).
- Where possible, use removable, floating breakwaters in place of permanent, continuous breakwater walls.

11.6.2 Riverine Environments

Construction of marina/terminal facilities often involves project activities such as channel modifications, bank hardening, groins and bank barbs, and other such projects. If channel modification cannot be avoided, identify the area affected by the impacts. In addition, ascertain the number of species affected by the modification and the importance of the affected habitat to those species. For example, the area of alteration includes areas affected by embedding, scour, or deposition. For projects of this size, hydraulic modeling of these impacts using common sediment transport models should be required (Miller et al. 2001).

On riverine systems, modifications to stabilize banks should mimic natural geomorphic and riparian conditions to the extent possible to limit risk of incidental take. Along riverine shorelines, this would include the placement of engineered logjams (see Figure 11-1), the reconnection of floodplains, and the restoration of riparian forests (Collins et al. 2003). In general, groins and bank barbs provide greater habitat diversity than simple rock revetments (Hjort et al. 1983; Li et al. 1984) and thus are preferred over the construction of rock revetments. Because rivers are dynamic systems, localized bank stabilization efforts can shift the ongoing channel response to an adjacent river segment (Leopold et al. 1964). Bank hardening projects should therefore consider such impacts and take appropriate measures to mitigate these effects.

Figure 11-1. Example of bank protection before (left) and after (right) removal of the rock revetment and installation of engineered logjams in the Mashel River near Eatonville, Washington.

The species occurrence in potentially affected areas can be determined via surveys, an inventory database, WDNR Aquatic Lands HCP, Forest Practices HCP (WDNR 2005c), Streamnet database, and/or the Priority Habitats and Species database. Estimating adverse effects of a proposed project should be guided using a limiting factors analysis. For example, the primary limiting factor, such as loss of spawning habitat, should be included in the determination of adverse effects. Baseline data for limiting factors are available for most Water Resource Inventory Areas (WRIAs) from the Washington State Conservation Commission at http://salmon.scc.wa.gov. The limiting factors quantitative analysis for salmonids is available for most streams using the Ecosystem Diagnosis and Treatment model (see http://www/mobrand.com/edt/).

11.6.3 Lacustrine Environments

Guidelines for marina projects in lacustrine environments should follow the same principles listed above for projects in marine environments. However, considering that many reservoirs are located in a distinctly different climate than those in marine settings, there are some BMPs that are specific to these projects. For instance, rock cribs, similar to jetties, were found to provide structural complexity for smaller fish in Lake Tahoe, California (Beauchamp et al. 1994), but this advantage may be outweighed by the interception of spawning materials from deposition in littoral zones and increased deposition of fine materials on rocky substrate. Coves, especially with inundated herbaceous vegetation, were found to yield the largest numbers of young fish in four Mississippi reservoirs (Meals and Miranda 1991).

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