OVERWATER STRUCTURES AND NON-STRUCTURAL PILING WHITE PAPER

Prepared for

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EXECUTIVE SUMMARY ES-1
Overview ES-1
Species and Habitat Use ES-2
Risk of Take and Potential Mitigation Measures ES-2
Shading ES-3
Littoral Vegetation ES-3
Freshwater Aquatic Vegetation ES-3
Riparian and Shoreline Vegetation ES-4
Noise ES-4
Water Quality ES-5
Channel Hydraulics ES-5
Littoral Drift ES-6
Substrate Modifications ES-6
Channel Dewatering ES-7
Artificial Light ES-7
Vessel Activities ES-7

1 INTRODUCTION 1-1

2 OBJECTIVES 2-1

3 METHODOLOGY 3-1

4 ACTIVITY DESCRIPTION 4-1

5 SPECIES AND HABITAT USE 5-1

6 CONCEPTUAL FRAMEWORK FOR ASSESSING IMPACTS 6-1

7 DIRECT AND INDIRECT IMPACTS 7-1
7.1 Shading 7-1
7.1.1 Fish Vision 7-2
7.1.2 Prey Abundance, Feeding, and Growth 7-4
7.1.3 Migration and Distribution 7-5
7.1.4 Predation 7-7
7.2 Littoral Vegetation 7-10
7.2.1 Ambient Light 7-12
7.2.2 Direct Disturbance and Displacement 7-13
7.2.3 Vessel Interactions 7-14
7.3 Freshwater Aquatic Vegetation 7-14
7.3.1 Ambient Light 7-16
7.3.2 Direct Disturbance and Displacement 7-16
7.3.3 Vessel Interactions 7-16
7.3.4 Introduction of Noxious Weeds 7-17

7.4 Riparian and Shoreline Vegetation 7-17
7.4.1 Shading and Water Temperature Regime 7-18
7.4.2 Streambank/Shoreline Stability 7-19
7.4.3 Altered Allochthonous Input 7-20
7.4.4 Groundwater Influence 7-21
7.4.5 Habitat Conditions 7-22
7.5 Noise 7-23
7.5.1 Pile Driving 7-23
7.5.2 Noise from Commercial and Recreational Boating Traffic 7-27
7.5.3 Noise from Construction Vessels and Equipment 7-27
7.6 Water Quality 7-28
7.6.1 Suspended Solids 7-28
7.6.2 Suspended Solids Impacts on Fish 7-30
7.6.3 Suspended Solids Impacts on Invertebrates 7-32
7.6.4 Contaminated Sediment Impacts 7-33
7.6.5 Dissolved Oxygen Impacts 7-33
7.6.6 pH Impacts 7-33
7.6.7 Treated Wood-Related Impacts 7-34
7.6.8 Stormwater and Nonpoint Source Water Quality Impacts 7-42
7.7 Channel Hydraulics 7-43
7.7.1 Controlling Factors in Channels 7-43
7.7.2 Habitat Structure in Channels 7-46
7.8 Littoral Drift 7-49
7.8.1 Wave Action 7-50
7.8.2 Littoral Currents 7-52
7.9 Substrate Modifications 7-53
7.10 Channel Dewatering 7-54
7.10.1 Fish Removal and Exclusion 7-54
7.10.2 Fish Entrainment 7-56
7.10.3 Alteration of Flow 7-56
7.10.4 Disturbance of the Streambed 7-57
7.10.5 Loss of Invertebrates 7-57
7.10.6 Elevated Turbidity During Rewatering 7-59
7.11 Artificial Light 7-59
7.12 Vessel Activities 7-62
7.12.1 Sediment Disturbance 7-62
7.12.2 Eelgrass and Macroalgae Disturbance 7-63
7.12.3 Freshwater Aquatic Vegetation Disturbance 7-64
7.12.4 Noise 7-64
7.12.5 Artificial Light 7-65

8 CUMULATIVE IMPACTS OF OVERWATER STRUCTURES AND NON-STRUCTURAL PILING 8-1

8.1 Shading ... 8-2
8.2 Littoral Vegetation ... 8-3
8.3 Freshwater Aquatic Vegetation ... 8-4
8.4 Riparian and Shoreline Vegetation ... 8-4
8.5 Noise ... 8-5
8.6 Water Quality ... 8-5
8.7 Channel Hydraulics ... 8-6
8.8 Littoral Drift ... 8-6
8.9 Substrate Modifications ... 8-6
8.10 Channel Dewatering ... 8-7
8.11 Artificial Light ... 8-8
8.12 Vessel Activities ... 8-8

9 POTENTIAL RISK OF TAKE ... 9-1
9.1 Shading ... 9-4
9.2 Eelgrass and Macroalgae ... 9-5
9.3 Freshwater Aquatic Vegetation ... 9-6
9.4 Riparian and Shoreline Vegetation ... 9-7
9.5 Noise ... 9-8
9.6 Water Quality ... 9-8
9.7 Channel Hydraulics ... 9-10
9.7.1 No Impact ... 9-11
9.7.2 Habitat Destruction ... 9-12
9.7.3 Embedding ... 9-12
9.7.4 Scour ... 9-14
9.7.5 Deposition ... 9-15
9.8 Littoral Drift ... 9-17
9.9 Substrate Modifications ... 9-19
9.10 Channel Dewatering ... 9-19
9.11 Artificial Light ... 9-21
9.12 Vessel Activities ... 9-21
9.13 Risk Evaluation ... 9-22

10 DATA GAPS ... 10-1
10.1 Shading ... 10-1
10.2 Littoral Vegetation ... 10-2
10.3 Freshwater Aquatic Vegetation ... 10-2
10.4 Riparian and Shoreline Vegetation ... 10-3
10.5 Noise ... 10-3
10.6 Water Quality ... 10-8
10.7 Channel Hydraulics ... 10-8
10.8 Littoral Drift ... 10-9
10.9 Substrate Modifications ... 10-9
10.10 Channel Dewatering ... 10-10

10.11 Artificial Light 10-10
10.12 Vessel Activities 10-10

11 HABITAT PROTECTION, CONSERVATION, MITIGATION, AND MANAGEMENT STRATEGIES 11-1
11.1 Shading 11-1
11.2 Littoral Vegetation 11-4
11.3 Freshwater Aquatic Vegetation....11-5
11.4 Riparian and Shoreline Vegetation....11-6
11.5 Noise 11-8
11.6 Water Quality 11-9
11.7 Channel Hydraulics 11-12
11.8 Littoral Drift 11-13
11.9 Substrate Modifications....11-14
11.10 Channel Dewatering 11-14
11.11 Artificial Light 11-15
11.12 Vessel Activities 11-16

12 REFERENCES 12-1

List of Tables

Table ES-1 Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species ES-6
Table 1 Potentially Covered Fish and Wildlife Species....1-2
Table 2 Range of Potentially Covered Species Listed in Table 1....5-1
Table 3 Habitat Requirements of Potentially Covered Species....5-3
Table 4 Principal Impact Pathways Evaluated 6-2
Table 5 Hearing Categories for Potentially Covered Fish Species....7-25
Table 6 Effects Thresholds for PAHs in Surface Water 7-37
Table 7 U.S. Water Quality Criteria for the Protection of Aquatic Life (“aquatic life criteria”) for Water Soluble Chemicals Used in Treating Wood 7-40
Table 8 Threshold Effects Concentrations (TECs) for Freshwater Sediment 7-41
Table 9 Probable Effects Concentrations (PECs) for Freshwater Sediment....7-42
Table 10 Summary of Potential for Incidental Take of Potentially Covered Species 9-1
Table 11 Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species 9-11
Table 12 Conclusions of the Risk Evaluation....9-23
Table 13 Research Questions on the Impact of Pile Driving on Fishes 10-5

List of Figures

Figure 1 Conceptual Framework for Assessment 6-1
Figure 2 Juvenile Salmon Behavior Patterns Related to Light Intensity 7-3

List of Appendices

Appendix A Standard HPA Provisions
Appendix B Maps: TRAs and WRIAs

List of Abbreviations and Acronyms

ACZA	ammoniacal copper zinc arsenate
ALC	aquatic life criteria
BLM	Biotic Ligand Model
BMP	best management practice
CCA	chromated copper arsenate
CCC	criterion chronic concentration
CMC	criterion maximum concentration
Corps, the	U.S. Army Corps of Engineers
DNA	deoxyribonucleic acid
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
HCP	Habitat Conservation Plan
HPA	Hydraulic Project Approval
ITP	Incidental Take Permit
LWD	large woody debris
MHHW	mean higher high water
MLLW	mean lower low water
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OHWL	ordinary high water line
PAH	polycyclic aromatic hydrocarbon
PAR	photosynthetically active radiation
PEC	probable effects concentration
RCW	Revised Code of Washington
RMS	root mean square
SEL	sound exposure level
TEC	threshold effects concentration
TRA	Tidal Reference Area
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USC	United States Code
USEPA	U.S. Environmental Protection Agency

USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

C	Celsius
cfs	cubic feet per second
cm	centimeter
cm/sec	centimeters per second
dB	decibels
dB_{peak}	peak decibels during each pulse (either maximum or minimum)
dB_{SEL}	decibels sound exposure level
dB_{RMS}	decibels root mean square – square root of sound energy divided by impulse duration
F	Fahrenheit
JTU	Jackson turbidity unit
m	meter
$\mu g/cm^2/mm$	micrograms per square centimeter per millimeter
μg/L	micrograms per liter
$\mu M/m^2/sec$	micro-moles per square meter per second
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeter
NTU	nephelometric turbidity unit
ppb	parts per billion

Note: In general, English measurement units (e.g., feet, inches, miles) are used in this white paper; when the source material expresses a value in metric units, that measurement is also provided in parentheses. However, measurements that by convention are typically made only in metric units are reported in those units (e.g., mg/L, $\mu M/m^2/sec$). Temperatures are reported in both Fahrenheit and Celsius, regardless of the scale used in the source material.

EXECUTIVE SUMMARY

Overview

In Washington State, activities that use, divert, obstruct, or change the natural bed or flow of state waters require a Hydraulic Project Approval (HPA) from the Washington Department of Fish and Wildlife (WDFW). The purpose of the HPA program is to ensure that such activities do not damage public fish and shellfish resources and their habitats. To ensure that activities conducted under an HPA comply with the Endangered Species Act (ESA), WDFW is preparing 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 (known as NOAA Fisheries). WDFW's objective is to avoid, minimize, or compensate for the incidental take of species potentially covered under the HCP resulting from the implementation of permits issued under the HPA authority. In this context, to "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct (16 U.S.C. 1532(19)).

To evaluate the feasibility of and develop a scientific foundation for the HCP, the WDFW has commissioned a series of white papers that will review and summarize the best available science for up to 21 HPA activities that could be included in the HCP.

This white paper addresses the availability of scientific information on two such HPA activities, overwater structures and the installation and removal of non-structural piling. Overwater structures are defined by WDFW as "docks, piers, floats, ramps, wharfs, ferry terminals and other structures that are supported above or float on the water. This includes all structural or supporting pilings. This does not include structures associated with a Marina." Non-structural piling is defined by the WDFW as "individual, non-structural pilings, power poles, transmission lines, conduits, etc. Pilings are driven into the stream, lake, and ocean bed."

The literature review conducted for this white paper identified 12 impact mechanisms associated with the construction and operation of overwater structures and non-structural piling that could potentially affect aquatic species being considered for coverage under the HCP ("potentially covered species"). These mechanisms describe activities and modifications to habitat arising from activities that can be temporary or permanent in duration. The impact mechanisms evaluated in this white paper are:

- Shading
- Littoral vegetation
- Freshwater aquatic vegetation
- Riparian and shoreline vegetation
- Noise
- Water quality
- Channel hydraulics
- Littoral drift
- Substrate modifications
- Channel dewatering
- Artificial light
- Vessel activities

Following a brief description of overwater structures and non-structural piling activities and potential impact mechanisms, the 52 aquatic species being considered for coverage under the HCP are described. Based on this information, the risks of direct and indirect impacts to the potentially covered species or their habitats are discussed. In addition, the potential for cumulative impacts is discussed, and the risk for incidental take of potentially covered species is qualitatively estimated. The white paper then identifies data gaps (i.e., instances in which the data or literature are insufficient to allow conclusions on the risk of take). The white paper concludes by providing habitat protection, conservation, mitigation, and management strategies consisting of actions that could be taken to avoid or minimize the impacts of overwater structures and non-structural piling. Key elements of the white paper are summarized below.

Species and Habitat Use

This white paper considers potential impacts on 52 potentially covered species and summarizes the geographic distribution and habitat requirements of those species. That information is used to assess potential impacts on the potentially covered species.

Risk of Take and Potential Mitigation Measures

The risk of take and potential mitigation measures are summarized below for each of the impact mechanisms listed above.

Shading

Shading has been identified as causing incidental take of juvenile salmon in both marine and freshwater environments. However, almost nothing is known about the effects of shading on other potentially covered species.

Various authors have suggested minimization measures to reduce shading impacts, such as:

- Increasing the height of overwater structures to allow light transmission under the structures
- Decreasing structure width to decrease the shade footprint
- Aligning the structure in a north-south orientation to allow the arc of the sun to cross perpendicular to the structure
- Using the smallest number of pilings possible, allowing more light beneath the structure

Littoral Vegetation

Littoral vegetation includes eelgrass, macroalgae, and intertidal vascular plants. Generally, the federal agencies have treated loss or reduced density of eelgrass as equivalent to loss of essential habitat for listed species known to occur in the area; as such, it constitutes a take of listed species such as salmon and bull trout. Thus, eelgrass loss is almost certain to result in incidental take of potentially covered species that use eelgrass, including anadromous salmonids, anadromous and marine forage fishes, and certain larval pelagic fishes. Mitigation of impacts to littoral vegetation is best achieved through avoidance.

Freshwater Aquatic Vegetation

Most impacts on aquatic vegetation are not directly addressed by current best management practices or minimization measures required under the HPA authority, so they represent impacts that have a high potential to occur in practice. This oversight has likely occurred because salmonids do not show a very strong dependence on freshwater aquatic vegetation. However, some other potentially covered species, including freshwater molluscs and an array of fishes, have a strong association with freshwater aquatic vegetation and would be at relatively high risk of incidental take from projects that remove or reduce such vegetation within their habitat. There are few recommendations for how to minimize impacts to aquatic vegetation, except via avoidance.

Riparian and Shoreline Vegetation

In past biological opinions, the National Marine Fisheries Service (NMFS) has found that loss of riparian and shoreline vegetation amounts to incidental take of listed fish, even though the relationship between habitat conditions and the distribution and abundance of those individuals in the action area was imprecise. Many other potentially covered species also have demonstrated dependence on riparian and shoreline vegetation and so would be at high risk of incidental take.

The following measures could help avoid and minimize incidental take arising from impacts to riparian and shoreline vegetation:

- Prepare revegetation plans for projects that temporarily disturb vegetation during construction.
- Submit monitoring reports to WDFW as part of the revegetation plan and require remedial action if pre-established goals are not met.
- Save vegetation (specifically large trees and root wads) removed for the project for later use in restoration efforts.
- To the extent practicable, do not permit removal or disturbance of riparian vegetation in areas with high erosion hazard (Knutson and Naef 1997).

Noise

Underwater noise produced in association with the construction of overwater structures includes noise generated from pile driving (when applicable) and by construction vessels and equipment. It is well established that impact pile driving can result in incidental take to fish. However, the sound sensitivity of individual species is not well known, so it is difficult to predict the likelihood of incidental take for species other than salmonids.

Several noise reduction devices have been developed for pile driving, including air bubble curtains, fabric barriers, pile caps, cofferdams, and use of vibratory hammers. The usual strategy for minimizing other types of underwater noise is to time activities to occur when sensitive life stages of potentially covered species are less likely to be present.

Water Quality

Placing constructed features in aquatic settings may adversely impact water quality mainly by causing increases in suspended solids concentrations, reducing dissolved oxygen levels, changing pH, or releasing toxic substances from treated wood products. Stormwater runoff from constructed surfaces also poses a threat to water quality from its associated nonpoint source pollutant load. With respect to suspended solids, the take risk to potentially covered fish species increases in proportion to the magnitude and duration of the impact; vulnerability of the affected life-history stage; inability of the fish to alter behavior to avoid the impact; physiological, developmental, and behavioral impairments suffered by the fish; and indirect mechanisms such as exposure to predation. In contrast, incidental take risk associated with dissolved oxygen impacts is probably quite low and, because the potential impact of pH change from uncured concrete is avoided in standard HPA measures, the risk of incidental take from pH change is near zero. Risk of incidental take of potentially covered species due to the use of treated wood is significant but highly variable and is related to factors that include proximity, dilution, and type of treatment. Risk of incidental take due to release of stormwater treated in accordance with current Washington State Department of Ecology guidance is generally low, but this finding has reduced confidence because some data indicate high salmonid vulnerability to some stormwater constituents (such as dissolved copper), and stormwater effects on most potentially covered species have received little study.

There are a number of avoidance and minimization measures that could help to address water quality issues. Current practice effectively addresses most potential impacts, but suspended sediment impacts warrant more detailed advance studies to determine site-specific vulnerability to impacts, and there are a variety of measures that could further reduce impacts associated with use of treated wood.

Channel Hydraulics

Impacts to potentially covered species as a result of channel hydraulic changes are summarized in Table ES-1.

Table ES-1
Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species

Impact	Potentially Affected Species
No impact identified	Marine species or marine life stages of estuarine and anadromous species
Habitat destruction due to siting of structure	Species potentially occupying the affected stream
Embedding due to reduced sediment transport capacity or indirectly as a result of bank erosion	Species potentially occupying the affected streambed: gravel spawners and benthos
Scour due to locally increased transport capacity	Species potentially occupying the affected streambed: gravel spawners and benthos
Deposition downstream of scour areas	Species potentially occupying the affected streambed: gravel spawners and benthos
Loss of riparian vegetation due to bank erosion	Species potentially occupying the affected stream

Each of these changes (excepting "no impact") can potentially result in incidental take of animals or an adverse impact on their habitat. We found no studies specifically addressing the cumulative impacts of channel hydraulic changes on potentially covered species. Generally, the question of cumulative impacts emerges as a data gap. The HPA program itself offers the best means of measuring these impacts, because WDFW has authority to require monitoring of the impacts of authorized projects.

Littoral Drift

Incidental take is most likely to result from changes in littoral drift via impacts on beach-spawning fishes and through eelgrass changes. Some potentially covered species are beach spawners and these could suffer reduced reproductive success due to altered littoral drift. Other potentially covered species prey upon the beach spawners and could suffer reduced foraging success due to altered littoral drift. Littoral drift could also change the distribution of eelgrass, with effects described under "Littoral Vegetation."

Impacts to littoral drift can be avoided or minimized by the following measures:

- Design pile-supported structures with open space between pilings.
- Minimize the dimensions of floating structures placed perpendicular to shorelines.
- Perform thorough hydraulic design to determine how a structure is likely to impact littoral drift.

Substrate Modifications

Piling associated with overwater structures, as well as non-structural piling, in nearshore environments can alter adjacent substrates through shellfish deposition and changes to substrate bathymetry. Changes in substrate type can alter the flora and fauna. Along with the minimization measures for eelgrass and macroalgae discussed above, use of fewer and more widely spaced pilings will help to reduce this risk.

Channel Dewatering

The primary risk of incidental take associated with channel dewatering results from the capture and handling of fish. Past biological opinions have found that all such activity constitutes incidental take. Potential additional causes of incidental take include impacts attributable to increases in turbidity and suspended solids. These include indicators of major and minor physiological stress, habitat degradation, and impaired homing behavior. These effects are sublethal, but are still considered take under the ESA (NMFS 2006b). Many measures can be employed to minimize or avoid incidental take during channel dewatering.

Artificial Light

Incidental take of listed fish species as a result of artificial light to build or operate overwater structures has not been quantified in past biological opinions and corresponding incidental take statements. Although artificial light responses are unknown for most potentially covered species, there is a plausible risk that nighttime illumination of the water surface may contribute to incidental take. However, such a risk is relatively easy to minimize by requiring structures to be lit so as to minimize direct illumination of the water surface.

Vessel Activities

Vessel activities associated with the installation and operation of in-water and overwater structures may adversely impact potentially covered species. Impact mechanisms include:

- Physical disturbance of sediment, organisms, and submerged vegetation through grounding or water turbulence caused by propeller wash
- Noise from vessel activity
- Propeller-wash entrained air bubbles that combine with turbidity increases from disturbed sediment, leading to a temporary reduction in the availability of light

Incidental take may result from vessel activities via each of these mechanisms. To minimize these impacts, it may be appropriate to require construction vessel operation plans for larger projects, or projects located in particularly sensitive habitats to ensure that the potential for vessel and construction activity impacts to sensitive habitats and species is minimized.

1 INTRODUCTION

In Washington State, activities that use, divert, obstruct, or change the natural bed[1] or flow of state waters require a Hydraulic Project Approval (HPA) from the Washington Department of Fish and Wildlife (WDFW) (Revised Code of Washington [RCW] 77.55.011). The purpose of the HPA program is to ensure that such activities are completed in a manner that prevents damage to public fish and shellfish resources and their habitats. Because several fish and aquatic species in the state are listed as threatened or endangered under the federal Endangered Species Act (ESA), many of the activities requiring an HPA may also require approvals from the National Oceanic and Atmospheric Administration Fisheries Service (NOAA Fisheries) and the U.S. Fish and Wildlife Service (USFWS). Such approvals can be in the form of an ESA Section 7 Incidental Take Statement or an ESA Section 10 Incidental Take Permit (ITP). As authorized in Section 10 of the ESA, ITPs may be issued for otherwise lawful activities that could result in the "take" of ESA-listed species or their habitats. In this context, to take means to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct" (16 United States Code [USC] §1532(19)).

To ensure that the HPA program complies with the ESA and to facilitate ESA compliance for persons conducting work under an HPA, WDFW is preparing a programmatic, multispecies Habitat Conservation Plan (HCP) to obtain an ITP from the USFWS and NOAA Fisheries. An HCP must provide an operating conservation plan for avoiding, minimizing, and mitigating, to the maximum extent practicable, the impacts of the permitted take on the potentially covered species[2]. The federal agencies must also find in their biological opinion that any permitted incidental take will not jeopardize the continued existence of the species, i.e., the taking will not appreciably reduce the likelihood of survival and recovery of the species in the wild.

To develop a scientific foundation for the HCP, WDFW has commissioned a series of white papers that will review and summarize the best available science for up to 21 HPA activities that could be included in the HCP.

[1] Bed is defined as the land below the ordinary high water line of the state waters, but does not include irrigation ditches, canals, the outflow from stormwater runoff devices, or other artificial watercourses except where they exist in a natural watercourse that has been altered by humans.

[2] In this white paper, "potentially covered species" refers to fish and wildlife species that could be covered in the HCP; however, that determination would be made at the time the HCP is finalized between WDFW and the federal agencies.

Two of those activities, overwater structures and non-structural piling, form the subject of this white paper. Overwater structures are defined by WDFW[3] as "docks, piers, floats, ramps, wharfs, ferry terminals and other structures that are supported above or float on the water. This includes all structural or supporting pilings. This does not include structures associated with a Marina." Marinas will be the subject of a separate white paper. Non-structural pilings are defined by WDFW as "individual, non-structural pilings, power poles, transmission lines, conduits, etc. Pilings are driven into the stream, lake, and ocean bed." This white paper compiles and synthesizes existing scientific and commercial information, describes potential take mechanisms, and makes recommendations for measures to avoid or minimize the impacts on potentially covered species of constructing and operating overwater structures and non-structural piling. Species being proposed for coverage under the HCP (the "potentially covered species") are listed in Table 1.

Table 1
Potentially Covered Fish and Wildlife Species

Common Name	Scientific Name	Status	Habitat
California floater (mussel)	*Anodonta californiensis*	FSC/SC	Freshwater
Mountain sucker	*Catostomus platyrhynchus*	SC	Freshwater
Margined sculpin	*Cottus marginatus*	FSC/SS	Freshwater
Lake chub	*Couesius plumbeus*	SC	Freshwater
Giant Columbia River limpet	*Fisherola nuttalli*	SC	Freshwater
Great Columbia River spire snail	*Fluminicola columbiana*	FSC/SC	Freshwater
Western ridged mussel	*Gonidea angulata*	(none)	Freshwater
Western brook lamprey	*Lampetra richardsoni*	FSC	Freshwater
Olympic mudminnow	*Novumbra hubbsi*	SS	Freshwater
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	FSC	Freshwater
Redband trout	*Oncorhynchus mykiss*	FSC	Freshwater
Pygmy whitefish	*Prosopium coulteri*	FSC/SS	Freshwater
Leopard dace	*Rhinichthys falcatus*	SC	Freshwater
Umatilla dace	*Rhinichthys umatilla*	SC	Freshwater
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	FSC	Freshwater & Anadromous
Bull trout	*Salvelinus confluentus*	FT/SC	Freshwater & Anadromous
Sockeye salmon	*Oncorhynchus nerka*	FE/FT/SC	Freshwater (kokanee) & Anadromous
Pink salmon	*Oncorhynchus gorbuscha*	SPHS	Anadromous
Chum salmon	*Oncorhynchus keta*	FT/SC	Anadromous
Coho salmon	*Oncorhynchus kisutch*	FC/FSC	Anadromous
Steelhead	*Oncorhynchus mykiss*	FE/FT/SC	Anadromous
Chinook salmon	*Oncorhynchus tschawytscha*	FE/FT/SC	Anadromous
Green sturgeon	*Acipenser medirostris*	SPHS	Anadromous
White sturgeon	*Acipenser transmontanus*	SPHS	Anadromous
River lamprey	*Lampetra ayresi*	FSC/SC	Anadromous
Pacific lamprey	*Lampetra tridentata*	FSC	Anadromous
Dolly Varden	*Salvelinus malma*	FP	Anadromous

[3] The definitions of overwater structures and non-structural piling presented here were provided by WDFW in Appendix B of Exhibit B of the Request for Proposal for this project, RFP No. 06-0005.

Common Name	Scientific Name	Status	Habitat
Longfin smelt	*Spirinchus thaleichthys*	SPHS	Anadromous
Eulachon	*Thaleichthys pacificus*	FC/SC	Anadromous
Olympia oyster	*Ostrea lurida*	SC	Estuarine
Pacific sand lance	*Ammodytes hexapterus*	SPHS	Marine & Estuarine
Pacific herring	*Clupea harengus pallasi*	FC/SC	Marine & Estuarine
Surf smelt	*Hypomesus pretiosus*	SPHS	Marine & Estuarine
Pacific hake	*Merluccius productus*	FSC/SC	Marine & Estuarine
Lingcod	*Ophiodon elongatus*	SPHS	Marine & Estuarine
Pacific cod	*Gadus macrocephalus*	FSC/SC	Marine (occ. Estuarine)
Walleye pollock	*Theragra chalcogramma*	FSC/SC	Marine (occ. Estuarine)
Newcomb's littorine snail	*Algamorda subrotundata*	FSC/SC	Marine
Northern abalone	*Haliotis kamtschatkana*	FSC/SC	Marine
Brown rockfish	*Sebastes auriculatus*	SC	Marine
Copper rockfish	*Sebastes caurinus*	FSC/SC	Marine
Greenstriped rockfish	*Sebastes elongates*	SC	Marine
Widow rockfish	*Sebastes entomelas*	SC	Marine
Yellowtail rockfish	*Sebastes flavidus*	SC	Marine
Quillback rockfish	*Sebastes maliger*	FSC/SC	Marine
Black rockfish	*Sebastes melanops*	SC	Marine
China rockfish	*Sebastes nebulosus*	SC	Marine
Tiger rockfish	*Sebastes nigrocinctus*	SC	Marine
Bocaccio rockfish	*Sebastes paucispinis*	SC	Marine
Canary rockfish	*Sebastes pinniger*	SC	Marine
Redstripe rockfish	*Sebastes proriger*	SC	Marine
Yelloweye rockfish	*Sebastes ruberrimus*	SC	Marine

Notes:

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

Source: The list of species being considered for coverage under the HCP was provided in "WDFW Hydraulic Project Approval HCP Exhibit B HPA Final Grant Proposal," which was distributed with the Request for Proposal for this analysis.

Note: Species listed by habitat type; within habitat type, species listed in alphabetical order by scientific name.

This white paper focuses on overwater structures for which WDFW would benefit from securing programmatic coverage under the ESA; examples include docks, piers, ramps, and floats.

The remainder of this white paper is organized as follows:

- Objectives and methodology are detailed in Sections 2 and 3.
- Permitted overwater structures and non-structural piling activities are described in Section 4.
- Habitats used by the potentially covered species are summarized in Section 5.

- The conceptual framework for assessing impacts is presented in Section 6.
- The impact analysis appears in Section 7.
- Cumulative impacts of overwater structures and non-structural piling are discussed in Section 8.
- The potential risk of take is summarized in Section 9.
- An analysis of data gaps is presented in Section 10.
- Strategies to offset impacts and management recommendations are provided in Section 11.
- Section 12 lists publication details for the references cited in this white paper.

2 OBJECTIVES

The objectives of this white paper are:

- To compile and synthesize the best available scientific information related to the potential human impacts on potentially covered species, their habitats, and associated ecological processes resulting from the construction and operation of overwater structures and non-structural piling permitted under the HPA authority
- To use this scientific information to estimate the circumstances, mechanisms, and risk of incidental take potentially or likely resulting from construction and operation of various types of overwater structures and non-structural piling
- To identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), for avoiding, minimizing, or mitigating the risk of incidental take

3 METHODOLOGY

We employed the following procedures in preparing this white paper:

1. Existing WDFW rules and guidance were reviewed to identify current knowledge and practices relevant to the analysis of the impacts to potentially covered species associated with overwater structures and non-structurual piling.
2. A literature review was conducted to review the current state of knowledge regarding potential impacts associated with overwater structures and non-structural piling on potentially covered species. The compiled literature set included (a) relevant previous white papers prepared for WDFW; (b) copies of HPAs for overwater structures and non-structural piling, provided by WDFW; (c) documents secured as a result of keyword searches on the Internet and in other literature databases; and (d) a review of biological opinions prepared by NOAA Fisheries and USFWS, addressing various projects involving overwater structures and non-structural piling in Washington, Oregon, Idaho, and California. The principal keyword search strategy was to look for documents linking terms describing the species (i.e., common and scientific names of all potentially covered species) with terms describing overwater structures and non-structural piling or mechanisms of impact associated with the construction and operation of such structures.
3. The compiled documents were reviewed to determine which potential mechanisms of impact were addressed in each document; the majority considered impacts to salmonids or to physical habitat features. Documents that evaluated impacts to potentially covered species and physical habitat features were identified and evaluated during the literature review. The literature review results were entered into a matrix, which allowed easy identification of literature relevant to each impact mechanism. Documents located during the literature review were in turn used in Internet searches (mostly conducted using the Google® search tool) to locate additional relevant literature addressing specific impact pathways.
4. Impact mechanism analyses were prepared for each of the principal impact mechanisms and for both overwater structures and non-structural piling.
5. The text of the white paper was prepared and subjected to review by technical specialists with Anchor Environmental L.L.C., Jones & Stokes Associates, and R2 Resource Consultants, as well as by WDFW personnel.

4 ACTIVITY 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." Overwater structures and non-structural piling are addressed together in this white paper because of the overlap in potential impact mechanisms associated with the construction and presence of these structures. Overwater structures are defined by WDFW[4] as "docks, piers, floats, ramps, wharfs, ferry terminals, and other structures that are supported above or float on the water. This includes all structural or supporting pilings for the overwater structure. This does not include structures associated with a Marina, or Non-Structural (Supporting) Pilings." For the purposes of this analysis:

- A pier is defined as an elevated and stationary walkway supported by piling 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 ships can lie alongside to load and unload cargo and passengers.

Non-structural pilings are defined by WDFW as "individual, non-structural pilings, power poles, transmission lines, conduits, etc. Pilings are driven into the stream, lake, and ocean bed."

The complete legal description of these activities is contained in Washington Administrative Code (WAC) 220-110, the *Hydraulic Code Rules*, and is particularly detailed in WAC 220-110-060, *Construction of freshwater docks, piers, and floats and the driving or removal of piling,* and WAC 220-110-300, *Saltwater piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings*. Appendix A reproduces the full text of these WAC sections.

For this white paper, overwater structures and non-structural piling are defined as hydraulic projects that comply with all provisions specified in WAC 220-110-060 or WAC 220-110-300. The analysis presented in this white paper addresses the impacts of lawful activities, which are the

[4] The definitions of overwater structures and non-structural piling presented here were provided by WDFW in Appendix B of Exhibit B of the Request for Proposal for this project, RFP No. 06-0005.

only activities that can be authorized under an ITP. Accordingly, the impact analyses presented below were prepared with the assumption that all applicable provisions of WAC 220-110, and any other applicable laws and regulations of the United States and the State of Washington, are observed in the construction and operation of overwater structures and non-structural piling authorized by WDFW.

Most overwater structures and non-structural piling affect waters of the United States as well as waters of the State of Washington. Thus, their construction also requires a permit from the U.S. Army Corps of Engineers (the Corps; USACE) authorizing the placement of fill in waters of the United States (known as a Section 404 permit) or the placement of structures in navigable waters (known as a Section 10 permit). In many cases, the permit is some form of a Corps Nationwide Permit, meaning that standard conditions apply. However, on September 26, 2006, the Corps proposed revision of the Nationwide Permit system; therefore, it is not practical for this analysis to make assumptions about future permit conditions that might be imposed by the Corps for projects authorized under the Nationwide Permit system. Moreover, all projects authorized under Corps permits are subject to additional conditions, some of which may be derived pursuant to interagency consultation with the federal agencies as provided for under Section 7 of the ESA. The analyses presented in this white paper do not reflect assumptions about what those conditions might be.

5 SPECIES AND HABITAT USE

Table 2 identifies the approximate distribution of each of the 52 potentially covered species listed in Table 1 by noting its documented presence within Water Resource Inventory Areas (WRIAs) for freshwater and estuarine environments or Tidal Reference Areas (TRAs) for marine environments. Figures in Appendix B show the locations of WRIAs and TRAs in Washington State. The risk of incidental take is approximately zero for any species not present in the region where a given HPA is applicable. Because the WRIAs and TRAs represent large areas, species habitat requirements are further identified in Table 3, which describes the critical life-history stages of each species and the habitat dependency for each life-history stage.

Table 2
Range of Potentially Covered Species Listed in Table 1

Common Name	Scientific Name	Water Resource Inventory Area*	Tidal Reference Area (see list below)*
Green sturgeon	*Acipenser medirostris*	25, 26, 27, 28	All
White sturgeon	*Acipenser transmontanus*	3, 22, 24-37, 40-42, 44-61 (Columbia and Snake rivers)	All
Newcomb's littorine snail	*Algamorda subrotundata*	N/A	14, 15, 16, 17
Pacific sand lance	*Ammodytes hexapterus*	N/A	All
California floater (mussel)	*Anodonta californiensis*	30, 36, 37, 40, 42, 47-49, 52-54, 58-61	N/A
Mountain sucker	*Catostomus platyrhynchus*	23, 26-33, 35-41, 44-46 (Columbia, Snake, and Yakima rivers)	N/A
Pacific herring	*Clupea harengus pallasi*	N/A	1, 2, 4, 5, 8, 9, 10, 11, 12, 13, 16, 17
Margined sculpin	*Cottus marginatus*	32, 35	N/A
Lake chub	*Couesius plumbeus*	48, 61; other locations unknown	N/A
Giant Columbia River limpet	*Fisherola nuttalli*	35, 36, 40, 47-49, 54, 57; other locations unknown	N/A
Great Columbia River spire snail	*Fluminicola columbiana*	35, 45, 48, 49; other locations unknown	N/A
Pacific cod	*Gadus macrocephalus*	N/A	All
Western ridged mussel	*Gonidea angulata*	1, 3-5, 7-11, 13, 21-42, 44-55, 57-62	N/A
Northern abalone	*Haliotis kamtschatkana*	N/A	10
Surf smelt	*Hypomesus pretiosus*	N/A	All
River lamprey	*Lampetra ayresi*	1, 3, 5, 7-16, 20-40	N/A
Western brook lamprey	*Lampetra richardsoni*	1, 3, 5, 7-14, 16, 20-40	N/A
Pacific lamprey	*Lampetra tridentata*	1, 3, 5, 7-42, 44-46, 58, 61	N/A
Pacific hake	*Merluccius productus*	N/A	All
Olympic mudminnow	*Novumbra hubbsi*	5, 7-14, 20-24, 26	N/A
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	1-5, 7-30	All
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	37-39, 44-55, 58-62	N/A
Pink salmon	*Oncorhynchus gorbuscha*	1, 3-5, 7-13, 16-19, 21	1-13
Chum salmon	*Oncorhynchus keta*	1, 3-5, 7-29	All
Coho salmon	*Oncorhynchus kisutch*	1-42, 44-48, 50	All

Common Name	Scientific Name	Water Resource Inventory Area*	Tidal Reference Area (see list below)*
Redband trout	*Oncorhynchus mykiss*	37-40, 45-49, 54-57	N/A
Steelhead	*Oncorhynchus mykiss*	1, 3, 4, 5, 7, 8, 9, 10-12, 14, 15, 17-41, 44-50	All
Sockeye salmon	*Oncorhynchus nerka*	1, 3-5, 7-12, 16, 19-22, 25-33, 35-37, 40, 41, 44-50, Columbia River and Snake River	5, 8, 14
Chinook salmon	*Oncorhynchus tschawytscha*	1-41, 44-50	All
Lingcod	*Ophiodon elongatus*	N/A	All
Olympia oyster	*Ostrea lurida*	N/A	1-14, 17
Pygmy whitefish	*Prosopium coulteri*	7, 8, 19, 39, 47, 49, 53, 55, 58, 59, 62	N/A
Leopard dace	*Rhinicthys falcatus*	21, 26-41, 44-50	N/A
Umatilla dace	*Rhinicthys umatilla*	31, 36-41, 44-50, 59-61	N/A
Bull trout	*Salvelinus confluentus*	1-23, 26, 27, 29-41, 44-55, 57-62	All
Dolly Varden	*Salvelinus malma*	1, 3, 5, 7, 17-22, 24	6-10, 14-17
Brown rockfish	*Sebastes auriculatus*	N/A	All
Copper rockfish	*Sebastes caurinus*	N/A	All
Greenstriped rockfish	*Sebastes elongates*	N/A	All
Widow rockfish	*Sebastes entomelas*	N/A	All
Yellowtail rockfish	*Sebastes flavidus*	N/A	All
Quillback rockfish	*Sebastes maliger*	N/A	All
Black rockfish	*Sebastes melanops*	N/A	All
China rockfish	*Sebastes nebulosus*	N/A	All
Tiger rockfish	*Sebastes nigrocinctus*	N/A	All
Bocaccio rockfish	*Sebastes paucispinis*	N/A	All
Canary rockfish	*Sebastes pinniger*	N/A	All
Redstripe rockfish	*Sebastes proriger*	N/A	All
Yelloweye rockfish	*Sebastes ruberrimus*	N/A	All
Longfin smelt	*Spirinchus thaleichthys*	1,2,3, 6-17, 22 and 24	1-9, 15-17 (mouths of rivers and streams; Lake Washington)
Eulachon	*Thaleichthys pacificus*	20-29 (mouths of major rivers)	14-17 (tidal areas of rivers)
Walleye pollock	*Theragra chalcogramma*	N/A	All

Tidal Reference Areas:

TRA 1 – Shelton
TRA 2 – Olympia
TRA 3 – South Puget Sound
TRA 4 – Tacoma
TRA 5 – Seattle
TRA 6 – Edmonds
TRA 7 - Everett
TRA 8 – Yokeko Point
TRA 9 – Blaine
TRA 10 – Port Townsend
TRA 11 – Union
TRA 12 – Seabeck.
TRA 13 – Bangor
TRA 14 – Ocean Beaches
TRA 15 – Westport
TRA 16 – Aberdeen
TRA 17 – Willapa Bay

*Please refer to Appendix B for figures showing WRIA and TRA locations. Estuarine and marine distributions are characterized by TRA rather than WRIA.
Note: Species listed in alphabetical order by scientific name.
Note: The distribution of all fish species in this table is based on visual examination of range maps published by Wydoski and Whitney (2003) and comparison to published maps showing WRIA and TRA boundaries. The distribution of all non-fish (invertebrate) species is based on narrative descriptions presented by the Washington Department of Natural Resources (WDNR 2006b).
N/A – Not applicable, because the species does not occur within a WRIA and/or a TRA.

Table 3
Habitat Requirements of Potentially Covered Species

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Green sturgeon	*Acipenser medirostris*	Habits and life history not well known; found in all marine waters in Washington and in estuaries; spend much of life in marine nearshore waters and estuaries, returning to rivers to spawn; spawn in deep pools, substrate preferences unclear but are likely large cobbles, although range from sand to bedrock; reside in lower reaches of fresh water for up to 3 years; age at sexual maturity uncertain; feed on fishes and invertebrates (Wydoski and Whitney 2003; Nakamoto and Kisanuki 1995; Adams et al. 2002; Emmett et al. 1991)	Spawning: Spring Incubation and Emergence: Large eggs sink to bottom, weak swimmers (Kynard et al. 2005)
White sturgeon	*Acipenser transmontanus*	Found in marine waters and major rivers in Washington; in marine settings, adults and subadults use estuarine and marine nearshore, including some movement into intertidal flats to feed at high tide; some landlocked populations behind dams; seasonally use main channels and sloughs; juveniles also occupy boulder and bedrock substrate; prefers swift (2.6 to 9.2 feet per second) and deep (13 to 66 feet) water on bedrock substrate for spawning; juveniles feed on mysid shrimp and amphipods; large fish feed on variety of crustaceans, annelid worms, molluscs, and fish (Parsley et al. 1993; Wydoski and Whitney 2003; Emmett et al. 1991)	Spawning: April to July Incubation: Approx. 7 days Emergence: Approx. 7 days
Newcomb's littorine snail	*Algamorda subrotundata*	Found in Grays Harbor and Willapa Bay on Washington coast; current distribution uncertain; algae feeder occupying narrow band in Salicornia salt marshes above mean higher high water (MHHW); not a true marine gastropod (Larsen et al. 1995)	Egg Laying: Unknown
Pacific sand lance	*Ammodytes hexapterus*	Schooling plankton feeders; spawn on sand and gravel at tidal elevations of 4 to 5 feet (+1.5 meters [m]) MHHW; larvae and young rear in bays and nearshore; adults feed during the day and burrow into the sand at night (Garrison and Miller 1982, In: Nightingale and Simenstad 2001b; WDFW 1997b, In: NRC 2001).	Spawning: November to February Incubation: On sand substrate Emergence: January to April
California floater (mussel)	*Anodonta californiensis*	Freshwater filter feeder requiring clean, well-oxygenated water; declining through much of historical range; known to occur in Columbia and Okanogan rivers and several lakes; intolerant of habitats with shifting substrates, excessive water flow fluctuations, or seasonal hypoxia; fertilization takes place within the brood chambers of the female mussel; the fertilized eggs develop into a parasitic stage called glochidia; released glochidia attach to species-specific host fish; juvenile and adult mussels attach to gravel and rocks (Nedeau et al. 2005; Larsen et al. 1995; Box et al. 2003; Frest and Johannes 1995, In: WDNR 2006b)	Spawning: Spring Incubation: In brood pouch, duration unknown; glochidia attach to host fish during metamorphosis
Mountain sucker	*Catostomus platyrhynchus*	Distribution restricted to Columbia River system; found in clear, cold mountain streams less than 40 feet wide and in some lakes; prefer deep pools in summer with moderate current; juveniles prefer slower side channels or weedy backwaters; food consists of algae and diatoms (Wydoski and Whitney 2003)	Spawning: June and July

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Pacific herring	*Clupea harengus pallasi*	18 separate stocks in Puget Sound; utilize shallow subtidal habitats (between 0 and –10 feet mean lower low water [MLLW]) for spawning and juvenile rearing; spawning has also occurred above MLLW; widely distributed throughout Puget Sound and coastal wetlands; feed on harpacticoid copepods; important forage fish (WDFW 1997a; Simenstad et al. 1979, In: NRC 2001 and In: Nightingale and Simenstad 2001b).	Spawning: Late January to early April, oviparous Egg Incubation: 10 to 14 days; eggs adhere to eelgrass, kelp, seaweed Emergence: Larvae are pelagic (i.e., free floating)
Margined sculpin	*Cottus marginatus*	Endemic to southeastern Washington; habitat is in deeper pools and slow-moving glides in headwater tributaries with silt and small gravel substrate; spawn under rocks in pools; prefer cool water less than 68 degrees Fahrenheit (F) (20 degrees Celsius [C]); avoid high-velocity areas; food is unknown (Wydoski and Whitney 2003; Mongillo and Hallock 1998)	Spawning: May to June Incubation and Emergence: Unknown
Lake chub	*Couesius plumbeus*	Bottom dwellers inhabiting a variety of habitats in lakes and streams; prefer small, slow streams; spawn on rocky and gravelly substrate in tributary streams to lakes; juveniles feed on zooplankton and phytoplankton; adults feed on insects (Wydoski and Whitney 2003)	Spawning: April to June, broadcast spawn
Giant Columbia River limpet	*Fisherola nuttalli*	Also known as the shortface lanx; occupies fast-moving and well-oxygenated streams, specifically the Hanford Reach, Wenatchee and Methow rivers; found in shallow, rocky areas of cobble to boulder substrate; species feeds by grazing on algae and small crustaceans attached to rocks (Neitzel and Frest 1990, In: WDNR 2006b)	Unknown
Great Columbia River spire snail	*Fluminicola columbiana*	Also known as the Columbia pebblesnail and ashy pebblesnail; current range is restricted to rivers, streams, and creeks of the Columbia River basin; require clear, cold streams with highly oxygenated water; found in riffle pool on substrates ranging from sand to gravel or rock; graze on algae and small crustaceans (Neitzel and Frest 1990; Neitzel and Frest 1989, In: WDNR 2006b)	Unknown
Pacific cod	*Gadus macrocephalus*	Adults and large juveniles found over clay, mud, and coarse gravel bottoms; juveniles use shallow vegetated habitats such as sand-eelgrass; opportunistic feeders on invertebrates (worms, crabs, shrimp) and fishes (sand lance, pollock, flatfishes); larval feeding unknown (Bargmann 1980; Hart 1973; Dunn and Matarese 1987; NMFS 1990; Garrison and Miller 1982; Albers and Anderson 1985, In: NRC 2001 and In: Nightingale and Simenstad 2001b)	Spawning: Oviparous Incubation: Late fall to early spring, 1 to 4 weeks Emergence: Larvae and juveniles are pelagic
Western ridged mussel	*Gonidea angulata*	Specific information on this species is generally lacking; reside on substrates ranging from dense mud to coarse gravel in creeks, streams, and rivers; found in a variety of flow regimes; species may tolerate seasonal turbidity but is absent from areas with continuous turbidity (WDNR 2006b)	Larvae generally attach to the gills of fish for 1 to 6 weeks; post-larval mussels “hatch” from cysts as free living juveniles to settle and bury in the substrate
Northern abalone	*Haliotis kamtschatkana*	Also known as pinto abalone; limited to the Strait of Juan de Fuca and the San Juan Islands; occupies bedrock and boulders from extreme low to 100 feet (30 m) below MLLW; usually associated with kelp beds (NMFS 2004; Gardner 1981; West 1997; In: WDNR 2006b)	Spawning: Broadcast spawners; release pelagic gametes that develop into free-swimming larvae; mature larvae settle on crustose corralline algae

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Surf smelt	*Hypomesus pretiosus*	Schooling plankton-feeding forage fish, spawn at the highest tides at high slack tide on coarse sand and pea gravel; juveniles rear in nearshore areas and adults form school offshore; feed on planktonic organisms; important forage fish (WDFW 1997c; Penttila 2000a, In: NRC 2001 and In: Nightingale and Simenstad 2001b)	Spawning: Year round in north Puget Sound, fall and winter spawning in south Puget Sound, and summer spawning along the coast Incubation: 2 to 5 weeks Emergence: Varies with season; 27 to 56 days in winter; 11 to 16 days in summer
River lamprey	*Lampetra ayresi*	Detailed distribution records not available for Washington; occupy fine silt substrates in backwaters of cold-water streams; larvae (ammocoetes) are filter feeders in mud substrates of cold-water streams; juveniles believed to migrate to Pacific Ocean several years after hatching; adults spend May to September in ocean before migrating to fresh water; adults attach to and feed on fish (Wydoski and Whitney 2003)	Spawning: April to July Incubation: April to July Emergence: 2 to 3 weeks after spawning
Western brook lamprey	*Lampetra richardsoni*	Found in small coastal and Puget Sound rivers and lower Columbia and Yakima river basins; spend entire life in fresh water; adults found in cool water (52 to 64 degrees F; 11 to 17.8 degrees C) on pebble/rocky substrate; ammocoetes inhabit silty stream bottoms in quiet backwaters; ammocoetes are filter feeders; mature adults do not feed (Wydoski and Whitney 2003)	Spawning: April to July Incubation and Emergence: Adhesive eggs hatch in 10 days
Pacific lamprey	*Lampetra tridentata*	Found in most large coastal and Puget Sound rivers and Columbia, Snake, and Yakima river basins; larvae (ammocoetes) are filter feeders in mud substrates of cold-water streams; juveniles migrate to Pacific Ocean 4 to 7 years after hatching; attach to fish in ocean for 20 to 40 months before returning to rivers to spawn (Wydoski and Whitney 2003)	Spawning: April to July Incubation: April to July Emergence: 2 to 3 weeks after spawning
Pacific hake	*Merluccius productus*	The coastal stock of hake is migratory; Puget Sound stocks reside in estuaries and rarely migrate; schooling fish; larvae feed on calanid copepods; juveniles and small adults feed on euphausiids; adults eat amphipods, squid, herring, smelt (Bailey 1982; NMFS 1990; Quirollo 1992; McFarlane and Beamish 1986, In: NRC 2001)	Spawning: May spawn more than once per season Incubation: January to April Emergence: Pelagic eggs and larvae
Olympic mudminnow	*Novumbra hubbsi*	Occur in the southern and western lowlands of the Olympic Peninsula, the Chehalis River drainage, lower Deschutes River drainage, and south Puget Sound lowlands west of the Nisqually River and in King County; found in quiet water with mud substrate, preferring bogs and swamps with dense aquatic vegetation; feed on annelids, insects, and crustaceans (Harris 1974; Mongillo and Hallock 1999, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: Late November to December Early March to mid-June Incubation: 9 days Emergence: 7 days after hatching
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	NOAA Fisheries recognizes three Evolutionarily Significant Units (ESUs) in Washington: (1) Puget Sound; (2) Olympic Peninsula; (3) Southwestern Washington; coastal cutthroat trout exhibit resident (stays in streams), fluvial (migrates to rivers), adfluvial (migrates to lakes), and anadromous life-history forms; resident coastal cutthroat trout utilize small headwater streams for all of their life stages; coastal cutthroat trout are repeat spawners; typically rear in the natal streams for up to 2 years; juveniles feed primarily on aquatic invertebrates but are opportunistic feeders; utilize estuaries and nearshore habitat but has been caught offshore (Johnson et al. 1999; Pauley et al. 1988, In: WDNR 2006a)	Spawning: Late December to February Incubation: 2 to 4 months Emergence: 4 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Subspecies of cutthroat trout; three possible life forms: adfluvial, fluvial, or resident; all three life forms spawn in tributary streams in the spring when water temperature is about 50 degrees F (10 degrees C); fry spend 1 to 4 years in their natal streams; cutthroat trout tend to thrive in streams with more pool habitat and cover; fry feed on zooplankton, fingerlings feed on aquatic insect larvae, and adults feed on terrestrial and aquatic insects (Liknes and Graham 1988; Shepard et al. 1984; Wydoski and Whitney 2003)	Spawning: March to July Incubation: April to August Emergence: May to August
Pink salmon	*Oncorhynchus gorbuscha*	Pink salmon is the most abundant species of salmon, with 13 stocks identified in Washington; pink salmon, the smallest of the Pacific salmon, mature and spawn on a 2-year cycle; opportunistic feeder in marine habitat, foraging on a variety of forage fish, crustaceans, ichthyoplankton, and zooplankton; will spawn in rivers with substantial amounts of silt; migrate downstream almost immediately after emergence, moving quickly to marine nearshore habitats where they grow rapidly, feeding on small crustaceans, such as euphausiids, amphipods, and cladocerans (Hard et al. 1996; Heard 1991, In: WDNR 2006a)	Spawning: August to October Incubation: 3 to 5 months Emergence: 3 to 5 months
Chum salmon	*Oncorhynchus keta*	NOAA Fisheries recognizes four ESUs in Washington: (1) Hood Canal summer run; (2) Columbia; (3) Puget Sound/Strait of Georgia; (4) Pacific Coast; little is known regarding their ocean distribution; maturing individuals that return to Washington streams have primarily been found in the Gulf of Alaska; usually found in the rivers and streams of the Washington coast, Hood Canal, Strait of Juan de Fuca, and Puget Sound; in the Columbia River basin, their range does not extend above the Dalles Dam; chum salmon rear in the ocean for the majority of their adult lives; at maturity, adults migrate homeward between May and June, entering coastal streams from June to November; chum fry feed on chironomid and mayfly larvae, as well as other aquatic insects; chum fry arrive in estuaries earlier than most salmon; juvenile chum reside in estuaries longer than most other anadromous species (Quinn 2005; Salo 1991; Healey 1982, In: Wydoski and Whitney 2003 and WDNR 2006a)	Spawning: October to December Incubation: 0.5 to 4.5 months Emergence: 6 months
Coho salmon	*Oncorhynchus kisutch*	NOAA Fisheries recognizes three ESUs in Washington: (1) Lower Columbia River/SW Washington; (2) Puget Sound and Strait of Georgia; and (3) Olympic Peninsula; this species is found in a broader diversity of habitats than any of the other native anadromous salmonids; coho spend between 1 and 2 years in the ocean before returning to spawn; adult coho feed on invertebrates but become more piscivorous as they grow larger; spawning occurs in gravel free of heavy sedimentation; developing young remain in gravel for up to 3 months after hatching; coho fry feed primarily on aquatic insects and prefer pools and undercut banks with woody debris; coho rear in fresh water for 12 to 18 months before moving downstream to the ocean in the spring (Meehan 1991; Groot and Margolis 1991, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: September to late January Incubation: 1.5 to 2 months Emergence: 2 to 3 weeks
Redband trout	*Oncorhynchus mykiss gairdneri*	Redband trout is a subspecies of rainbow trout found east of the Cascade Mountains; prefer cool water, less than 70 degrees F (21 degrees C), and occupy streams and lakes containing high amounts of dissolved oxygen; spawn in streams; food consists of Daphnia and chironomids as well as fish eggs, fish, and insect larvae and pupae (Busby et al. 1996; Wydoski and Whitney 2003).	Spawning: March to April Incubation: 1 to 3 months Emergence: 3 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Steelhead	*Oncorhynchus mykiss*	NOAA Fisheries recognizes 15 ESUs of steelhead, seven of which occur in Washington; during their ocean phase of life, steelhead are generally found within 10 to 25 miles of the shore; steelhead remain in the marine environment 2 to 4 years; most steelhead spawn at least twice in their lifetimes; a summer spawning run enters fresh water in August and September, and a winter run occurs from December through February; escape cover, such as logs, undercut banks, and deep pools, is important for adult and young steelhead; after hatching and emergence, 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 (McKinnell et al. 1997, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: March to April Incubation: 1 to 3 months Emergence: 3 months
Sockeye salmon	*Oncorhynchus nerka*	WDFW recognizes nine sockeye salmon stocks in the state; of these, three are in Lake Washington and two in the Columbia River. Sockeye are found in the Snake and Okanogan, Lake Wenatchee, Lake Quinault, Lake Ozette, Baker River, Lake Pleasant, and Big Bear Creek drainages. Kokanee (landlocked sockeye) occur in many lakes, with the larger populations in Banks and Loon Lakes and Lake Whatcom and Lake Washington-Sammamish; spawn in shallow gravelly habitat in rivers and lakes and live in lakes 1 to 2 years before migrating to ocean; juveniles feed on zooplankton, adults feed on fishes, euphausiids, and copepods (Wydoski and Whitney 2003)	Spawning: August to October Incubation: 3 to 5 months Emergence: 3 to 5 months
Chinook salmon	*Oncorhynchus tschawytscha*	Chinook 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 fresh water 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; spring Chinook are especially dependent on high water quality and good access to spawning areas; 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 saltwater at one of three phases: immediate fry migrants soon after yolk resorption, fry migrants after 60 to 150 day after emergence, and fingerling migrants which migrate in the late summer of fall of their first year; ocean-type Chinook are more dependent on estuarine habitats to complete their life history than any other species of salmon Chinook “runs” are designated on the basis of adult migration timing. Early, spring-run chinook salmon tend to enter freshwater as immature fish, migrate far upriver, and finally spawn in the late summer and early autumn. Late, fall-run Chinook salmon enter freshwater 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 Chinook generally feed on invertebrates, but become more piscivorous with age (Wydoski and Whitney 2003; Myers et al. 1998, In: WDNR 2006a; Healey 1991)	Spring Chinook: Spawning: mid-July to mid-December Incubation: 6 to 8 months Emergence: 6 to 9 months Fall Chinook: Spawning: Late October to early December Incubation: 1 to 6 months Emergence: 6 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Lingcod	*Ophiodon elongatus*	Spawn in shallow water and intertidal zone; juveniles prefer sand habitats while adults prefer rocky substrates; larvae and juveniles found in upper 115 feet (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, adults on demersal fishes and squid and octopi (Adams and Hardwick 1992; Giorgi 1981; NMFS 1990; Emmett et al. 1991, In: NRC 2001)	Spawning: January to late March Incubation and Emergence: February to June; egg masses adhere to rocks
Olympia oyster	*Ostrea lurida*	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; occupy nearshore ecosystem on mixed substrates with solid attachment surfaces; found from 1 foot (0.3 m) above MLLW to 2 feet (0.6 m) below MLLW; intolerant of siltation; larvae settle onto hard substrate such as oyster shells, rocks (West 1997; Baker 1995; In: WDNR 2006b)	Spawning: Spring to fall; reproduce when water temperatures are between 54 and 61 degrees F (12.5 and 16 degrees C) Incubation and Emergence: After 8 to 12 days, larvae develop into free-swimming larvae; larvae are free-swimming for 2 to 3 weeks
Pygmy whitefish	*Prosopium coulteri*	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 nine; most often occur in deep, oligotrophic lakes with temperatures less than 50 degrees F (10 degrees C); use shallow water or tributary streams during the spawning season; feed on zooplankton, such as cladocerans, copepods, and midge larvae (Hallock and Mongillo 1998, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: July to November Incubation and Emergence: Unknown
Leopard dace	*Rhinicthys falcatus*	Within Washington, leopard dace currently inhabit the lower, mid, and upper reaches of the Columbia, Snake, Yakima and Similikameen rivers; utilize habitat on or near the bottom of streams and small to mid-sized rivers with velocities less than 1.6 feet/sec (0.5 m/second); prefers gravel and small cobble substrate covered by fine sediment with summer water temperatures ranging between 59 and 64 degrees F (15 and 18 degrees C); juveniles feed primarily on aquatic insects, adult leopard dace consume terrestrial insects; little is known about leopard dace spawning habitat or behavior (Wydoski and Whitney 2003)	Spawning: May to July Incubation and Emergence: Unknown
Umatilla dace	*Rhinicthys umatilla*	Umatilla dace are benthic fish found in relatively productive, low-elevation streams; inhabit streams with clean substrates of rock, boulders, and cobbles in reaches where water velocity is less than 1.5 feet/second; juveniles occupy streams with cobble and rubble substrates; adults occupy deeper water habitats; food habits are unknown (Wydoski and Whitney 2003)	Little known of reproduction Spawning: Early to mid-July Incubation and Emergence: Unknown
Bull trout	*Salvelinus confluentus*	Widely distributed in Washington; exhibits four life-history types – anadromous, adfluvial, fluvial, and resident; bull trout typically rear in their natal streams for 2 to 4 years, although resident fish may remain in these streams for their entire lives; multiple life-history forms occur together in the same water; young-of-the-year occupy side channels, with juveniles in pools, runs, and riffles; adults occupy deep pools; diet of juveniles includes larval and adult aquatic insects; subadults and adults feed on fish; bull trout in the nearshore ecosystem rely on estuarine wetlands and favor irregular shorelines with unconsolidated substrates (Wydoski and Whitney 2003; Goetz et al. 2004, In: WDNR 2006a)	Spawning: Late August to late December Incubation and Emergence: 4 to 6 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Dolly Varden	*Salvelinus malma*	Species restricted to coastal areas and rivers that empty into them; species occurs sympatrically in streams in Olympic Peninsula; prefer pool areas and cool temperatures; spawn and rear in streams, may feed and winter in lakes; juveniles extensively use instream cover; ages 1 to 13 utilize beaches composed of sand and gravel; opportunistic feeders on aquatic insects, crustaceans, salmon eggs, fish (Leary and Allendorf 1997, In: Wydoski and Whitney 2003)	Spawn mid-September to November; hatch 129 days after fertilization
Brown rockfish	*Sebastes auriculatus*	Utilize shallow-water bays with natural and artificial reefs and rock piles; estuaries are used as nurseries; can tolerate water temperatures to at least 71 degrees F (22 degrees C); eat small fishes, crabs, isopods (Stein and Hassler 1989; Eschmeyer et al. 1983; Love 1991, In: NRC 2001)	Spawning: March to June Incubation: June
Copper rockfish	*Sebastes caurinus*	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 molluscs (Eschmeyer et al. 1983; Matthews 1990a; Haldorson and Richards 1986; Stein and Hassler 1989, In: NRC 2001)	Spawning: March to May Incubation: April to June Emergence: Larvae are pelagic
Greenstriped rockfish	*Sebastes elongates*	Adults found in benthic and mid-water columns; utilize a variety of bottom types; feed on euphausiids, small fishes, and squid (Eschmeyer et al. 1983; Love et al. 1990, In: NRC 2001)	Spawning: Viviparous; spawn two or more times per season Emergence: Late April to late June
Widow rockfish	*Sebastes entomelas*	Adults found from 330- to 1,000-foot (100- to 300-m) depths near rocky banks, ridges, and seamounts; adults feed on pelagic crustaceans, Pacific hake, squids; juveniles feed on copepods, euphausiids (Eschmeyer et al. 1983; Laroche and Richardson 1981; NMFS 1990; Reilly et al. 1992, In: NRC 2001)	Spawning: Viviparous; October to December Incubation: 14 days Emergence: March to May
Yellowtail rockfish	*Sebastes flavidus*	Adults found from 165- to 1,000-foot (50- to 300-m) depths; adults semi-pelagic or pelagic over steep-sloping shores and rocky reefs; juveniles occur in nearshore area; opportunistic feeders on pelagic animals including hake, herring, smelt, squid, krill and euphausiids (Eschmeyer et al. 1983; Love 1991; O'Connell and Carlile 1993, In: NRC 2001)	Spawning: Viviparous; October to December Emergence: February to March Larvae and juveniles are pelagic
Quillback rockfish	*Sebastes maliger*	Shallow-water benthic species in inlets near shallow rock piles and reefs; juveniles use eelgrass/sand and beds of kelp; feed on amphipods, crabs, copepods (Clemens and Wilby 1961; Hart 1973; Love 1991; Matthews 1990b; Hueckel and Slayton 1982; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Viviparous; April to July Emergence: May to July
Black rockfish	*Sebastes melanops*	Low and high rock substrates in summer, deeper water in winter; kelp and eelgrass for juveniles; feed on nekton and zooplankton (Boehlert and Yoklavich 1983; Stein and Hassler 1989, In: NRC 2001)	Spawning: February to April Emergence: Larvae and juveniles are pelagic
China rockfish	*Sebastes nebulosus*	Occur inshore and on open coast in sheltered crevices; feed on crustacea (brittle stars and crabs), octopi, and fishes (Eschmeyer et al. 1983; Love 1991; Rosenthal et al. 1988, In: NRC 2001)	Spawning: January to July
Tiger rockfish	*Sebastes nigrocinctus*	Semi-demersal to demersal species occurring at depths ranging from shallows to 1,000 feet (305 m); larvae and juveniles occur near surface and range of depth; adults use rocky reefs, canyons, and headlands; generalized feeders on shrimp, crabs, small fishes (Garrison and Miller 1982; Moulton 1977; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Ovoviviparous; peak May and June Emergence: Juveniles are pelagic

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Bocaccio rockfish	*Sebastes paucispinis*	Adults semi-demersal in shallow water over rocks with algae, eelgrass, and floating kelp; larvae feed on diatoms; juveniles feed on copepods and euphausiids (MBC Applied Environmental Sciences 1987; Garrison and Miller 1982; Hart 1973; Sumida and Moser 1984 In: NRC 2001)	Spawning: Ovoviviparous; year-round Incubation: 40 to 50 days Emergence: Released 7 days after hatching; larvae and juveniles are pelagic
Canary rockfish	*Sebastes pinniger*	Adults use sharp dropoffs and pinnacles with hard bottoms; often associated with kelp beds (Sampson 1996); feed on krill and occasionally on fish (Boehlert 1980; Boehlert and Kappenman 1980; Hart 1973; Love 1991; Boehlert et al. 1989, In: NRC 2001)	Spawning: Ovoviviparous; January to March Emergence: Larvae and juveniles are pelagic
Redstripe rockfish	*Sebastes proriger*	Adults found at depths between 330 and 1,000 feet (100 and 350 m) and young often found in estuaries in high- and low-relief rocky areas; juveniles feed on copepods and euphausiids; adults eat anchovies, herring, squid (Hart 1973; Kendall and Lenarz 1986; Garrison and Miller 1982; Starr et al. 1996, In: NRC 2001)	Spawning: Ovoviviparous Emergence: July; larvae and juveniles are pelagic and semi-demersal
Yelloweye rockfish	*Sebastes ruberrimus*	Adults found from 80- to 1,800-foot (25- to 550-m) depths near reefs and cobble bottom; juveniles prefer shallow, broken-bottom habitat; feed on other rockfish species, cods, sand lance, herring, shrimp, snails (Clemens and Wilby 1961; Eschmeyer et al. 1983; Hart 1973; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Ovoviviparous Emergence: June
Longfin smelt	*Spirinchus thaleichthys*	Marine species that spawns in streams not far from marine waters; juveniles utilize nearshore habitats of a variety of substrates; juveniles feed on small Neomysis; adults feed on copepods and euphausiids; most adults die after spawning (Wydoski and Whitney 2003; Lee et al. 1980, In: Alaska Natural Heritage Program 2006)	Spawning: October to December Incubation and Emergence: Hatch in 40 days; larvae drift downstream to salt water
Eulachon	*Thaleichthys pacificus*	Eulachon occur from northern California to southwestern Alaska; occur in offshore marine waters and spawn in tidal portions of rivers; spawn in variety of substrates but sand most common; juveniles rear in nearshore marine areas; plankton-feeders eating crustaceans such as copepods and euphausiids; larvae and post-larvae eat phytoplankton, copepods; important prey species for fishes, marine mammals, and birds (Langer et al. 1977; Howell et al. 2001; Lewis et al. 2002; WDFW and ODFW 2001, In: Willson et al. 2006)	Spawning: During spring when water temperature is 40 to 50 degrees F (4 to 10 degrees C); eggs stick to substrate Incubation: Temperature-dependent, range 20 to 40 days Emergence: Larvae drift downstream to salt water
Walleye pollock	*Theragra chalcogramma*	Widespread species in northern Pacific; larvae and small juveniles found at 200-foot (60-m) depth; juveniles utilize nearshore habitats of a variety of substrates; juveniles feed on small crustaceans, adults feed on copepods, euphausiids, and young pollock; important prey species (Garrison and Miller 1982; Miller et al. 1976; Bailey et al. 1999; Livingston 1991, In: NRC 2001)	Spawning: February to April Incubation: Eggs suspended at depths ranging from 330 to 1,320 feet (100 to 400 m) Emergence: Pelagic larvae

Note: Species listed in alphabetical order by scientific name.

Definitions:
demersal—living near, deposited on, or sinking to the bottom
oviparous—producing eggs that develop and hatch outside the maternal body
ovoviviparous—producing eggs that develop within the maternal body and hatch before or immediately after release
piscivorous—fish-eating
viviparous—producing living young rather than eggs

[1]Comments related to distribution pertain only to the Washington portion of species distribution.

[2]Spawning is given as seasonal timing, when information is available. Incubation is the time elapsed between spawning and hatching. Emergence is the time elapsed between hatching and when juveniles enter the water column; as noted above where relevant, some hatchlings enter the water column immediately.

6 CONCEPTUAL FRAMEWORK FOR ASSESSING IMPACTS

Overwater structures and non-structural piling can impact potentially covered species via a number of mechanisms affecting organisms, their habitats, or critical ecological functions. Such impacts can affect organisms either directly, such as when an organism is injured by a piece of machinery, or indirectly by affecting any of the elements shown on Figure 1 (reprinted from Williams and Thom 2001).

Figure 1
Conceptual Framework for Assessment

The conceptual framework begins with an impact, which in this case would consist of activities authorized under an HPA for an overwater structure or non-structural piling. That impact can in turn alter controlling factors (e.g., flow conditions or sediment sources), which are expressed in the environment via habitat structure (e.g., sediment composition or the structure of the vegetation community). Habitat structure is linked to habitat processes (e.g., shading or pool formation), which underpin ecological functions (e.g., production of forage fish) that support the ecosystem. Altering any of these elements can potentially result in an impact to one or more of the potentially covered species.

The literature reviewed for this white paper primarily identifies certain critical controlling factors, habitat structural elements, and habitat processes that have high potential to be affected by human activities in general and by overwater structures or non-structural piling in particular. The impact analysis that follows in Section 7 is based on a review of specific impact pathways associated with the controlling factors, habitat structural elements, and habitat processes. Table 4 lists and defines the impact pathways evaluated in this white paper and describes how human alteration of a pathway can affect potentially covered species. Section 7 discusses the direct and indirect impacts associated with each impact pathway.

Table 4
Principal Impact Pathways Evaluated

Pathway	Description
Shading	All shading of waters, whether by natural or artificial means.
Littoral vegetation	Artificial changes in submerged or intertidal marine or estuarine vegetation.
Freshwater aquatic vegetation	Artificial changes in submerged freshwater vegetation.
Riparian and shoreline vegetation	Artificial changes in riparian or shoreline vegetation, including all functions performed by large woody debris in or near the channel.
Noise	Artificial noise from pile driving, motors, vessel operations, and other noise-generating activities.
Water quality	Changes in water quality, primarily in turbidity but also in temperature, pH, dissolved oxygen content, and metallic or organic toxins.
Channel hydraulics	Changes in substrate composition or morphology that result when channel processes are altered by artificial means.
Littoral drift	Changes in substrate composition or morphology that result when littoral processes are altered by artificial means.
Substrate modifications	Changes in substrate composition (grain size) or restructuring by artificial means (e.g., excavation, fill).
Channel dewatering	Changes that result from altered flow, principally dewatering that occurs due to stream diversion during overwater structure construction.
Artificial light	Artificial light used during construction or operation of a structure.
Vessel activities	Changes resulting from the operation of vessels and other submerged equipment during construction or other vessel-related activities that occur during construction of the overwater structure or installation of non-structural piling.

7 DIRECT AND INDIRECT IMPACTS

Potentially covered species are vulnerable to incidental take via certain impact pathways, as identified in Section 6. These pathways correspond to controlling factors and habitat structure elements (Figure 1). The following discussion describes each of these pathways and how each pathway is linked to essential life-history traits or particular habitat requirements of potentially covered species. The risk of causing incidental take is discussed in Section 9, and potential means of avoiding or minimizing take are discussed in Section 11.

Note that there is an element of overlap among some impact pathways; for instance, vessel activities (Section 7.12) necessarily include some element of noise (Section 7.5) and artificial light (Section 7.11). In the following impact analysis, such areas of overlap are identified by cross-references.

7.1 Shading

The information summarized in this section is largely taken from two extensive literature reviews prepared for WDFW that analyze the biological impacts of overwater structures: *Marine Overwater Structures: Marine Issues* (Nightingale and Simenstad 2001b) and *Over-Water Structures: Freshwater Issues* (Carrasquero 2001). The white papers discuss relevant literature on the environmental effects, data gaps, and recommended impact reduction techniques applicable to overwater structures, non-structural pilings, marinas, and other structures found in and around water bodies of the state. More recent studies and reports published between 2000 and October 2006 were also reviewed to augment information on the impacts of shading.

Populations and diversity of aquatic species in the Pacific Northwest can be severely limited in environments shaded by overwater structures when compared to adjacent unshaded, vegetated habitats (Orth and Moore 1983, Thayer et al. 1984, Fresh et al. 1995, Parametrix and Battelle 1996, Thom et al. 1996, Ludwig et al. 1997, Fresh et al. 2000, all in Nightingale and Simenstad 2001b; Thom et al. 1998). Overwater structures can create sharp underwater light contrasts by casting shade in ambient daylight conditions, in turn limiting light availability for plant photosynthesis and growth. Limiting photosynthesis indirectly impacts the food chain for fish and invertebrates. Artificial structures affect distributions, behavior, growth, and survival of fish and invertebrates in the vicinity of the structure.

Because teleost (i.e., bony) fishes such as salmonids, rockfish, flatfish, cod, pollock, and other common fishes in Washington place strong reliance on vision and light for migration, foraging, and refuge, changes in the ambient light regime can make such fishes vulnerable to predation, starvation, or reduced fitness (Nightingale and Simenstad 2001b).

The effects of reduced underwater vegetation on potentially covered species are addressed in Sections 7.2 and 7.3, which discuss littoral vegetation (e.g., eelgrass and macroalgae) and freshwater aquatic vegetation, respectively. Therefore, the following discussion focuses on the direct impacts of shading on potentially covered species.

7.1.1 Fish Vision

In addition to affecting aquatic vegetation, shade can affect fish and invertebrates by disrupting normal migration patterns, reducing the ability to avoid predators, and reducing available refuge. Teleost fishes, which include all potentially covered fish species except sturgeon and lamprey, depend on sight for feeding and schooling. As juveniles, they utilize nearshore or shallow water habitats and share a sensitivity to ultraviolet wavelengths reflected in shallow-water habitats (Tribble 2000, Britt 2001, both in Nightingale and Simenstad 2001b). Figure 2 depicts light conditions related to juvenile salmon behavior such as schooling, predator avoidance, feeding, and migratory behavior.

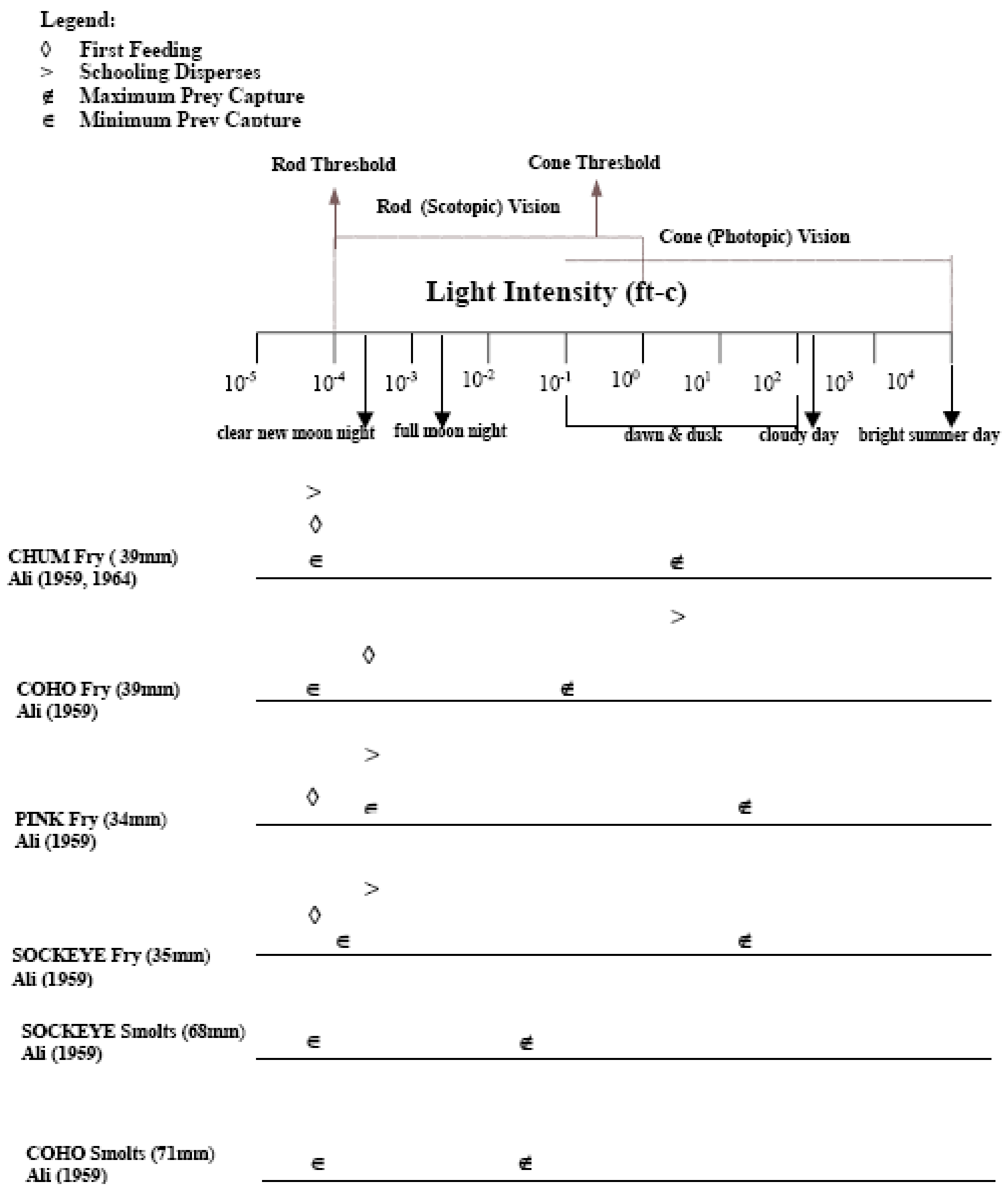

Figure 2
Juvenile Salmon Behavior Patterns Related to Light Intensity
Source: Nightingale and Simenstad 2001b

Tribble (2000, in Nightingale and Simenstad 2001b) found the swimming and feeding behavior of juvenile and larval sand lance (*Ammodytes hexapterus*) to be reduced with low light levels. Similar to other juvenile fishes with cone-based vision, the retinal cells of larval sand lance fall in the violet to green range, with limited visual acuity in low-light environments. Their visual acuity increases with growth as their cone pigments shift from violet to blue sensitivity. Tribble (2000, in Nightingale and Simenstad 2001b) reports that sand lance visual development reflects the habitats they occupy at given total lengths. Rods appear to develop when the fish reach approximately 1 inch (24 millimeters [mm]), and full adult visual acuity develops at 1.4 inches (35 mm). At approximately 2 inches (50 mm) in size, the fish will 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. At this point they will largely depart from the range of water depths where they may be affected by overwater structures. A similar change in visual sensitivity has been observed in yellow perch. Brownan and Hawryshyn (1994, in Nightingale and Simenstad 2001b) report this loss of ultraviolet sensitivity to be size-dependent rather than age-dependent and to likely correlates with the time when fishes move from shallow to deeper water. These results suggest that shading effects attributable to overwater structures predominantly affect smaller fish, and that "shading" as an impact includes the loss of both visual and ultraviolet wavelengths of light.

7.1.2 Prey Abundance, Feeding, and Growth

Juvenile and larval fish are primarily visual feeders, and starvation is the major cause of larval mortality in marine fish populations. Early life-history stage survival is linked to the ability to locate and capture prey and avoid predators (Britt 2001, in Nightingale and Simenstad 2001b).

Capture success is often directly related to prey abundance in a given location, as well as to fish growth and fitness. Kahler et al. (2000) states that shading from overwater structures may reduce the abundance of prey organisms available to juvenile salmonids and forage fish by reducing aquatic vegetation and phytoplankton abundance. Similarly, Haas et al. (2002) found that densities and assemblages of important epibenthic prey organisms were reduced under large overwater structures. In New York Harbor, Able et al. (1998, in Nightingale and Simenstad 2001b) found juvenile fish abundance to be reduced under piers when compared to open-water areas or areas having only piles. This is likely due to limitations in both prey abundance and prey capture. In another study, Duffy-Anderson and Able (1999, in Nightingale and Simenstad 2001b) compared growth rates of caged juvenile fish under municipal piers to those of fish caged at pier edges and to fish caged in open waters. Those fishes caged under the piers showed periods of starvation, making these individuals more vulnerable to predation, physiological stress, and disease. Along the pier edges, variability in growth rate was found to be high and likely light related. The authors concluded that light availability is likely an important component of feeding success. They also concluded that large piers do not appear to provide suitable habitat for some species of juvenile fishes and that increased sunlight enhances fish growth.

For young outmigrant salmon such as juvenile chum, pink, and ocean-type Chinook, prey availability is an important component to migration behavior.

7.1.3 Migration and Distribution

Investigations on shading impacts to fish migration and distribution have primarily focused on impacts to juvenile salmonids. Shading has been shown to have different consequences for migration and distribution of some fish in freshwater environments; therefore, shading impacts of overwater structures in freshwater and marine environments are discussed separately.

7.1.3.1 Marine Environment

Changes in ambient underwater light environments can alter juvenile salmon migration and distribution and potentially increase mortality risks. For example, studies have consistently documented a tendency for juvenile salmon to avoid passing beneath shaded habitats (Pentec 1997; Weitkamp 1982; and Heiser and Finn 1970, all in Nightingale and Simenstad 2001b; Southard et al. 2006; Tabor et al. 2006).

Studies in the Puget Sound region have found that under-pier light limitations and shadowing often change behaviors of juvenile salmonids in ways that could delay migration, alter schooling refuge behavior, and change migratory routes to deeper waters (which may increase their risk of predation). Juvenile salmonids encountering docks and piers have been observed variously to pass under the structure, pause and go around the structure, break up from schools, aggregate in the lighted portion of the water column, or pause and eventually go under the structure (Weitkamp 1982, Feist 1991, Pentec 1997, all in Nightingale and Simenstad

2001b; Feist et al. 1992; Toft et al. 2004; Southard et al. 2006; Tabor et al. 2006). Taylor and Wiley (1997, in Nightingale and Simenstad 2001b) and Weitkamp (1981, in Nightingale and Simenstad 2001b) found juvenile salmon distributed along the outer bulkheaded perimeters of marinas but did not find a significant abundance under or around floating docks. Southard et al. (2006) consistently found juvenile Chinook, chum, and coho salmon aggregating on the light side of the shadow line of ferry terminals during the day, and then sometimes passing under the terminals in the evening when the shadow was less distinct. Southard et al. (2006) also determined that, during the day, juvenile salmon may move more readily under structures at low tide, when more ambient light penetrates underneath. In an experimental release at the Port Townsend ferry terminal, Shreffler and Moursund (1999) found that released Chinook fry ceased their migration at the terminal's shadow line before consistently swimming from the shadow line to lighted areas, then darting back into the light-dark transition zone. As the sun dropped along the horizon and the shadow line moved in under the terminal dock, the Chinook school appeared to follow the shadow line, staying with the light-dark transition area. In studies of juvenile salmonid behavior around the Port of Seattle’s Terminals 90 and 91, Weitkamp (1982, in Nightingale and Simenstad 2001b) observed that juvenile salmonids primarily congregated on the more sun-exposed west side rather than on the darker east side of the terminals. Salo et al. (1980, in Nightingale and Simenstad 2001b) observed that chum salmon shifted from nearshore migration to an offshore route upon encountering a wharf in Hood Canal, and Pentec (1997, in Nightingale and Simenstad 2001b) found that when juvenile chum salmon encountered piers in Everett Harbor, they milled around with no net movement for periods ranging from 30 minutes to 2 hours. Fewer and smaller schools were observed at piers, while the greatest number of and the largest schools were observed along riprapped shorelines, with feeding occurring along these shorelines but not under piers. Although the study revealed that fish encountering piers split up and moved around the piers, the conclusion was that the net effect of juvenile salmon encountering overwater structures was impossible to assess given the available data. Williams and Thom (2001), however, state that although individual shoreline structures may not impose significant impacts on salmon species, populations, or stocks, the cumulative effect of dense, contiguous shoreline modifications has likely contributed to the decline of several Puget Sound salmon species.

7.1.3.2 Freshwater Environment

Juvenile salmonids behave similarly when approaching overwater structures in freshwater environments as they do in marine environments, according to recent studies (Tabor et al. 2006). Tabor et al. (2006) found that when migrating Chinook smolts approached piers in Lake Washington, they appeared to move into deeper water and then either pass directly under the structure or swim around the pier.

Research data on adult salmon, however, indicate that migrating adults hold at various locations within the Sammamish River, and most of the holding locations are underneath bridges, where it is shaded (King County 2000, in Carrasquero 2001).

7.1.4 Predation

In freshwater, ambush predators are often found distributed in natural or man-made shaded and covered environments (Stein 1970, Helfman 1979, both in Carrasquero 2001). Helfman (1979), studying shade-producing experimental floats in Cazenovia Lake, New York, found that several species of predator fishes are particularly attracted to the area under the floats. Carrasquero's (2001) review found that the attraction of fish to floating or overhanging objects is linked to the shade produced by the objects, and Kahler et al. (2000) suggests that piers, piles, boatlifts, and moored boats provide cover, shade, and focal points that benefit exotic predators of juvenile salmon, such as smallmouth and largemouth bass. An alternative explanation of fish attraction to on-water and overwater structures in fresh water was presented by Fresh (pers. comm., in Carrasquero 2001), who explains that both the structures and the shade they cast may provide fishes with physical reference points for orientation.

In the marine nearshore, daytime light reduction caused by shading under overwater structures could cause migrating juveniles to move into deeper waters, increasing the risk of predation by larger predators that occupy pelagic waters (Heiser and Finn 1981, Pentec 1977, in Nightingale and Simenstad 2001b). Predation mortality may increase through altering predator detection and reducing refugia provided by the schooling behavior of juvenile salmonids (Pentec 1997, in Nightingale and Simenstad 2001b).

Although it is believed that predation risks are elevated when fish move into deeper waters around piers, the actual potential for increased predation due to aggregating predators under structures in marine environments is uncertain (Weitkamp 1981; Taylor and Wiley 1997, in Nightingale and Simenstad 2001b). Taylor and Wiley (1997) found no aggregation of avian predators and Weitkamp (1981) reported no aggregation of aquatic predators during the peak juvenile chum outmigration. Consistent with these findings, Penttila and Aguero (1978, in Nightingale and Simenstad 2001b) found no empirical evidence of predation among the marina floats in Birch Bay, but instead found evidence of competition among fish species for mutually preferred prey resources (i.e., the calanoid and harpacticoid copepods). Fresh and Cardwell (1978, in Nightingale and Simenstad 2001b) list 17 potential predators of juvenile salmon in the southern Puget Sound region and find that only three (maturing Chinook, copper rockfish, and staghorn sculpins) prey extensively on nearshore fishes. Their analysis of food habits found only staghorn sculpins with juvenile salmon in their stomachs, and there was no evidence that staghorn sculpins were in greater abundance under structures than elsewhere in the study area. Additionally, Ratte (1985, in Nightingale and Simenstad 2001b) found sea perch and pile perch, which do not prey on salmonids, to be the most abundant fish species under docks. Nightingale and Simenstad (2001b) and Southard et al. (2006) summarize these and additional studies that pertain to fish behavior, including migration, distribution, and predator/prey relationships potentially associated with overwater structures in marine areas of Puget Sound.

In freshwater environments of Western Washington, largemouth bass and smallmouth bass are common predators of juvenile salmonids, and several authors have documented the use of overwater structures by bass in Western Washington waters. Stein (1970, in Carrasquero 2001) examined the types of cover used by largemouth bass in Lake Washington and found that they prefer areas of heavy log and brush cover over other habitat types (including docks). However, largemouth bass are commonly found under docks in early spring and are thought to be present there until late summer (Stein 1970, in Carrasquero 2001). Carrasquero (2001) found studies that suggest the attraction of predatory fish (including largemouth bass) to floating or overhanging objects is linked to the shade produced by the objects rather than to the tactile stimulus and that the larger the floating object, the greater the shaded area, and thus the greater the number of fish attracted to such objects. This assumption suggests that shading from overwater structures alters fish distribution and aggregation in fresh water.

Interactions between smallmouth bass and juvenile salmonids depend on factors such as the timing of salmonid outmigration, salmonid species, and residence time of juvenile salmonids in lentic (still-water) or lotic (flowing) environments (Warner 1972; Gray et al. 1984; Pflug and Pauley 1984; Gray and Rondorf 1986; Poe et al. 1991; Shively et al. 1991; Tabor et al. 1993; Fayram and Sibley 2000, in Carrasquero 2001; Tabor et al. 2000).

Carrasquero (2001) presents the following observations and inferences of predator/prey aggregations in freshwater environments under and around structures:

- Different fish species respond differently to the shade produced by overwater structures.
- Smallmouth bass and largemouth bass have a strong affinity to structures, including piers, docks, and associated pilings.
- Bass have been observed foraging and spawning in the vicinity of docks, piers, and pilings; where vegetation is lacking, largemouth bass seek other forms of structures, such as dock pilings.
- Smallmouth bass are opportunistic predators that consume prey items as they are encountered and are major predators of juvenile salmonids.
- Fish, particularly largemouth bass, seem to be attracted to the shade produced by floats, rather than their physical structure. In contrast, smallmouth bass do not seem to be attracted to the shade produced by such structures.
- In reservoir systems of Eastern Washington, juvenile salmonid predation is specific to the behavior and distribution of each salmonid species and its predator. The behavior and distribution of predator and prey species reportedly depend on temperature, the degree of shore-zone development, the slope and substrate of the shoreline, and the presence of man-made in-water structures.

Additional details on shading and predation in fresh water can be found in Carrasquero (2001).

7.2 Littoral Vegetation

Impacts to habitats and species may occur through the loss of littoral vegetation, which includes eelgrass, macroalgae, and intertidal vascular plants (e.g., salt marsh plants) resulting from construction of overwater structures in estuarine or marine settings. Eelgrass and macroalgae are recognized as important habitat for a wide variety of organisms. The Washington State hydraulic code rules (WAC 220-110-250) designate eelgrass, kelp, and intertidal vascular plants as saltwater habitats of special concern and require that hydraulic projects result in no net loss of these habitats. Furthermore, the hydraulic code rules require that overwater structures be designed or located to avoid shading or other impacts that could result in the loss of eelgrass and kelp habitat (WAC 220-110-300(3) and (4)).

Phillips (1984) and Wyllie-Echeverria and Phillips (1994) describe eelgrass ecology in the Pacific Northwest. Two species of eelgrass (*Zostera* spp.) grow in Washington State and are considered saltwater habitats of special concern (WAC 220-110-250): the native eelgrass, *Zostera marina*, and the smaller Asian species, *Zostera japonica* (Wyllie-Echeverria and Phillips 1994). Typically, *Z. marina* grows at lower elevations than *Z. japonica* and may either form extensive beds covering many acres or exist in smaller patches (Phillips 1984). *Z. japonica* is generally found at higher elevations than *Z. marina* and typically grows in patches or a narrow fringe (Phillips 1984). Many species of macroalgae (e.g., brown algae) also grow in the marine waters of Washington, generally attached to rocky substrates and always within the nearshore photic zone (Kozloff 1983).

Eelgrass typically grows in sand and mud substrates in sheltered or turbulent waters (Phillips 1984). Native eelgrass distributions range from approximately +2 feet mean lower low water (MLLW) to -22 feet MLLW (PSAT 2001), although light penetration in many portions of Puget Sound typically limits the lower elevation to less than -12 feet MLLW. Macroalgae have a wider tidal elevation range, and species such as rockweed (*Fucus gardneri*) can grow as high as mean higher high water (MHHW). At the other extreme, brown algae (kelp) may grow at elevations as low as -100 feet MLLW where the water is clear enough to allow light penetration and the substrate supports algal attachment (WDNR

2004). However, in Puget Sound, the depth to which sufficient light penetrates to support plant growth (i.e., photic zone) is considered to be –33 feet (-10 meters [m]) MLLW (PSNERP 2003).

Eelgrass and macroalgae provide vertical structure in nearshore marine habitats and facilitate several important ecological functions. Eelgrass and macroalgae are very productive and support marine food webs through the plant biomass and detritus that they produce, as well as provide shelter and influence the physical and chemical properties of the nearshore environment (Nightingale and Simenstad 2001b). Eelgrass provides substrate for colonies of epiphytic algae and many crustacean species that are prey items for juvenile salmon and other fish (Nightingale and Simenstad 2001b). Studies of eelgrass communities in Padilla Bay show that a specific group of copepods (*Harpacticus uniremis* and other copepods of the genera *Zaus* and *Tisbe*) is unique to the eelgrass epiphyte assemblage and the principal prey of juvenile chum salmon, Pacific herring, Pacific sand lance, and surf smelt (Nightingale and Simenstad 2001b), with *Harpacticus* spp. less likely to be found in low-light conditions and *Tisbe* spp. found in areas high in detritus, irrespective of light levels. Juvenile Dungeness crab, an important salmonid prey species, show a preference for eelgrass compared to other benthic habitats; this is thought to be due in part to the abundance of food items in eelgrass habitat (Pauley et al. 1989). The complex structure of eelgrass communities and their associated epifauna and epiflora are also thought to limit the success of predators that typically associate and feed in unvegetated communities (Heck and Orth 1980, in Nightingale and Simenstad 2001b; Heck and Thoman 1984). Given the strong association of important fish prey resources with eelgrass, reductions in eelgrass extent or vigor may also reduce prey resources for fish.

Eelgrass retards current velocity at the sediment-water interface, allowing fine particulates to settle (Phillips 1984). This action typically affects sediment dynamics and local sediment characteristics, favoring continued growth and survival of eelgrass (Phillips1984). The vertical structure of kelp forests also affords dissipation of wave energy (Jackson 1984), which can offer shoreline protection for other sensitive shoreline habitats.

Both eelgrass and macroalgae provide substrate for herring spawning (Bargmann 1998). Herring is a key species in the nutrient and energy dynamics of the Puget Sound environment, providing an important link between zooplankton and larger predators, including Chinook salmon, bull trout, and other salmonid species (Bargmann 1998).

Blackmon et al. (2006) provides a synopsis of research on the use of seagrass and kelp habitats by fish, including many of the marine potentially covered species. Forage fish and juvenile Pacific salmon species preferentially use eelgrass over other habitats. Juvenile salmon are found in kelp habitat as well. Rockfish (*Sebastes* sp.) produce planktonic larvae that settle in eelgrass, shallow kelp beds, and floating kelp mats. Juvenile rockfish occupy shallow vegetated habitats, especially areas with eelgrass and kelp, during the summer growing period (Byerly et al. [no date]; Murphy et al. 2000), likely due to the enhanced forage opportunities and refuge from predators that the vertical structure can provide. Likewise, juvenile Dungeness crab (a major prey species for some rearing salmonids) are more frequently found in eelgrass and *Ulva* beds than in other habitats, and eelgrass beds are considered valuable nursery habitat for Dungeness crab (Blackmon et al. 2006).

HPA-regulated activities in marine waters have the potential to affect littoral vegetation through the following impact mechanisms:

- Ambient light
- Direct disturbance and displacement
- Vessel interactions

Each of these impact mechanisms is discussed below.

7.2.1 Ambient Light

Light availability is a fundamental requirement for eelgrass and macroalgae growth. Thom et al. (1998) analyzed the photosynthetically active radiation (PAR) levels at seven Washington State ferry terminal sites and found no eelgrass where instantaneous mid-day PAR levels were less than about 100 micro-moles of photons within the PAR range of wavelengths striking a square meter in one second (μM/m^2/sec). They found low eelgrass shoot densities where instantaneous mid-day PAR was less than 150 μM/m^2/sec, while maximum shoot densities required instantaneous PAR of 325 μM/m^2/sec. PAR intensities less than about 300 μM/m^2/sec can be limiting to eelgrass, whereas intertidal macroalgae may be limited by PAR less than 400 to 600 μM/m^2/sec (Thom and Shreffler 1996, in Simenstad et al. 1999). Subtidal macroalgae can survive lower light levels and may be limited only by PAR less than 100 μM/m²/sec (Luning 1981, in Simenstad et al. 1999).

Overwater structures are generally expected to limit light penetration to the substrate and can shade the area underneath and adjacent to the structures. The orientation of the structures and their density (solid or open), height above water, water depth, and tidal range all affect the extent and degree of shading (Nightingale and Simenstad 2001b). Where shading reduces PAR, eelgrass and macroalgae growth may be impaired or prevented (Nightingale and Simenstad 2001b; Penttila and Doty 1990). Burdick and Short (1999) found that floating docks severely impact eelgrass. Three of the four floating docks they studied had no rooted eelgrass under them. Increased structure height above the bottom was identified as the most important pier characteristic correlating to eelgrass bed quality. Burdick and Short (1999) also found light to be the most important variable affecting canopy structure (i.e., shoot density and height) and eelgrass bed quality. A dock study in Montauk, New York (Ludwig et al. 1997) reported the exclusion of eelgrass near a floating pier due to insufficient light in the float's impact zone. Penttila and Doty (1990) found that piers and floating docks largely eliminate existing eelgrass and macroalgae, even when the structures are only partially shading. Such shading impacts to eelgrass can be seen to occur in as little as 18 days (Backman and Barilotti 1976, in Nightingale and Simenstad 2001b), although light reduction capacity varies depending on combinations of both dock and environmental factors. For example, Penttila and Doty (1990) found no apparent eelgrass loss due to shading under a floating dock secured by anchors and chains. In that case, it was thought that, given the winds and current of the site, the degree of movement allowed by the anchor-chain system resulted in no area beneath the dock being continuously shaded, thereby reducing the stress of shade on the eelgrass bed.

7.2.2 Direct Disturbance and Displacement

Aquatic vegetation may be uprooted or displaced during in-water construction of overwater structures and non-structural pilings; in-water ground disturbance has been used as a measure of habitat take in ESA biological opinions (NMFS 2006e). Structures located on or within eelgrass beds displace eelgrass. Pilings that support overwater structures may also reduce eelgrass recruitment and survival through biotic interactions with the piling reef community (Nightingale and Simenstad 2001b). Pilings in marine waters become encrusted with mussels and other sessile organisms. Shell material from these organisms ("shellhash") is then deposited around the pilings over time, altering the local substrate and its ability to support eelgrass growth (Nightingale and Simenstad 2001b). The shellhash surrounding pilings is prime settling habitat for juvenile Dungeness crab (Nightingale and Simenstad 2001b). The burrowing activities of large numbers of crabs can also affect the establishment of eelgrass (Nightingale and Simenstad 2001b).

7.2.3 Vessel Interactions

Vessels used during construction of overwater structures may physically disturb submerged vegetation as a result of propeller wash (Lagler et al. 1950, in Carrasquero 2001; Haas et al. 2002) or grounding (direct disturbance). Propeller wash may also entrain air bubbles and cause sediment suspension (Haas et al 2002). The potential adverse impacts of vessel activities on eelgrass and macroalgae are discussed in Section 7.12.

7.3 Freshwater Aquatic Vegetation

Freshwater aquatic vegetation includes submerged and emergent plants rooted below the ordinary high water line (OHWL) of freshwater bodies (rivers, streams, lakes, ponds, and open-water wetlands). Freshwater aquatic vegetation provides fish and wildlife habitat and is important to the cycling of nutrients and materials in freshwater ecosystems (Petr 2000). Aquatic vegetation can modify its physicochemical environment by slowing water velocity, trapping sediment, and altering temperature and water quality (Chambers et al. 1999).

Aquatic plants provide shelter habitat and clinging substrate for a variety of aquatic invertebrate species, including insects and zooplankton (Petr 2000). Aquatic plants provide energy to aquatic ecosystems through photosynthesis and provide food for herbivores and detritivores (Petr 2000). Fish use aquatic plants for cover, and terrestrial wildlife species (in addition to potentially covered species) use emergent aquatic plants for food and habitat (Petr 2000). Emergent aquatic vegetation can reduce wave-induced bank erosion (Coops et al. 1996). A review of the interactions of fish and macrophytes worldwide reiterated a number of beneficial functions that macrophytes provide that have direct or indirect benefits for fish (Petr 2000). The benefits listed by Petr (Cowx and Welcomme 1988, in Petr 2000) include:

- Water purification, both direct (for example, by oxygenation and conversion of toxic ammonia to usable nitrates) and indirect (for example, by plants providing a huge surface area for microbes to do the same tasks)
- Nutrient recycling, including nutrient removal during the growth season and return during senescence
- Physical link between water and air for many invertebrates, e.g., larvae and nymphs of caddis flies, mayflies, and chironomids, which are food for fish and have aquatic larval stages and aerial adults
- Refugia for zooplankton, which graze phytoplankton and keep water clear
- Cover for a large variety of invertebrates, many of which are food for fish
- Cover for fish, which varies as to value and type with the age and species of fish, as well as type of vegetation
- Spawning areas and sites of oviposition for many fish species, including Olympic mudminnow, a potentially covered species
- Food sources for herbivorous fish or indirect food sources from invertebrate prey living on vegetation surfaces
- Effects on flow patterns, i.e., accretion of sediments and deflection of flow, thus providing quiescent waters and faster shallows
- Creation of discrete habitat that is as functional as physical structure

The distribution of aquatic vegetation is limited by the ecological conditions of the water body and the requirements of aquatic plant species (Chambers et al. 1999). Aquatic vegetation can provide valuable cover habitat for a number of fish species, including some freshwater potentially covered species. Olympic mudminnow lay eggs in aquatic vegetation and juveniles stay close to vegetation (Wydoski and Whitney 1979; Mongillo and Hallock 1999). An indirect link between aquatic vegetation and the California floater exists, in that the larvae (glochidea) of the California floater in Curlew Lake depend primarily on the Tui chub (*Gila bicolor*) as a host (Pacific Biodiversity Institute 2006), and juvenile Tui chub typically stay close to vegetation until they are longer than 0.5 inch (Wydoski and Whitney 1979).

HPA-regulated activities in fresh waters have the potential to affect freshwater aquatic vegetation through the following impact mechanisms:

- Ambient light
- Direct disturbance and displacement
- Vessel interactions
- Introduction of noxious weeds

Each of these impact mechanisms is discussed below.

7.3.1 Ambient Light

Light availability is a fundamental requirement for plant growth. The light requirements of different plant species vary, but reduced light in the littoral zone of freshwater environments can potentially limit the growth of aquatic vegetation (Chambers et al. 1999). Light limitations can lead to local reductions in primary production and reductions in other functions of aquatic vegetation, including cover, substrate for invertebrate species, and food for herbivores (Hruby et al. 1999).

7.3.2 Direct Disturbance and Displacement

Human activity associated with the installation of overwater structures can reduce submerged and floating leaved vegetation. This results in temporary and sometimes permanent loss of the affected vegetation, with associated loss of the ecological functions described above.

7.3.3 Vessel Interactions

The potential impacts of vessel activities on freshwater aquatic vegetation are discussed in Section 7.12. Briefly, vessels used during installation of overwater structures may physically disturb submerged vegetation through increased velocity from propeller wash. As discussed in Section 7.12, Lagler et al. (1950, in Carrasquero 2001) reported that outboard motor use has been shown to clear a swath when the propeller was used within 1 foot of aquatic vegetation. In addition, propeller use may entrain air bubbles and cause sediment suspension that results in a temporary reduction in light availability.

7.3.4 Introduction of Noxious Weeds

The introduction of noxious weeds can be a concern in aquatic environments (Chambers et al. 1999; WNWCB 2006). These plants are opportunistic and under the right conditions can out-compete native vegetation and reduce habitat quality for native fish species (Chambers et al. 1999). For example, the Lake Washington shorelines have developed extensive beds of Eurasian milfoil since it was first observed in the lake in 1974 (WNWCB 2005). The impacts of invasive plants on potentially covered species are not clear and depend on a variety of highly variable factors. However, Eurasian milfoil can cause several adverse habitat conditions, including reduced dissolved oxygen and reduced access to habitat (Chambers et al. 1999). Interlake transfer from boats is thought to be the chief means by which Eurasian milfoil is spread (WNWCB 2005). Thus, support vessels used during the construction of overwater structures could facilitate the introduction of invasive aquatic plants by transporting invasive plants from one water body to another.

7.4 Riparian and Shoreline Vegetation

Riparian zones form the transition zone between terrestrial and aquatic systems. Riparian/shoreline vegetation is an important component of freshwater, estuarine, and marine systems, providing shade, streambank and shoreline stability, and allochthonous inputs (material that is produced in one area and consumed in another), as well as influencing groundwater conveyance and storage and the condition and complexity of aquatic habitats (Knutson and Naef 1997; Murphy and Meehan 1991). Removal or disturbance of riparian/shoreline vegetation during construction or maintenance of overwater structures can have several potential impacts to habitat and species in each of these systems, including:

- Shading and water temperature regime
- Streambank/shoreline stability
- Altered allochthonous input
- Groundwater influence
- Habitat conditions

Each of these impact mechanisms is discussed below.

7.4.1 Shading and Water Temperature Regime

Riparian vegetation provides shade from solar radiation (Murphy and Meehan 1991). In general, the smaller the stream, the more closely water temperature will tend to track air temperature; exposure to the sun's energy (due to a lack of riparian vegetation) causes an increase in water temperature, while streams without an insulating canopy of riparian vegetation may also lose heat more rapidly when the air temperature is colder. Removal of trees can thus affect the water temperature in streams both by affecting local air temperatures and by increasing incident radiation[5] and heat loss (Quinn 2005; Bolton and Shellberg 2001; Poole and Berman 2001; Knutson and Naef 1997; Murphy and Meehan 1991). The influence of riparian vegetation 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).

Water temperatures significantly affect the distribution, health, and survival of fish, especially salmonids. Because fish are ectothermic (cold-blooded), their survival is dependent upon external water temperatures, and they will experience adverse health effects when exposed to temperatures outside their optimal range (USEPA 2003).

In lentic (still-water) systems, water temperatures generally change gradually with the seasons, show less change from night to day, and are often stratified vertically. Water temperatures associated with lotic (flowing) systems often change on a diel cycle, and can affect water quality, specifically dissolved oxygen. Salmon, trout and other cold water fish, and many aquatic invertebrates require cool and well-oxygenated water, with a preferred temperature range of 40 to 58 degrees Fahrenheit (F) (5.5 to 14.4 degrees Celsius [C]), and dissolved oxygen levels of greater than 5 parts per million. As stream temperatures rise, dissolved oxygen content decreases. Temperature increases and consequent reductions in dissolved oxygen tend to have deleterious effects on fish and other aquatic organisms by (Knutson and Naef 1997):

- Inhibiting growth and altering metabolism

[5] Incident radiation is solar radiation (i.e., sunshine) that falls directly upon an object (from the sky), as distinguished from reflected or reradiated radiation.

- Amplifying effects of toxic substances
- Increasing susceptibility to disease and pathogens
- Increasing potential risk of eutrophication through increased growth of bacteria and algae

In marine and estuarine waters, shoreline vegetation is not likely to have much influence on marine water temperatures (Lemieux et al. 2004). However, solar radiation has long been recognized as one of the classic limiting factors for upper intertidal organisms and plays an important role in determining distribution, abundance and species composition. Although the influence and importance of shade derived from shoreline vegetation in the Puget Sound nearshore ecosystem is not well understood, it is recognized as a limiting factor to be considered and has prompted investigations to determine direct linkages between riparian vegetation and marine organisms. One such link is the relationship between shad and surf smelt. On the basis of a comparison of adjacent shaded and unshaded spawning sites sampled in northern Puget Sound, Penttila (2001, in Brennan and Culverwell 2004 and Lemieux et al. 2004) found significantly higher egg mortality on the unshaded beaches. Anthropogenic changes in shoreline microclimate will change the intertidal incubating environment, potentially altering developmental rates or increasing physiological stress in fish embryos (Rice 2006). Considering the influences of temperature, moisture, and exposure on the diversity, distribution, and abundance of organisms that use upper intertidal zones, additional benefits of natural shading likely will be discovered as further investigations continue (Brennan and Culverwell 2004).

7.4.2 Streambank/Shoreline Stability

The root structure of riparian/shoreline vegetation resists the shear stresses created by flowing water and thus retards bank cutting by streams, stabilizes streambanks and shorelines, maintains undercut banks along stream margins, and inhibits sediment from entering streams by dissipating the erosive energy of flood waters, wind, and rain (Knutson and Naef 1997). Removal of riparian/shoreline vegetation exposes streambanks and shorelines to the erosive effects of wind, rain, and current and increases the input of fine sediments to the aquatic system (Waters 1995). Much of the scientific literature discusses the potential impacts of increased sediment as it relates to salmonids (Quinn 2005; Waters 1995; Furniss et al. 1991). Refer to Section 7.7 for further information on the impacts to potentially covered species associated with sediment regime changes.

For marine shorelines, and particularly those in areas with steep and eroding bluffs, native vegetation is usually the best tool for keeping the bluff intact and/or minimizing erosion (Brennan and Culverwell 2004). Disturbing the face or toe of a bluff or bank may cause destabilization, slides and cave-ins (Clark et al. 1980, in Brennan and Culverwell 2004). Removal of the vegetation that helps to stabilize the face, or excavation along the face, increases the chance of slumping, which results in imperiled structures, lost land, a disruption to the ecological edge-zone, and increased sedimentation to the aquatic environment (Brennan and Culverwell 2004).

7.4.3 Altered Allochthonous Input

Riparian/shoreline vegetation provides allochthonous input such as terrestrial macroinvertebrates, which supplement the diets of fishes, and detritus like leaves and branches, which provide food sources for benthic macroinvertebrates (Knutson and Naef 1997; Murphy and Meehan 1991). Additionally, riparian/shoreline vegetation supplies large woody debris (LWD) to the aquatic environment, which in streams influences channel morphology/habitat complexity, retains organic matter, and provides essential cover for fish (Quinn 2005; Naiman et al. 2002; Knutson and Naef 1997; Murphy and Meehan 1991), as discussed below with regard to altered habitat conditions (Section 7.4.5).

In lakes, estuaries, and marine environments, woody debris increases habitat complexity, affording cover for fish, protection from currents, and foraging opportunities (Quinn 2005).

Removal of riparian vegetation diminishes allochthonous input into the aquatic environment, which can affect the prey base available to fish, the forage detritus available for benthic macroinvertebrates, future LWD recruitment, and aquatic habitat complexity, diminishing the quality and complexity of habitat and species diversity of fish and benthic macroinvertebrates (Murphy and Meehan 1991).

One of the characteristics that make marine nearshore areas so productive is that they act as sinks for nutrients derived from upland and marine sources. The primary source of nutrients in the system is derived from primary producers (i.e. aquatic and terrestrial vegetation, phytoplankton), although terrestrial-derived organic contributions have not been well studied. Alterations of intertidal and subtidal areas by dredging, filling, diking, overwater structures, and shoreline armoring have dramatically affected marine wetland and other aquatic vegetation (i.e. eelgrass, algae) (Brennan and Culverwell 2004 and Lemieux et al. 2004). Similarly, upland development has greatly reduced the amount of vegetation and nutrients available to the marine system. Such modifications have resulted in decreased abundance and taxa richness in both benthic and infaunal invertebrate and insect assemblages (Brennan and Culverwell 2004).

7.4.4 Groundwater Influence

Riparian/shoreline vegetation acts as a filter for groundwater, filtering out sediments and taking up nutrients (Knutson and Naef 1997). Riparian vegetation, in conjunction with upland vegetation, also moderates stream flow by intercepting rainfall, contributing to water infiltration, and using water via evapotranspiration (Knutson and Naef 1997). Plant roots increase soil porosity, and vegetation helps to trap water flowing on the surface, thereby aiding in infiltration (Knutson and Naef 1997). 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 (Knutson and Naef 1997). 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 stream flows during rainless periods (Knutson and Naef 1997).

The interface between flow within the hyporheic zone[6] and the stream channel is an important buffer for stream temperatures, so alteration of groundwater flow can affect stream temperature as well (Poole and Berman 2001). The magnitude of the influence depends on many factors, such as stream channel pattern, structure of the alluvial aquifer, and variability in the stream hydrograph (Poole and Berman 2001).

[6] The zone of hydrologic interchange between groundwater and surface water in stream channels.

7.4.5 Habitat Conditions

Habitat conditions within freshwater, estuarine, and marine environments are influenced by riparian/shoreline vegetation. Inputs of woody debris into these environments from riparian areas contribute significantly to habitat conditions within freshwater environments (Naiman et al. 2002). Woody debris input in streams is important in controlling channel morphology, regulating the storage and transport of sediment and particulate organic matter, and creating and maintaining fish habitat (Murphy and Meehan 1991). 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 small streams, LWD is a major factor influencing pool formation in plane-bed and step-pool channels. Bilby (1984, in Naiman et al. 2002) and Sedell et al. (1985, in Naiman et al. 2002) found that approximately 80 percent of the pools in several small streams in southwest Washington and Idaho are associated with wood. Additionally, juvenile salmonid abundance in winter, particularly juvenile coho salmon, is positively correlated to abundance of LWD (Hicks et al. 1991). 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 formation of backwater pools along margins of the mainstem (Naiman et al. 2002).

In lakes, estuaries, and marine waters, large woody debris provides cover and foraging opportunities for fish (Quinn 2005). Structurally, LWD provides foraging, refuge and spawning substrate for fishes; and foraging, refuge, spawning and attachment substrate for aquatic invertebrates and algae in the marine/estuarine environment (Brennan and Culverwell 2004). The removal of riparian/shoreline vegetation limits the future input of woody debris to the aquatic environment and can limit habitat complexity, foraging opportunities, and predator avoidance (Quinn 2005).

7.5 Noise

Underwater noise produced in association with the construction of overwater structures includes noise generated from pile driving (when applicable) and by construction vessels and equipment. An increase in underwater noise may also be attributed to the operation of the structure if it involves increased boating traffic. This section discusses potential impacts to fish and invertebrates from underwater noise produced by these activities.

7.5.1 Pile Driving

Pile driving within the water column is often necessary in the construction and retrofitting of overwater structures. Placing piles in the benthic substrate affects both the substrate directly beneath the piles and the physical attributes of the water column in the vicinity of the activity (Nightingale and Simenstad 2001b). One important physical attribute of the aquatic habitat affected by pile driving is sound pressure (noise) within the water column.

Hastings and Popper (2005) recently performed a comprehensive literature review to evaluate the current best available science regarding noise thresholds at which fish would be injured by the percussive sound generated by pile driving. Much of the information presented below has been extracted from that review.

Fish are sometimes injured or killed by the impact of sounds generated by percussive pile driving (Yelverton et al. 1975; Hastings 1995, in Hastings and Popper 2005). The specific effects of pile driving on fish depend on a wide range of factors, including the types of piles and hammer used, the fish species and life stages present, the environmental setting, and many other controlling factors (Hastings and Popper 2005; Popper et al. 2006; WSDOT 2006a). Noise generated by pile driving can cause physiological and/or behavioral impacts depending on the size of the fish relative to the wavelength of sound, the mass and anatomical structure of the fish (Hastings and Popper 2005), the received sound, and the level and duration of noise produced (Popper et al. 2006; Scholik and Yan 2002). Feist et al. (1992) found that pile driving impacted distributions and behaviors of juvenile pink and chum salmon relative to their location to the activity and to schooling behavior, although the consequences of these effects on the survivability or fitness of juvenile salmon are unknown.

Anatomical variations of the inner ear, swim bladder, esophagus, lateral line, and other structures determine how fish hear and feel sound pressure (Hastings and Popper 2005). All fish fall into two hearing categories: "hearing generalists" such as salmon and trout, and "hearing specialists" such as herring and eulachon (Hastings and Popper 2005).

Hearing specialists have particular adaptations that enhance their hearing bandwidth and sensitivity (Hastings and Popper 2005). Hearing specialists found on the Pacific coast include the sardine and related Clupeiforms such as herring, shad, menhaden, and anchovy (Hastings and Popper 2005).

The majority of fish on the Pacific coast are hearing generalists and do not have specialized hearing capabilities apart from their swim bladder, inner ear, and lateral line (Hastings and Popper 2005). Hearing generalists sense sound directly through the inner ear, and some use the inner ear coupled with the swim bladder to sense additional energy (Hastings and Popper 2005).

In using the existing scientific literature to address potential effects of underwater noise on potentially covered species, it is not sufficient to simply extrapolate information by comparing species that are taxonomically related, because hearing categories do not usually follow fish taxonomic groupings. Both hearing generalists and hearing specialists are found in many taxonomic groups (Hastings and Popper 2005). Ideally, fish should be compared based on biomechanical properties of their swim bladder and any other internal gas-filled chamber, hearing capabilities, and aspects of their behavior (Hastings and Popper 2005). However, when such data are not available, it is probably more appropriate to extrapolate between species that have somewhat similar auditory structures or pressure-detecting mechanisms (most notably the swim bladder) and species of similar size, mass, and anatomical variety (Hastings and Popper 2005). This would enable at least a first-order approximation of extrapolation to fishes such as salmonids and other teleost fishes that presumably do not have hearing specialization (e.g., rockfish). The results are less easily extrapolated to teleosts without a swim bladder, such as sand lance and lingcod, and to fish with very different ear structures, such as lamprey and sturgeon (Hastings and Popper 2005).

Table 5 outlines the known and presumed hearing categories of potentially covered fish species.

Table 5
Hearing Categories for Potentially Covered Fish Species

Common Name (Scientific Name)	Hearing Category	Notes and/or References
Trout and salmon (*Salvelinus, Onchorynchus* spp.)	Generalist	Popper and Carlson 1998
Sturgeon (*Acipenser* spp.)	Undetermined	Popper (2005) states that sturgeon can detect an extremely wide range of sounds, and several studies have found that some sturgeon produce sounds that may be used to facilitate breeding. However, further studies are necessary to determine how sturgeon vocalize, what levels of sound are produced in the natural environment, and how their vocalizations are used in their behavior.
Eulachon (*Thaleichthys pacificus*)	Specialist	Blaxter et al. 1981, in Scholik and Yan 2001a
Rockfish (*Sebastes* spp.)	Generalist	Hastings and Popper 2005
Lake chub (*Couesius plumbeus*)	Specialist	Hastings and Popper 2005; Popper et al. 2005
Dace (*Rhinicthys* spp.)	Unknown/ Presumed Generalist	Not a member of a family or grouping identified as containing hearing specialists (Fay and Popper 1999)
Lingcod (*Ophiodon elongates*)	Generalist	Does not have a swim bladder, which is generally an indication of poor hearing (Moyle and Cech 2004; Kapoor and Khanna 2004)
Surf smelt (*Hypomesus pretiosus*)	Generalist	Included in the taxonomic order Salmoniformes – hearing generalists (Hastings and Popper 2005)
Lamprey (*Lampetra* spp.)	Generalist	Popper 2005
Margined sculpin (*Cottus marginatus*)	Generalist	Closely related to the bullhead (*Cottus scorpius*), which is identified as a generalist (Fay and Popper 1999); also not a member of a family or grouping identified as containing hearing specialists (Fay and Popper 1999)
Mountain sucker (*Catostomus platyrhynchus*)	Unknown/ Presumed Specialist	*Catostomus* spp. are known to have weberian ossicles to assist with hearing (Krumholz 1943)
Olympic mudminnow (*Novumbra hubbsi*)	Unknown/ Presumed Specialist	May have weberian ossicles to assist with hearing (Moyle and Cech 2004). Many closely related fish (minnows, pikeminnow cyprinids) are specialists (Scholik and Yan 2001b; Popper 2005).
Pacific cod (*Gadus macrocephalus*)	Generalist	*Gadus* sp. more sensitive than most generalists (Astrup and Mohl 1998, in Scholik and Yan 2002; Hastings and Popper 2005)
Pacific hake (*Merluccius productus*)	Unknown/ Presumed Generalist	Not a member of a family or grouping identified as hearing specialists (Fay and Popper 1999)
Pacific herring (*Clupea harengus pallasi*)	Specialist	Hastings and Popper 2005
Pacific sand lance (*Ammodytes hexapterus*)	Generalist	Does not have a swim bladder, which is generally an indication of poor hearing (Moyle and Cech 2004; Kapoor and Khanna 2004)
Pygmy whitefish (*Prosopium coulteri*)	Generalist	Of the order Salmoniformes – hearing generalists (Hastings and Popper 2005)
Walleye pollock (*Theragra chalcogramma*)	Unknown/ Presumed Generalist	Not a member of a family or grouping identified as containing hearing specialists (Fay and Popper 1999)

Physical impacts to fish from intense noises may include temporary hearing loss (referred to as temporary threshold shift), permanent hearing loss (referred to as permanent threshold shift), damage or rupture to gas organs such as the swim bladder and the surrounding tissues, rupture of capillaries in the skin, neurotrauma, and eye hemorrhage (Hastings and Popper 2005). The more serious of these impacts could cause instantaneous death or later death from injuries (e.g., breakdown of tissues in some organs) (NMFS 2003a).

Behavioral and indirect effects may include movement of fish away from feeding grounds, reduced fitness to survive, increased vulnerability to predators, reduced success locating prey, effects on fish communications, effects on the fish's sense of the physical environment, and many other possible scenarios (Hastings and Popper 2005).

Not enough is known to provide discrete injury thresholds for different fish species, and even less is known regarding behavioral thresholds (Hastings and Popper 2005; Popper et al. 2006). The National Marine Fisheries Service (NMFS) and the USFWS have adopted injury and disturbance thresholds for threatened and endangered salmonids at 180 dB_{peak} (i.e., peak decibels during each pulse) for injury and 150 dB_{RMS} (i.e., decibels root mean square, the square root of sound energy divided by impulse duration) for behavioral disturbance (WSDOT 2006a and numerous biological opinions).

Recently, after extensive review of the existing literature (Hastings and Popper 2005), Popper et al. (2006) recommended using a combined, interim single-strike criterion as a threshold for pile driving injury to salmonids: 187dB_{SEL} and 208dB_{peak}, where SEL is the sound exposure level, which accounts for the accumulation of energy over a complete pile strike. These thresholds are considered conservative by the authors, but current science limits the extrapolation of the single-strike SEL to estimate the effects on fish due to accumulated energy from multiple pile strikes. Discussions on the use of these proposed dual criteria are currently in progress.

7.5.1.1 Impacts on Eggs and Larvae

Although it is possible that some (but not all) fish species would swim away from a sound source, thereby decreasing exposure to sound, larvae and eggs are often at the mercy of currents, move slowly, or are sedentary (Hastings and Popper 2005). Data on the effects of sound on developing eggs and larvae are limited, although in a study by Banner and Hyatt (1973), increased mortality was found in eggs and embryos of sheepshead minnow (*Cyprinodon variegates*) exposed to broadband noise (100 to 1,000 hertz) that was about 15 dB above the ambient sound level. Hatched fry of sheepshead minnow and fry of longnose killifish (*Fundulus similes*) were not affected in this study.

7.5.1.2 Impacts on Invertebrates

Although studies of noise impacts on invertebrates have consistently shown that very high sound pressure levels (in excess of 217 dB) can cause serious injury, the information is sparse, is poorly reported, and was obtained without due experimental rigor (Turnpenny et al. 1994). The studies reported in Turnpenny et al. (1994) exposed mussels, periwinkles, amphipods, squid, scallops, and sea urchins to high airgun and slow-rise-time sounds at between 217 dB and 260 dB. Mussels, periwinkles, and amphipods showed no detectable effect at 229 dB (Kosheleva 1992, in Turnpenny et al. 1994), although one Iceland scallop suffered a split shell after being exposed to 217 dB from a single airgun strike (Matishov 1992, in Turnpenny et al. 1994).

7.5.2 Noise from Commercial and Recreational Boating Traffic

Motors, sonars, and depth sounders used on commercial vessels and recreational boats can produce high levels of continuous underwater noise that can impact fish behavior (Blaxter et al. 1981, Boussard 1981, both in Scholik and Yan 2001a; Pearson et al. 1992; Scholik and Yan 2001a) and result in temporary hearing loss (Scholik and Yan 2001b).

The potential impacts to fish from vessel noise are discussed in greater detail in Section 7.12.

7.5.3 Noise from Construction Vessels and Equipment

Equipment and vessels necessary to dig trenches, place riprap, support equipment over water, and perform other activities associated with the construction of overwater structures also produce underwater noise. Construction equipment tends to produce the same type of slow-rise-time noise as do motor boats and ship engines. Jones and Stokes (2006) estimated that noise produced by a rather large ocean-cable-installation vessel is about 154 dB_{RMS}. JASCO (2005) estimated that noise produced by a rock-dumping vessel is approximately 177 dB (neither peak nor RMS identified) at 3.28 feet (1 m), and Richardson et al. (1995, in Jones and Stokes 2006) estimated that an equipment support vessel produces noise levels of 152 dB_{peak} at 3.28 feet (1 m). Sounds of this amplitude may affect the behavior or physiology of fishes, depending on their hearing sensitivity and proximity to the sound.

7.6 Water Quality

Placing constructed features in aquatic settings may adversely impact water quality in several different ways, mainly by causing increases in suspended solids concentrations, reducing dissolved oxygen levels, changing pH, or releasing toxic substances from treated wood products. Stormwater runoff from constructed surfaces also poses a threat to water quality from its often-associated nonpoint source pollutant load. These potential impact mechanisms may adversely impact potentially covered species.

7.6.1 Suspended Solids

Particulate matter suspended in the water column can have adverse impacts on aquatic life (Bash et al. 2001). Disturbance of instream sediment during instream work, such as dock construction, or stormwater runoff from upland portions of construction sites may increase suspended sediment levels (E. Molash, pers. comm., in Bash et al. 2001). Sediment disturbance can be further increased by instream operation of equipment or storage of excavated material within the floodplain (Reid et al. 2004), although the latter activity is commonly prohibited under the HPA authority.

Changes in stream profile and the presence of submersed structures often cause changes to hydraulic conditions that redistribute the energy of moving water, which may cause chronic increases in suspended sediment (NMFS 2005a). The effects of hydraulic alteration are discussed in Section 7.7. Similarly, vessel activities associated with construction or operation and maintenance of structures may also resuspend sediments and increase turbidity on a periodic to continuous basis, depending on nautical traffic conditions (Simenstad et al. 1999). The effects of vessel activities are detailed in Section 7.12.

7.6.1.1 Measuring Suspended Solids

Suspended sediments are generally measured and reported in one of three ways: as turbidity, as total suspended solids (TSS), or as water clarity (Bash et al. 2001). These three measurement methods are not always well correlated and may yield different results for any single sample (Duchrow and Everhart 1971).

- Turbidity can be quantified by the degree to which light is scattered as it passes through water. Turbidity is reported in nephelometric turbidity units (NTUs), measured using a nephelometer, or in Jackson turbidity units (JTUs), measured using an older tool called a Jackson candle turbidimeter. NTUs and JTUs are roughly equivalent at higher values but measurement of JTUs below 25 relies on human judgment (USEPA 1999). NTUs are now the preferred turbidity unit (USEPA 1999).
- TSS concentration is measured by filtering the sample, weighing the dried, filtered residue, and reporting TSS as weight of dried residue per volume of water sample. Older literature sometimes refers to TSS as suspended sediment concentration. TSS and suspended sediment concentration are equivalent (Bash et al. 2001).
- Water clarity is a measure of sight distance through water and is affected by both suspended and dissolved loads.

7.6.1.2 Determining Background Suspended Solids Levels

Determining background suspended solids levels is a difficult process confounded by the inconsistency in measurement methods and natural environmental variation in factors contributing to turbidity levels (Bash et al. 2001). Turbidity often varies temporally with variations in precipitation, runoff, and discharge regimes as erosion and transport of suspended material varies. Turbidity may also vary spatially between watersheds or within watersheds as geology and water velocity vary. Widespread, continuous sampling would be required to determine a reasonable estimate of natural background turbidity levels (Bash et al. 2001).

7.6.2 Suspended Solids Impacts on Fish

Fine sediment has been recognized as detrimental to the reproductive success of salmonids since at least 1923 (Harrison 1923). Bash et al. (2001) exhaustively reviews 40 years of research on the physiological and behavioral effects of turbidity and suspended solids on salmonids, with findings as briefly summarized below:

Physiological effects of suspended sediment on salmonids include gill trauma and altered osmoregulation[7], blood chemistry, reproduction, and growth. Most research has entailed laboratory studies. Stress response is a result of the combination of duration, frequency, and magnitude of exposure and other environmental factors. Stress responses vary between salmonid species and life stages. Abrasive suspended sediments may irritate gills. Several laboratory studies have shown gill trauma and increased coughing frequency with increased turbidity. Other studies have shown impairment of osmoregulation during smolting in association with increases in suspended sediment (Bash et al. 2001).

The behavioral effects of suspended sediments on salmonids are described by laboratory and field studies in the categories of avoidance and changes in territoriality, foraging, predation, homing, and migration. Salmonids appear to avoid areas of increased turbidity in laboratory and field studies. Laboratory studies have shown alterations in social interactions and territoriality in response to increases in turbidity. It has been suggested that decreased territoriality and a breakdown in social structure can lead to secondary effects such as altered feeding and growth rates which may, in turn, lead to increased mortality. Some laboratory studies have shown a negative impact of increased turbidity on foraging, possibly due to reduced visibility, while other studies have shown a positive effect of increased turbidity on foraging, possibly due to reduced risk of predation. Laboratory and field studies have shown a link between increased turbidity and reduced primary production and prey availability. Field studies have indicated that increased turbidity may delay migration (Bash et al. 2001).

Additional studies have supported the assertion that water clarity affects fish behavior. Avoidance responses, changes in territorial behavior, feeding patterns and homing

[7] The act of regulating osmotic pressure to maintain water and mineral salt content in body fluids.

ability have been observed in association with increased turbidity levels (Sigler 1988). Avoidance responses of rainbow trout and Atlantic herring to suspended sediment have been observed at concentrations of 10 milligrams per liter (mg/L) and 20 mg/L, respectively (Wildish and Power 1985). Juvenile chum salmon, considered a species more tolerant of suspended sediment (Nightingale and Simenstad 2001a), have also exhibited avoidance behavior in response to elevated turbidity levels (Salo et al. 1979). However, turbidity plumes that do not extend from bank to bank are not expected to significantly impact the behavior of migrating fish, as they are able to avoid the areas of high turbidity (Nightingale and Simenstad 2001a).

Water clarity is important to fish during the development of visual acuity (Nightingale and Simenstad 2001a). Water clarity affects light transmission, which in turn is thought to play a role in the development of visual acuity in fish (Nightingale and Simenstad 2001a). Visual acuity adjustment in estuarine waters is part of the smolting process of salmonids (Beatty 1965; Folmar and Dickhoff 1981). Similar visual development has been reported in juveniles of other species, such as sand lance, kelp greenling, and lingcod (Britt 2001; Tribble 2000).

Recent literature maintains that water clarity is important to fish as visual feeders. Larval fish have little or no swimming capability, are visual feeders, and undergo high mortality rates due to starvation (Nightingale and Simenstad 2001a). Increased turbidity and reduced water clarity could negatively impact the already limited prey-catching ability of larval fish (Nightingale and Simenstad 2001a).

Several NMFS biological opinions on overwater structures and piling projects have been reviewed for their conclusions on potential water quality impacts to listed fish species. In all cases, sediment- and turbidity-related impacts comprised the overwhelming majority of discussion on water quality effects. In most cases, the magnitude, frequency, and duration of sediment pulses are expected to be similar to naturally occurring conditions during natural fluctuations in flow conditions, and few salmonids are predicted to be present during in-water work windows; therefore, NMFS concluded that potential increases in turbidity would have negligible impacts on salmonids and their habitats (NMFS 2006a; NMFS 2006f; NMFS 2006h; NMFS 2006i; NMFS 2006j; NMFS

2006k; NMFS 2006m; NMFS 2006n). However, NMFS found that elevated turbidity can cause direct mortality (NMFS 2006g), while sublethal threats include harassment, as feeding patterns may be affected and fish are likely to avoid areas of increased turbidity (NMFS 2006d).

7.6.3 Suspended Solids Impacts on Invertebrates

The limited mobility of many invertebrates prevents them from escaping even temporary pulses of increased suspended sediment loads. Suspended sediment levels of 188 and 1,000 mg/L have been observed to hinder egg development of eastern oyster (*Crassostrea virginica*) (Cake 1983) and hard clam (*Mercenaria mercenaria*) (Mullholland 1984). Comparable impacts could be expected in other benthic bivalves such as the California floater, Western ridged mussel, and Olympia oyster, which are all potentially covered species. There appears to be a break point at 750 mg/L between chronic and acute impacts of suspended sediment (Nightingale and Simenstad 2001a). At levels below 750 mg/L, development continues for both clams and oysters, but at levels above 750 mg/L that last for 10 to 12 days, effects become lethal (Nightingale and Simenstad 2001a). Evidence of physiological responses among shellfish to increased turbidity appears to be ambiguous; it has been hypothesized that at lower turbidity levels, resuspended chlorophyll may act as a food supplement enhancing growth, while at higher levels, planktonic food resources are diluted to the point of inhibiting growth (Nightingale and Simenstad 2001a). Increased suspended sediment has also been associated with behavioral changes among shellfish. Changes have been observed in siphons and mantles of soft-shelled clams (*Mya arenaria*) at suspended sediment concentrations of 100 to 200 mg/L (Grant and Thorpe 1991). Based on these studies, it appears likely that shellfish are generally less vulnerable to acute effects of suspended sediment than are fish, but have some risk from chronic exposure. Thus, there is a risk that potentially covered shellfish species could experience some level of incidental take due to increased suspended sediments. However, general minimization measures commonly required by HPAs will limit the dispersion of resuspended sediment and normally result in only temporary turbidity increases.

7.6.4 Contaminated Sediment Impacts

Sediment can be contaminated with chemicals known to have potential to cause adverse impacts to potentially covered species if resuspended in the water column. Sediment contamination and the potential for resuspension must be determined prior to construction on a site-by-site basis as part of a project-specific assessment. It is unlikely that a project with the potential to resuspend contaminated sediments would qualify under a programmatic evaluation of ESA-related impacts, because the range of potential impacts is extremely wide and the state of the science is rapidly evolving. There exist many scenarios under which the risk of incidental take is extremely high; site-specific analyses and conservation measures may be required to effectively reduce that risk. Because the potential impacts of resuspended contaminated sediment are site-specific, they are not further discussed in this paper.

7.6.5 Dissolved Oxygen Impacts

Juvenile salmon are highly sensitive to reductions in dissolved oxygen concentrations (USFWS 1986) and so are probably among the more vulnerable potentially covered species with regard to dissolved oxygen impairments. It has been hypothesized that resuspension of large quantities of anoxic sediments, an effect more commonly associated with dredging activities than with the construction of overwater structures, may reduce dissolved oxygen levels in surrounding water as a result of oxidation reactions (Nightingale and Simenstad 2001a). However, even with the potentially large amounts of resuspended, deep-water, anoxic sediments associated with dredging, little evidence supports the notion that associated dissolved oxygen reduction in surrounding water poses a risk to fish moving through the area (Nightingale and Simenstad 2001a). Given the low levels of organic material commonly mobilized during the construction and operation of overwater structures, the risk of adverse impacts to covered species is quite low.

7.6.6 pH Impacts

Structures constructed in aquatic settings can adversely impact the pH of surrounding water via contact between water and uncured concrete (Ecology 1999). Standard HPA provisions (Appendix A) prohibit fresh, uncured concrete from coming into contact with surrounding water or the bed of the water body.

7.6.7 Treated Wood-Related Impacts

Some overwater structures are supported by wood piles. Wood piles are also sometimes used to construct temporary trestles that support equipment during construction activities. Wood piles that have been chemically treated to resist rot and are in contact with water have the potential to leach chemical contaminants into the surrounding water (Poston 2001). In addition to this possible direct impact, indirect pathways of contamination also exist; for instance, stormwater runoff from surfaces elevated above the water body or splinters of treated material that are dislodged by activity above the water line and fall into the water body (Poston 2001). For this reason, creosote- and pentachlorophenol-treated wood products are not allowed in Washington lakes for applications that involve direct water contact (WACs 220-110-060(4), -170(6), -223(6), and –224(2)). However, wood that has been treated with other chemicals and is used in direct water contact applications may also pose a threat to water quality through the potential to leach toxic chemicals into surrounding water (Poston 2001). A common method for increasing the resistance of wood to rot is treatment with copper in the form of ammoniacal copper zinc arsenate (ACZA) or chromated copper arsenate (CCA Type C) (Poston 2001).

7.6.7.1 Creosote-Treated Wood

Poston (2001) reviews approximately 20 years of research on this topic with findings as summarized below:

- Creosote-treated wood poses a much greater risk to water quality from trace metals and polycyclic aromatic hydrocarbons (PAHs) in the immediate surrounding water over a relatively short period of time; toxic lighter-weight PAHs escape the wood, volatilize, and degrade rapidly, while higher-weight PAHs contribute to more chronic contamination as they incorporate into sediment. The greatest risk from creosote-treated wood in aquatic applications is to benthic organisms and organisms that directly colonize treated wood structures.
- Temporal and spatial impacts of creosote-treated wood on aquatic environments appear to be much greater than those of ACZA- or CCA-treated wood.

- The vast majority of research discussed in this review investigated the impacts of relatively small applications (<100 pilings) of treated wood. More investigation is needed into the potential impacts of larger projects.
- Impacts of treated wood projects alone may be difficult to assess in settings complicated by other ecological stressors.
- PAHs may continue to diffuse from creosote-treated wood for the life of the product, but diffusion from creosote-treated wood products that have been treated to fix or remove excess preservative may not be as great as previous studies have indicated. PAH releases from wood products may also reach equilibrium with PAH degradation in aerobic sediments over time; however, this may not be true for anaerobic sediments, where PAHs would likely persist for longer periods of time.
- Removal of creosote-treated wood structures may resuspend sediments contaminated with PAHs. Although no data were located regarding this, field data indicate higher degrees of PAH contamination in sediments immediately adjacent to creosote-treated structures.
- PAH contamination from both immersed and above-water structures appears to diminish with distance from the structure and, although PAHs are relatively mobile, PAH contamination of sediments is unpredictable in relation to water currents.
- Areas with less water circulation and lower pH are at greater risk for contamination, because leaching is faster and dilution occurs more slowly.
- Metals will not degrade but may mineralize or become physically or chemically sequestered as they are likely incorporated into sediment. However, long-term accumulation of metals at the bases of pilings has not been reported. The risk of sediment resuspension during the removal of pilings is not well understood at this time.
- The sediment content of fines and organic carbon plays a key role in the fate of metals contaminants in the sediment. The function of acid volatile sulfides in the bioavailability of metals contaminants is not understood at this time, but acid volatile sulfides likely also play a role in toxicity. Metals contamination of sediments appears to be localized, while sediment

disturbance will likely transport and redistribute metals, possibly diluting the contamination.

- The risk of potential impacts to salmonids from direct exposure to PAHs or metals leached from treated wood is low. Riverine spawning substrates for salmonids do not typically facilitate the accumulation of PAHs or metals, and juvenile salmonids are not likely to encounter high concentrations of such contamination in larger waterways when they begin their open-water, marine lifestage. However, salmonids are potentially at some risk of exposure from consumption of contaminated prey.

Some additional studies not described by Poston (2001) have been conducted to characterize PAH leaching rates associated with creosote-treated wood in aquatic applications. PAH leaching rates have been shown to increase with increased water circulation (Kang et al. 2003). PAH leaching rates also seem to increase with temperature, although water circulation appears to have a much greater effect on leaching rates than does water temperature, with the greatest leaching rates occurring in warm, turbulent water (Xiao et al. 2002). PAH leaching rates seem to vary with wood species (Cooper 1991; Rao and Kuppusamy 1992), decreasing as wood density increases as found in studies comparing loblolly pine and Douglas fir (Miller 1972, in Cooper 1991). PAH leaching rates also increase as treated wood surface area to volume ratios increase (Colley and Burch 1961, Stasse and Rogers 1965, Gjovik 1977, Miller 1977, all in Cooper 1991).

Table 6 summarizes several studies on biological effects thresholds for PAHs in surface water (from Stratus 2005a).

Table 6
Effects Thresholds for PAHs in Surface Water

Organism	Exposure Source	Toxicity Endpoint	Concentration in µg/L	Citation
Mysid, *Mysidopsis bahia*	Elizabeth River, Virginia, sediment extracts	24-hour LC50	180	Padma et al. 1999
Amphipod, *Rhepoxynius abronius*	Eagle Harbor, Washington, sediment extracts	96-hour LC50	100	Swartz et al. 1989
Pacific herring	PAHs leaching from ~ 40-year-old pilings	LC50 for hatching success	50	Vines et al. 2000
Zooplankton	PAHs leaching from pilings placed in microcosms	NOEC for communities	11.1	Sibley et al. 2004
Zooplankton	Commercial creosote added to microcosms	NOEC for communities	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	EC50 for abundance	2.9	Sibley et al. 2001
Trout	Commercial creosote added to microcosms	LOEC for immune effects	0.6	Karrow et al. 1999

EC_{50} = Exposure concentration of a material that has a defined effect on 50 percent of the test population.
LC_{50} = Lethal concentration of a chemical within a medium that kills 50 percent of a sample population.
LOEC = Lowest observable effects concentration
NOEC = No observable effects concentration
µg/L = micrograms per liter
Source: Stratus 2005a

Many studies have investigated thresholds for biological effects of PAH concentrations in sediment. Several effects thresholds have been determined using NMFS' many years of data on the effects of PAH-contaminated sediments on benthic fish in Puget Sound (Stratus 2005a). Thresholds for effect on English sole were determined at 230 parts per billion (ppb) for proliferated liver lesions; 630 ppb for spawning inhibition, infertile eggs, and abnormal larvae; and 288 ppb for DNA damage, measured as PAH-DNA adducts (Johnson et al. 2002).

Several models have been developed to estimate PAH leaching rates from creosote-treated wood (Brooks 1997; Poston et al. 1996; Xiao et al. 2002). The models attempt to describe complex interactions and generally rely heavily on site-specific data and assumptions (Stratus 2005a). Evaluations of the CREOSS model (Brooks 1997) and the box plume model (Poston et al. 1996) have shown that although they may not fully explain transient concentrations, such as those immediately following installation or severe disturbance such as abrasion, they are helpful in qualitatively describing the effect of many factors, such as salinity, temperature, wood density, water circulation, surface area to volume ratio, wood grain direction, time from treatment, and whether the wood was treated using BMPs to reduce leaching rate (Stratus 2005b).

7.6.7.2 ACZA- and CCA Type C-Treated Wood

Recent work on contaminant leaching from ACZA- and CCA Type C-treated wood not described by Poston (2001) includes a 2004 study of arsenic, copper, and zinc concentrations in sediment, water, and shellfish near four ACZA-treated wood structures on the Olympic Peninsula. In this study, there were insignificant increases in arsenic, copper, and zinc in sediment and water at three out of four sampling sites and minimal uptake by shellfish (Brooks 2004). Oysters growing on CCA-treated wood piles have been observed to have higher metals concentrations in soft tissues and a greater incidence of histopathological lesions than oysters collected from nearby rocks (Weis et al. 1993, in Stratus 2005b). Snails fed algae grown on CCA-treated docks showed mortality (Weis and Weis 1996, in Stratus 2005b). Significantly lower biomass and diversity of sessile epifaunal communities have been observed on treated wood panels than on untreated wood panels, but the response appeared to dissipate over time to negligible levels after three months of exposure (Weis et al. 1992a; Weis and Weis 1994, in Stratus 2005b).

Weis et al. (1998, in Stratus 2005b) measured metals concentrations in sediments and marine polychaete worms and diversity, abundance, and biomass in the benthic invertebrate community near five CCA-treated wood bulkheads ranging from one to eight years in age. It was found that concentrations of copper and arsenic in sediments were generally elevated within 3.3 feet (1 m) but diminished to background levels by 9.8 feet (3 m) from the bulkheads. Polychaete worms collected within 3.3 feet (1 m) of a one-year-old treated wood structure contained elevated copper and arsenic concentrations, and benthic community effects on abundance and diversity were noted at all treated wood sites, diminishing with distance from the bulkheads. Effects were negligible at distances greater than 3.3 feet (1 m) from bulkheads (Weis et al. 1998, in Stratus 2005b).

A study on the leaching rate of arsenic from CCA Type C-treated lumber under simulated precipitation showed leaching rates of 0.0143, 0.0079, and 0.0062 micrograms per square centimeter per millimeter ($\mu g/cm^2/mm$) of simulated rainfall for the 0.1, 0.33 and 1.0 inch/hour (2.5, 8.0, and 25.4 mm/hour) rainfall rates, respectively (Lebow et al. 2004). This same study also found little reduction in arsenic leaching rates with the application of a water repellent (Lebow et al. 2004). In some cases, leaching rates seemed to increase with water repellent application (Lebow et al. 2004). Another study found that semi-transparent water-repellent stain, latex paint, or oil-based paint greatly reduces leaching rates of arsenic, chromium, and copper (Lebow et al. 2004).

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). In both fresh water 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), and there may be a risk of bioaccumulated toxicity in salmonid prey species at the chronic chromium VI criterion (Stratus 2005b).

Table 7
U.S. Water Quality Criteria for the Protection of Aquatic Life ("aquatic life criteria") for Water Soluble Chemicals Used in Treating Wood

Chemical	Freshwater CMC (µg/L)	Freshwater CCC (µg/L)	Saltwater CMC (µg/L)	Saltwater CCC (µg/L)
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 mg/L (as CaCO3).
b. Criteria developed using site-specific chemistry and the Biotic Ligand Model (BLM).
c. No saltwater CMC. As a proxy, we report the lowest reported LC50 from the USEPA database (Lussier et al. 1985) divided by a factor of two. See text for additional details.
d. No saltwater CCC. As a proxy, we report the lowest reported chronic value from the USEPA database (Lussier et al. 1985) divided by a factor of two. See text for additional details.
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
µg/L = micrograms per liter
Source: USEPA 2002, except as noted, as taken from Stratus 2005b

There does not appear to be a pattern of sensitivity among species with respect to chromium III, but the ALC, although 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), 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 mg/L) (Hansen et al. 2002, in Stratus 2005b); however, the zinc ALC for 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 potentially covered species (Stratus 2005b).

Metals from treated wood in aquatic settings may contaminate sediment and affect benthic communities, in turn limiting food availability for fish and exposing fish to metals contamination through the consumption of contaminated prey (Stratus 2005b). However, site-specific sediment conditions such as particle size and organic content can dramatically influence metals toxicity, making sediment toxicity difficult to predict (Stratus 2005b). Tables 8 and 9 present some of the threshold effects concentrations (TECs) and probable effects concentrations (PECs) for arsenic, chromium, copper, and zinc in sediment as reported in recent literature (Stratus 2005b). In general, concentrations below the TEC are not expected to cause impacts, while concentrations above the PEC are expected to cause frequent impacts.

Table 8
Threshold Effects Concentrations (TECs) for Freshwater Sediment

Name	Definition	Concentration (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[a]	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. 2000a

a. Based on data from both freshwater and marine sites.
Source: Taken from Stratus 2005b
mg/kg = milligrams per kilogram
As = arsenic; Cr = chromium; Cu = copper; Zn = zinc

Table 9
Probable Effects Concentrations (PECs) for Freshwater Sediment

Name	Definition	Basis	Concentration (mg/kg dry wt) As	Cr	Cu	Zn	Reference
Severe effects level	Level at which pronounced disturbance of the sediment-dwelling community can be expected	Field data on benthic communities	33	110	110	820	Persaud et al. 1991
Probable effects level	Concentration that is frequently associated with adverse effects	Compiled results of modeling, laboratory, and field studies on aquatic invertebrates and fish	17	90	197	315	Smith et al. 1996
Toxic effects threshold	Critical concentration above which major damage is done to benthic organisms	Field data on benthic communities	17	100	86	540	Environment Canada 1992
Effects range median[a]	Concentration above which effects were frequently or always observed or predicted among most species	Field data on benthic communities and spiked laboratory toxicity test data	85	145	390	270	Long and Morgan 1991
Probable effects level	Concentration above which adverse effects on survival or growth are expected to occur frequently	Laboratory toxicity tests on the amphipod Hyalella azteca using field-collected sediment	48	120	100	540	Ingersoll et al.1996; USEPA 1996
Consensus probable effects concentration	Concentration above which harmful effects on sediment-dwelling organisms are expected to occur frequently	Geometric mean of above published effects concentrations	33.0	111	149	459	MacDonald et al. 2000a

a. Based on data from both freshwater and marine sites
Source: Taken from Stratus 2005b
mg/kg = milligrams per kilogram
As = arsenic; Cr = chromium; Cu = copper; Zn = zinc

7.6.8 Stormwater and Nonpoint Source Water Quality Impacts

Stormwater generated by above-water portions of structures may adversely impact potentially covered species by introducing nonpoint source pollution to waterways. Overwater structures provide a surface on which pollutants can accumulate, and those pollutants can become mobile with stormwater runoff. Overwater structures may also be associated with a variety of adjacent land uses, including roads and parking lots, and may act as conduits for stormwater delivery from those adjacent land uses to waterways. These stormwater impacts are mitigated by regulations promulgated by the Washington State Department of Ecology (Ecology) under the federal Clean Water Act

(33 USC §§ 1251-1387). The Ecology regulations are subject to USEPA review and Section 7 requirements of the ESA (16 USC 1531-1544).

7.7 Channel Hydraulics

7.7.1 Controlling Factors in Channels

Streams are dynamic systems that adjust to tectonic, climatic, and environmental changes (Dollar 2000). Environmental changes can be either human-induced or natural. A stream system adjusts to maintain a steady state, or dynamic equilibrium, between the driving mechanisms of flow and sediment transport and the resisting forces of bed and bank stability and resistance to flow (Soar and Thorne 2001). Alluvial channels (as opposed to channels incised into bedrock) have erodible bed and banks comprised of sediments. An alluvial stream adjusts the dimensions of its channel to the wide range of flows that mobilize its boundary sediments. For many rivers and streams, a single representative discharge may be used to determine a stable channel geometry. This representative channel-forming (dominant) discharge has been given several names by different researchers, including bankfull, specified recurrence interval, and effective discharge (Copeland et al. 2000).

Miller et al. (2001), a WDFW white paper, provides an overview of the geomorphic basis for and the principles of channel design and is incorporated herein by reference. Bolton and Shellberg (2001) also provides a literature review of geomorphic controls on streams and the ecological effects of stream channelization. As a WDFW white paper, Bolton and Shellberg (2001) is incorporated herein by reference. Additional useful sources of information on channel design include Watson et al. (1999), Papanicolaou and Maxwell (2000), Copeland et al. (2001), and Bates (2003).

Placement of structures within or beneath the stream channel can have the following primary effects on the channel (Brookes 1988, in Bolton and Shellberg 2001):

- Channel shortened by straightening
- Channel cross-sectional area reduced (by placing fill, pilings, and/or abutments in the channel)
- Channel bed and/or banks replaced with non-erodible artificial materials
- Channel loses the ability to migrate over time

Each of these effects constitutes an "impact" (Figure 1), but collectively these impacts affect channels primarily by altering only one controlling factor: stream power, which is in turn determined by water surface slope, flow volume, and channel roughness (Dunne and Leopold 1978). Structures placed in the channel have the potential to alter each of the factors identified in the above list.

Because the surface of a stream is roughly parallel to its bed (Dunne and Leopold 1978), water surface slope is mainly altered by changes in channel gradient. Overwater structures normally have little capacity to alter channel gradient.

Channel roughness elements affect stream velocity by increasing boundary shear stress, thereby increasing resistance to flow (Leopold et al. 1964). Structures can increase or decrease channel roughness in a variety of ways that alter habitat, such as changes in in-channel roughness elements, changes in channel perimeter roughness elements, or changes in the relationship between channel area and wetted perimeter. All materials in contact with the wetted channel constitute roughness elements. The principal in-channel roughness elements are artificial structures such as gratings or pilings, and natural structures such as large woody debris. An example of roughness effects on channels was encountered at a highway bridge reconstruction investigated by Barks and Funkhouser (2002), using a two-dimensional flow model to estimate conditions during the 100-year flood. Barks and Funkhouser (2002) found that relocating a bridge abutment from an area of dense vegetation to an agricultural area predicted a 67 percent decrease in channel roughness and a 29 percent increase in flow velocity, with associated high risk of scour and channel destabilization. They used the same model to show that planting trees and placing riprap in the area would alleviate the predicted flow increase and move the area of maximum flow back into the stream's thalweg (the line of steepest descent along the stream). This study identified some of the principal channel border roughness elements, such as sediment, vegetation, and artificial elements like riprap and bridge abutments. The fact that the investigated abutment supported a bridge is immaterial; the structure represented by the abutment could have supported any kind of overwater structure, such as a pier.

Because flow velocity is proportional to the product of roughness and wetted perimeter (Leopold et al. 1964), changes in the length of the wetted perimeter can also alter stream power. Structures in the channel alter the wetted perimeter directly, such as when flow is confined by a pier, or indirectly, such as when erosion or deposition causes changes in channel geometry. Structures such as docks and piers tend to confine the channel within artificial bounds and thus generally cause locally reduced channel roughness, potentially causing scour at the structure, with corresponding deposition downstream. Sturm (2004), modeling scour at bridge abutments in sandy sediments, found that scour could be significant enough to alter channel geometry, producing large excavations near bridge abutments and causing reduced water depths and sediment deposition immediately upstream. Sturm (2004) also found that this effect could be exacerbated in higher flows. The fact that the investigated abutment supported a bridge is immaterial; the structure represented by the abutment could have supported any kind of overwater structure, such a as pier. This study underscores the importance of using hydraulic modeling to avoid locally significant changes in channel structure.

Channels are dynamic landscape elements that integrate inputs from tributary channels and from valley and hillslope processes (Washington Forest Practices Board 1995). Thus, a structure placed in a channel is likely, over time, to experience the effects of altered stream power and an altered sediment transport regime caused by changes in the watershed upstream. For example, in areas subject to progressive urbanization, gradual increases in catchment impervious surface cause predictable hydrologic changes characterized by increased variance in the hydrograph (Booth et al. 2002). One consequence of this change is increased peak flows and correspondingly increased sediment transport capacity, which often cause streambank instability and channel downcutting (Dunne and Leopold 1978, pp. 693-695). The resulting increases in flow and sediment around and through in-water structures can exceed the structures' design capacity, leading to outcomes such as scour around abutments and pilings (discussed above).

To summarize, the placement of artificial structures in channels can, through a variety of mechanisms, cause increased erosion at or upstream of the structure, increased deposition downstream, and increased sediment transport past the structure. This amounts to a change in channel structure and thus potentially affects habitat structural elements of the channel: channel type, substrate size distribution, channel cross section, channel migration, bed mobility, and bank structure. These potential changes, and their significance to potentially covered species, are described below.

7.7.2 Habitat Structure in Channels

Channels are defined by the transport of water and sediment confined between identifiable banks (Dietrich and Dunne 1993). Natural stream channels show great variety, reflecting differences in channel processes, disturbance regimes, structural controls, and geologic history (Washington Forest Practices Board 1995). One of the channel classification schemes most widely employed in Washington distinguishes channels primarily according to their roughness characteristics and their sediment transport regime (Montgomery and Buffington 1993, 1997). Some channel types addressed in this classification, i.e., bedrock and colluvial channels, are of little concern here because they seldom provide significant habitat for potentially covered species and because bedrock channels, in any event, are unlikely to experience appreciable process change due to placement of artificial structures. Alluvial channels, however, are channels in which bed and banks are primarily comprised of alluvium (i.e., material previously transported by the stream), and thus alluvial channels represent a linked water-sediment transport system in which a wide variety of channel types may develop. Montgomery and Buffington (1993) recognize six such channel types: cascade, step-pool, plane bed, pool-riffle, braided, and regime. They propose that these types are controlled primarily by channel gradient and also by sediment supply (the amount of material available for transport) and transport capacity (determined by shear stress, which is similar to stream power). The singular importance of LWD as a structural element is also recognized. Changes in channel gradient, sediment supply, and stream power, which can be altered by placement of instream structures, therefore have the potential to directly alter habitat conditions for potentially covered species.

The steepest channels described by Montgomery and Buffington (1993) are cascade channels. Because of their high gradient (typically steeper than 8 percent), these channels usually have high roughness caused by boulder or bedrock bedforms. They typically have high transport capacity, so little sediment is stored in the bed or banks.

The most common disturbance is debris flow. Cascade channels are predominant in small mountain tributaries in Washington, where they are often seasonal, non-fish-bearing streams. Some cascade channels, however, occur lower in the stream system, commonly where a stream transits a layer of relatively erosion-resistant rock; in such areas, they may link lower-gradient reaches having greater habitat value.

Step-pool channels commonly have a lower gradient of about 3 to 8 percent (Montgomery and Buffington 1993; Papanicolaou and Maxwell 2000). Many perennial, fish-bearing streams in hilly and mountainous parts of Washington have a step-pool morphology. Step-pool channels commonly provide the principal spawning habitat for resident salmonids, especially when lower-gradient habitats downstream are utilized by anadromous salmonids (Montgomery and Buffington 1993). Step-pool channels are highly sensitive to the amount of LWD in a stream and to the stream's sediment supply; if LWD is removed from a step-pool channel, the channel's sediment storage capacity is reduced, sediment is transported from the reach, and the channel commonly shifts to a plane bed or pool-riffle morphology (Montgomery and Buffington 1993). This is an adverse habitat change for organisms that require deep and persistent pools, for example as cover or habitat buffer during low-flow periods. Severe increases in sediment supply also tend to cause loss of pools, again by filling, but step-pool channels tend to be robust against such a change, because filling pools reduces channel roughness, in turn increasing transport capacity and allowing scour to reestablish the pools (Montgomery and Buffington 1993). However, the pool filling and subsequent scour associated with this equilibration process could be expected to have adverse impacts on stream organisms. More moderate changes in sediment supply would also be expected to alter these channels, primarily by causing a general coarsening or fining of bed material. Generally, step-pool channels have a high enough gradient and transport capacity that it should be feasible to place additional roughness elements, such as artificial structures that occupy a fraction of the channel, without substantially altering channel hydraulics and sediment transport.

At more moderate gradients (typically 1 to 3 percent), the principal channel types are pool-riffle and plane-bedded channels. These channel types are highly vulnerable with regard to hydraulic or sediment source changes, because they represent channels that have low to moderate transport capacity; thus, relatively small changes in channel morphology can cause changes in net sediment accumulation or export, with associated changes in grain size and bedform (Montgomery and Buffington 1993, pg. 50).

Normally, plane-bed channels have well-defined bed and banks with a lack of bedforms. LWD plays a critical role in pool-riffle and plane-bed channels. Adding LWD to a system will often cause a plane-bed channel to become a pool-riffle channel, while removing LWD will often cause the reverse transformation (Montgomery and Buffington 1993, pp. 41, 53). This occurs because, since these channels lack the transport capacity to move boulders, LWD provides the principal sites for both scour (which forms pools) and sediment accumulation (which forms riffles). Artificial instream structures such as abutments and pilings are often local sites for scour in these channels. In larger rivers with plane-bed channels, significant scour can occur, particularly in response to channel structures such as LWD (Sedell et al. 1986; Collins et al. 2002). This has been described, for instance, as the historical condition on the South Fork Nooksack River (Maudlin et al. 2002; Sedell and Luchessa 1982) and the Willamette River (Sedell and Froggatt 1984) and in the general case for larger western Washington rivers (Abbé and Montgomery 1996).

Plane-bed and pool-riffle channels display a characteristic sensitivity to changes in sediment supply. Increases in fine sediment supply commonly lead to embedding, a process whereby fine sediments are incorporated to the bed of the stream and remain there after they become armored by a relatively thin surficial layer of coarse sediment. Embedding gives the stream a relatively hard, impervious bed that provides a poor substrate for salmonid spawning, impairs hyporheic exchange, and provides poor habitat for benthic invertebrate infauna. Typically, several years of peak flow events are required after the fine sediment inputs have ended for the bed to be sufficiently reworked that embedding abates.

Inputs of coarse sediment initially have little effect on pool-riffle channels, but as the inputs increase, the pools are filled, the channel aggrades, and the bedform changes from pool-riffle to plane bed (Montgomery and Buffington 1993). Continuing aggradation leads to channel widening and bar development (Montgomery and

Buffington 1993). With sufficiently large increases in coarse sediment supply, the channel may develop a braided form (Montgomery and Buffington 1993).

Plane-bed and pool-riffle channels are among the most important for salmonid spawning because they have a bed mobility and scour regime to which salmon are well adapted, providing spawning habitat for large numbers of fish (Montgomery et al. 1999). These channels are also a principal habitat for freshwater molluscs, such as the potentially covered mussels, limpets, and spire snails listed in Table 1.

The lowest-gradient channels, having gradients of less than 1 percent, are regime channels (Montgomery and Buffington 1993). These channels are abundant on floodplains and in tidewater areas of Washington. Regime channels are normally transport-limited and commonly have sand or silt beds. They are highly vulnerable to changes in sediment supply, alteration of bank vegetation, and artificial changes in gradient (Montgomery and Buffington 1993). Coarse sediment tends to fill the channel because the stream lacks the transport capacity to move it through the system. Finer sediment will be exported, but slowly; in the meantime, the channel tends to become wider and shallower (Montgomery and Buffington 1993). Because the bed and banks are comprised of relatively fine sediment, the roots of vegetation are particularly important to maintaining bank integrity; the loss of vegetation can trigger bank erosion, causing sediment inputs and channel widening/shallowing (Montgomery and Buffington 1993, p 53). Thus, preserving riparian vegetation is important when overwater structures are sited in regime channels.

7.8 Littoral Drift

Wave action striking shorelines at an angle causes littoral currents that move parallel to shore (Cox et al. 1994). While littoral processes are most conspicuous in marine waters, they can occur along lake shores as well, where fetch and wind speed combine to produce waves and subsequent longshore currents strong enough to move shoreline sediments. Shoreline features, including artificial structures, affect the velocity and direction of shoreline currents and sediment transport.

Washington State contains thousands of miles of shorelines, including about 2,000 miles in Puget Sound alone. Much of this shoreline consists of poorly consolidated bluffs of glacial sediments faced with cobble beaches in the upper intertidal zone and sandy sediments in the lower intertidal and subtidal areas. Erosion and occasional landslides on these bluffs provide a sediment source. The sediment moves from location to location through littoral drift and ultimately is deposited in deep water, where it no longer contributes to littoral processes. Local geomorphology, weather, fetch, and sediment sources determine the volume, timing, and direction of sediment transported past an individual beach. Each discrete unit of shoreline with sediment sources and sinks is considered a littoral drift cell (Cox et al. 1994). The direction of drift within a drift cell may reverse between winter and summer as prevailing wind and wave direction changes, causing sand to redistribute among beach areas (Cox et al. 1994). Littoral drift is estimated to transport volumes of 1,000 to 500,000 cubic feet (30 to 14,000 cubic meters) of sediment per year past Puget Sound beaches (Canning and Shipman 1994). Beaches along the Pacific coast of Washington have much greater wave energy and can experience annual littoral drift rates of 3.5 million to 10 million cubic feet (100,000 to 300,000 cubic meters) per year (MacDonald 1994).

The construction of overwater structures or non-structural piling may affect littoral drift when they alter wave action or littoral currents.

7.8.1 Wave Action

Overwater structures and piling can affect wave direction and intensity. The effects of piers and pilings on wave action depend on spacing, orientation, and number of pilings, as well as depth and proximity to shore (Fresh 1998, in Nightingale and Simenstad 2001b; Nightingale and Simenstad 2001b). Widely spaced piles in deep water have relatively little effect, as waves refract around them (Nightingale and Simenstad 2001b). In contrast, a series of pilings can reflect waves, resulting in reduced littoral currents (Nightingale and Simenstad 2001b). Floating structures can also attenuate waves and alter the intensity of wave action that cause and maintain littoral drift (Nightingale and Simenstad 2001b). The effectiveness of a floating structure as a wave attenuator depends on the shape, dimensions, and orientation of the structure (Cox et al. 1994).

Wave energy and water transport alterations imposed by docks, ramps, abutments, pilings, and associated structures often alter the size, distribution, and abundance of substrate and detrital materials required to maintain the nearshore detrital-based food web (Nightingale and Simenstad 2001b). 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 and Battelle 1996, Penttila 2000b, Thom et al. 1994, 1997, all in Nightingale and Simenstad 2001b; Thom and Shreffler 1996). For example, experimental investigations by Shteinman and Kamenir (1999, in Nightingale and Simenstad 2001b) demonstrate how the construction of jetties and other in-water structures can partially or completely disrupt the longshore transport process. In a natural hydraulic regime, size separation of sediments proceeds along the bottom slope with wave flow impact, and steep-sloped bottoms move larger sediments toward the shore, accumulating a thin nearshore strip along the shoreline. While smaller sediments were found to move toward deeper areas, where they accumulate or were further transported by currents, the opposite was found to occur on gentle bottom slopes, where smaller sediments accumulated near the shore and coarser sediments were moved toward the deeper areas (Shteinman and Kamenir 1999, in Nightingale and Simenstad 2001b).

Such changes in wave energy across substrates determine the size and distribution of sediments and associated detritus (Nightingale and Simenstad 2001b). Throughout Puget Sound, Hood Canal, and Washington's coastal estuaries, variations in the interface between bottom slopes, wave energy, and sediments build beaches, nearshore substrates, and habitats unique to the climate, currents, and conditions of specific sites (Nightingale and Simenstad 2001b). Although specific characteristics of the factors at play vary with the geology of each region or subsystem, changing the type and distribution of sediment will generally alter key plant and animal assemblages (Nightingale and Simenstad 2001b).

Wave and current interactions in shallow water (depths less than 3 feet) are particularly important to intertidal flora and fauna. For example, along the shallow edge of the tidal water, high suspended sediment concentrations may flow over a mudflat. This passage across the intertidal area potentially deposits large quantities of sediment and nutrients on upper mudflat areas, particularly at slack water (Christie and Dyner 1998, in Nightingale and Simenstad 2001b). These are part of the sedimentation and water transport processes that shape the geomorphology and consequently the plant and animal communities that rely on the shallow, soft sediment habitats of mud and sandflats (Nightingale and Simenstad 2001b).

Depending on the geomorphology, current transport processes, and climatic conditions of a specific area, overwater structures have the potential to alter these important habitat-building processes (Nightingale and Simenstad 2001b).

7.8.2 Littoral Currents

In-water structures such as piers and pilings have the potential to block or divert littoral currents. Alteration of littoral currents can cause sediment deposition and reduce beach nourishment down-current from the structure (Thom et al. 1994). Changes in beach nourishment and sediment deposition can in turn alter benthic and epibenthic communities, as well as bank erosion rates (Thom et al. 1994). The significance of these effects depends on the location and orientation of the structures (Thom et al. 1994). Closely spaced pilings can collect sediment along the up-current side (Nightingale and Simenstad 2001b), but widely spaced pilings allow currents to flow freely and sediment transport is essentially unaffected (Nightingale and Simenstad 2001b). WDFW noted that miles of historical habitat have been permanently lost due to the placement of structures and fill, with commensurate permanent loss of riparian vegetation and large organic debris, as well as extensive intertidal habitat degradation from increased wave and current turbulence waterward of such structures (Canning and Shipman 1994).

Benthic habitat may be impacted by alterations in natural sediment movement. For instance, a structure that interferes with littoral drift cells poses the risk of interference with the deposition of fine sediments to adjacent beaches that support beach spawning forage fish, such as surf smelt and sand lance (Nightingale and Simenstad 2001b). Limiting the fine sediments deposited to adjacent beaches also poses the risk of limiting the establishment of rooted vegetation, such as eelgrass, along submerged areas of adjacent shorelines and therefore the risk of reducing the available habitat for fish and shellfish species that rely on such vegetated habitats for spawning and rearing (Nightingale and Simenstad 2001b). The manner in which a structure is used by vessels will determine additional effects of wave energy from vessel traffic and other effects such as vessel pollutant distribution or impacts to other adjacent shoreline structures (Nightingale and Simenstad 2001b).

Alterations to littoral drift can also affect the beach profile (Thom et al. 1994). Changes in littoral drift that reduce sediment supply can make beach slopes steeper and increase erosional processes, especially in shorelines hardened by development resulting in a coarsening of the beach substrate, which can substantially interfere with the quality and quantity of intertidal forage fish spawning habitats (Thom et al. 1994).

7.9 Substrate Modifications

Modifications of substrate caused by channel hydraulic processes are discussed in Section 7.7, and modifications caused by the analogous shoreline process, littoral drift, are discussed in Section 7.8. These include most substrate modifications observed in association with construction and operation of overwater structures in stream channels and along shorelines. However, there are also substrate modifications that occur in conjunction with overwater structures (such as docks along many lakeshores or along rocky seacoasts) in waters where sediment transport is not a significant habitat-forming process. In such settings, the structure itself constitutes the substrate modification.

In the nearshore environment, dock pilings have been found to alter adjacent substrates with increased shellhash deposition from piling communities and changes to substrate bathymetry (Penttila 1990, Shreffler and Moursund 1999, both in Nightingale and Simenstad 2001b). The change in substrate type can also alter the nature of the flora and fauna native to a given site, and native dominant communities typically associated with sand, gravel, mud, and seagrass substrates are replaced by those communities associated with shellhash substrates (Nightingale and Simenstad 2001b).

WAC 220-110-300(1) does allow for the grounding of up to 20 percent of floats or rafts in marine waters that do not provide spawning for surf smelt, Pacific herring, Pacific sand lance or rock sole. Grounding of these structures can affect substrates and the aquatic organisms occupying the substrates found beneath these structures by directly resting and grinding upon (during tidal fluctuations and wave action) the substrate and the organisms that occupy the substrate. Grounding of floats can also occur in freshwater systems that are managed, such as reservoirs, and have similar impacts, although the draw down of the water is not a natural occurrence and typically is of a longer duration (i.e. seasonal fluctuations).

7.10 Channel Dewatering

Channel dewatering occurs primarily in freshwater settings and is typically associated with the need to work "in the dry" during construction of overwater structures, such as when fabricating and pouring concrete supports. Basic requirements for channel dewatering are provided in WAC 220-110-120. Review of numerous biological opinions prepared by NMFS indicates that channel dewatering typically requires the installation of a cofferdam and a bypass system to divert flowing water around the construction site and allow work to occur in the dry.

The impacts associated with channel dewatering include:

- Fish removal and exclusion
- Fish entrainment in dewatering pump
- Alteration of flow
- Disturbance of the streambed
- Loss of invertebrates and undetected fish
- Elevated turbidity when the construction area is rewatered

Each of these impacts is discussed below.

7.10.1 Fish Removal and Exclusion

Fish removal and exclusion is performed using passive methods, such as the volitional movement of fish from the construction area during its slow dewatering, or through active methods, such as the use of hand nets, beach seining, or electrofishing equipment to capture and move fish from the construction area that will be dewatered (NMFS 2003b). Potentially covered invertebrate species are typically not removed, and potentially covered invertebrate species present within the area to be dewatered may be subject to injury or mortality, depending on the duration of dewatering and the nature of the work that will be performed in the dewatered area.

Passive capture of fish typically involves installing an upstream block net (when a flowing water is dewatered) and a cofferdam (in flowing or lentic waters) and slowly dewatering the construction area. It has been suggested that reductions in streamflow of 80 percent result in the greatest number of fish volitionally moving out of the dewatered construction area (NMFS 2006a). This type of passive fish removal eliminates the need to capture and handle some fish.

More active methods of fish removal include the use of a beach seine to "herd" fish beyond the construction area, where dewatering will not occur. In streams, a block net is installed at the downstream-most point to exclude fish from moving back upstream and entering the construction and dewatering areas. Once the block nets are in place, several passes of the construction area may be made with the nets or beach seine to capture any fish that may remain within the construction area. Once fish are no longer being captured with the beach seine, a portable electrofishing unit can be employed to ensure that as many fish as possible have been removed from the construction area being dewatered (NMFS 2003b).

Captured fish are typically released downstream or outside of the construction area. Depending on the number of fish captured, the size of the stream, and whether flowing or lentic waters are dewatered, fish may be released at multiple sites to minimize overcrowding of available habitat (NMFS 2003b).

Beach seining can affect fish in several ways, including stress, scale loss, physical damage, suffocation, and desiccation. The amount of unintentional injury and mortality attributed to seining can vary widely depending on the seine used, the ambient conditions, and the expertise of the field crew (NMFS 2003b). Professional experience has shown that beach seining in areas of dense aquatic vegetation can also result in significant mortality of seined fish that become trapped in a mass of vegetation. However, adverse effects are often less for seining compared to electrofishing, and first using a seine to remove fish will minimize the adverse effects of electrofishing (NMFS 2003b).

Electrofishing can kill both juvenile and adult fish if improperly conducted. Mortality can be immediate as a result of trauma or delayed as a result of disease or fungal attack. Researchers have also found that sublethal effects, such as spinal injury, occur (NMFS 2003b; Snyder 2003). Although fish may receive spinal injuries as a result of electrofishing, research indicates that few die of these injuries. However, severely injured fish grow at slower rates and sometimes show no measurable growth (NMFS 2006a).

7.10.2 Fish Entrainment

Dewatering a portion of a stream channel requires a flow bypass system and may rely on either gravity or a pump to convey the flow around the dewatered portion of the channel. This type of activity has the potential to entrain fish within the bypass system.

If pumps are used to bypass water around a work site, or to complete dewatering within a cofferdam, the hose or pipe pulling water from the channel is typically fitted with a mesh screen to prevent entrainment of aquatic life into the intake hose/pipe of the pump (WSDOT 2006b). Such measures are required for all pumped diversions (WAC 220-110-190). Screens should be placed approximately 2 to 4 feet from the end of the intake hose to reduce velocity at the screen as a measure to ensure that fish are not impinged upon the screen (WSDOT 2006b).

7.10.3 Alteration of Flow

Dewatering can temporarily alter the flow regime in the affected stream. Flow must be diverted around the construction area and discharged downstream. Generally, cofferdams are installed upstream and downstream of the construction area to assist with dewatering. This approach allows the work area to be completely dewatered so the work can be performed in the dry. The alteration of flow associated with dewatering a work area depends on the size of the area dewatered, but generally is only temporary.

In general, flow alteration associated with channel dewatering is of relatively short duration and affects a relatively small area. The hydraulic effects of overwater structures on stream channels are discussed in more detail in Section 7.7.

7.10.4 Disturbance of the Streambed

Disturbance of the streambed associated with channel dewatering can be extensive, depending on the purpose of the dewatering. If an overwater structure is being installed where one did not previously exist, a permanent loss of streambed and associated habitat components (e.g., riparian habitat, floodplain, and substrate) occurs, such as when a new dock or pier is constructed. The effects of such substrate disturbance are discussed in greater detail in Section 7.7.

7.10.5 Loss of Invertebrates

Channel dewatering may lead to loss of potentially covered invertebrate species within the portion of the channel being dewatered. Although no studies were located that specifically examined the impacts of construction related dewatering, several studies have looked at the influence of dam operations on freshwater mussel habitats, which provide insight to the potential impacts from construction dewatering (summarized in Watters 1999). Depending on the use of the dam, water levels may fluctuate at regular intervals (for hydroelectric purposes) or random intervals (for flood control). In some areas, water levels may become shallow enough that thermal buffering is lost, allowing extreme temperatures to occur (Watters 1999). Blinn et al. (1995, in Watters 1999) reported that substrate subjected to 2- to 12-hour exposures to air required more than four months for mussels to regain a biomass similar to that in unexposed habitat. Federally endangered mussel species were reported by Neck and Howells (1994, in Watters 1999) as casualties of scheduled dewatering processes, and Riggs and Webb (1956) reported that several thousand mussels died in the tailwaters of Lake Texoma, an impoundment of the Red River formed by Denison Dam, when water levels dropped, in turn allowing water temperatures to become excessively warm (exceeding 79 degrees F [26 degrees C]). This area was exposed for at least 20 days before being inundated again.

Exposure to cold air may be equally lethal (Watters 1999). Nagel (1987, in Watters 1999) believed mussels were more sensitive to cold water during frosts than to warm water during temporary droughts. Blinn et al. (1995) showed that a single overnight exposure to subzero temperatures resulted in at least a 90 percent loss of invertebrate biomass, and Valovirta (1990) reported that mussels were killed when water froze to the river bottom.

Benthic macroinvertebrates provide food for fish, and different species tend to be associated with different substrates. Chironomids of various species do well in silts and sands, but the larger ephemeropterans, trichopterans, and plecopterans prefer a mixture of coarse sands and gravels (Meehan 1991). The temporal and spatial impact of channel dewatering on macroinvertebrates depends on the amount of channel dewatered and the type of disturbance (temporary or permanent) to the channel.

Disturbance of the streambed from activities that generally result from channel dewatering also equates to direct disturbance of benthic macroinvertebrates. Loss of macroinvertebrates can result from excavation, installation of structures, and placement of fill material. Channel dewatering typically results in a localized loss of benthic macroinvertebrate abundance due to channel modifications.

Benthic macroinvertebrates are consumed by salmonids and other potentially covered species and may represent a substantial portion of their diet at various times of the year. The effect of macroinvertebrate loss on salmonids is generally temporary, unless construction has caused permanent loss of habitat (i.e., installation of a new structure). Once the dewatered area is rewatered, benthic macroinvertebrates from outside of the area affected by dewatering, and those which sought refuge in the hyporheic zone, will begin to recolonize the area. When the disturbance is temporary, a rapid recolonization of the disturbed area is anticipated. Reported rates of recolonization range from about one month to 45 days (NMFS 2003b), although some less motile species and species with long life cycles (e.g., freshwater mussels) would take longer to recolonize. NMFS (2003b) did not indicate the duration or area of the dewatering that corresponds to the one-month to 45-day time frame for recolonization.

7.10.6 Elevated Turbidity During Rewatering

To dewater a channel, a bypass system is needed to convey stream flow around the construction area. A typical bypass system consists of a pipe of adequate size to convey flows or a temporary channel built adjacent and parallel to the existing channel. The type of bypass system is determined by the size of the stream and other hydraulic or environmental factors.

Increased turbidity can result from the installation, operation, or removal of a stream bypass system. Installation of a stream bypass typically requires in-water work, which can disturb substrates and bank material and cause an increase in turbidity levels. Operation of a stream bypass generally will not result in disturbance to the streambed or cause an elevation in turbidity levels, unless the discharge of the pipe results in scouring of substrate material or erosion of streambanks. Removal of the stream bypass requires in-water work and will result in some disturbance to the streambed and banks as the cofferdam is removed and flow is returned to the channel. Generally, the downstream cofferdam is removed first to allow backwatering of a portion of the channel that was dewatered. Then the upstream cofferdam is removed, and flow is slowly returned to the channel to minimize resuspension of fine sediments and increases in turbidity.

7.11 Artificial Light

Artificial lighting may be used during the construction of overwater structures, and some kinds of structures also require nighttime lighting for security or operations. Nighttime artificial lighting has been shown to change fish species assemblages by:

- Attracting fish to lighted areas (Prinslow et al. 1979, in Nightingale and Simenstad 2001b; Simenstad et al. 1999; Nightingale and Simenstad 2001b)
- Delaying salmonid migrations (McDonald 1960, in Tabor et al. 1998; Prinslow et al. 1979, in Nightingale and Simenstad 2001b; Tabor et al. 1998)
- Increasing the risk of predation (Tabor et al. 1998; Kahler et al. 2000)
- Altering predator avoidance and detection (Tabor et al. 1998)
- Increasing prey capture success for some species of fish (Prinslow et al. 1979, in Nightingale and Simenstad 2001b; Nightingale and Simenstad 2001b)

Impacts to fish from artificial lighting are often the result of changes in nighttime behaviors such as migration, activity, and location (Nightingale and Simenstad 2001b) and potentially in schooling behavior in juvenile salmonids (Ali 1959, 1962, in Simenstad et al. 1999). Therefore, behavioral differences between species at differing life stages, life histories, and behaviors specific to the local environment must be considered when evaluating potential impacts from artificial light. For instance, different species of salmonids have different nighttime behaviors. Species that occupy and defend stream territories, such as coho salmon and steelhead trout, tend to be quiescent at night (Simenstad et al. 1999), while species that disperse to lakes and estuaries as juveniles, such as sockeye, Chinook, pink, and chum salmon, typically school and show nocturnal activity (Godin 1982, Hoar 1951, both in Nightingale and Simenstad 2001b). Behavioral differences in salmonid responses to artificial lighting have been observed by several authors. Ocean-type juvenile salmon, such as chum and summer and fall run Chinook, are attracted to lights at night (Simenstad et al. 1999). Pucket and Anderson (1988, in Simenstad et al. 1999) and Nemeth (1989, in Simenstad et al. 1999) found that different species of salmon react differently to strobe lights; Mork and Gulbrandsen (1994, in Simenstad et al. 1999) found differing activity levels in reaction to lights at surface and bottom depths in different species of salmon, trout, and char. Fields (1966, in Simenstad et al. 1999) found that spring migrant juvenile salmon were more repulsed by bright lights than were later migrants. Behavior patterns of different salmon species related to different light intensities and other details of artificial light impacts to juvenile salmonids are reviewed by Simenstad et al. (1999).

Impacts to fish also depend on the fish's ability to adapt to dark or lighted conditions and the intensity and type of light. Ali (1959, in Simenstad et al. 1999) found that the eyes of sockeye fry and smolts and coho smolts adapt to light more slowly than do the eyes of coho, Chinook, and pink fry. Other studies by Ali (1959, 1962, in Simenstad et al. 1999) reveal the threshold light intensities for different behaviors of juvenile salmon. For a description of fish vision, refer to the discussion of shading in Section 7.1. For a detailed discussion of salmonid vision and light adaptation, see Simenstad et al. (1999).

Impacts on predator-prey relationships resulting from artificial lighting include increased risk of predation (Tabor et al. 1998; Tabor, pers. comm. and Warner, pers. comm., both in Kahler et al. 2000), increased predator avoidance and detection (Tabor et al. 1998), and increased prey capture success (Prinslow et al. 1979, in Nightingale and Simenstad 2001b; Nightingale and Simenstad 2001b).

The few studies that have examined predation rates on juvenile salmonids under varying light intensities have generally shown that within the natural range of light intensities (e.g., overcast skies, moonless nights, clear nights, moonlit nights), predation increases with increasing light (Patten 1971, Ginetz and Larkin 1976, Mace 1983, all in Tabor et al. 1998); however, this occurrence cannot be extrapolated to determine impacts of artificial night lighting and for all species and life stages of fish. Ali (1959, in Simenstad et al. 1999) found that the maximum prey capture success for coho fry and sockeye and coho smolts was at light intensities equivalent to levels found at dawn or dusk, whereas maximum prey capture success for sockeye and pink fry was found to be equivalent to a cloudy day. Tabor et al. (1998) showed that under freshwater laboratory conditions, sculpin capture success of sockeye fry decreased with increased light. The authors also found that sculpin can capture sockeye fry even in complete darkness. Although sculpin success at capturing sockeye decreased with increasing light in a circular tank, the increased light slowed emigration of sockeye fry in a simulated stream, and predation increased under the lighted conditions due to the slower migration rate. The light may have also caused the fry to migrate in areas of lower water velocity and closer to the bottom, leaving them more susceptible to predation by sculpin (Tabor et al. 1998).

Predation rates may also increase due to predator congregations in lighted areas. Prinslow et al. (1979, in Nightingale and Simenstad 2001b) observed chum congregating at night below security lights in Hood Canal and suggested that lighting may provide increased feeding opportunities for chum at night. Prinslow et al. (1979, in Nightingale and Simenstad 2001b) also observed that dogfish (an important predator of herring and an occasional predator of juvenile and adult salmonids) were attracted to the security lights. Grebes, blue herons, and other birds have been observed feeding at night on the Cedar River delta in an area lit by Boeing Company facilities (Warner, pers. comm., in Kahler et al. 2000), and Tabor (pers. comm., in Kahler et al. 2000) observed grebes foraging under lights at night on Lake Washington. Finally, Kahler et al. (2000) suggests that lighting attached to piers in Lake Washington where bass congregate may benefit bass by extending the duration of predation because it allows the visual predators to forage at night.

7.12 Vessel Activities

Vessel activities associated with the installation and operation of in-water and overwater structures may adversely impact potentially covered species. Projects involving the use of large vessels such as ferries, cargo ships, or cruise ships would likely present complex potential risks to potentially covered species and are more difficult to address under a programmatic analysis. However, vessels used during construction and commercial and recreational boats have more predictable impacts. Impact mechanisms include:

- Physical disturbance of sediment, organisms (Haas et al. 2002), and submerged vegetation through grounding or water turbulence caused by propeller wash, potentially resuspending sediment, physically dislodging vegetation and organisms, or damaging vegetation
- Noise from vessel activity
- Propeller-wash entrained air bubbles that combine with turbidity increases from disturbed sediment, leading to a temporary reduction in the availability of light

Each of these impact mechanisms is discussed below.

7.12.1 Sediment Disturbance

Vessel traffic can disturb and suspend sediment in the water column as a result of water currents moving under and around the vessel, pressure fluctuations as the vessel displaces water during movement, propeller wash, and waves generated by the bow and stern of a vessel that wash up on the bank (McAnally et al. 2004). Vessel traffic has been correlated with an increase in turbidity of up to 50 percent in shallow waters (average depth 10 feet [2.9 m]) (Anthony and Downing 2003). Correlations of vessel traffic with turbidity patterns and sediment particle settling velocities suggest that vessel traffic may increase turbidity levels on a daily as well as seasonal temporal scale (Garrad and Hey 1988). Recreational vessel traffic has been observed to induce levee erosion at rates of 0.0004 to 0.009 inch (0.01 to 0.22 mm) per boat pass (Bauer et al. 2002). Water depth appears to have less influence on vessel-induced turbidity than does vessel speed (Hill and Beachler 2002). Field measurements have shown that at very low speeds and very high speeds, planing hull vessels have little effect on turbidity, even in shallow water, but at transitional speeds, significant sediment resuspension can occur, even in relatively deep water (Hill and Beachler 2002).

7.12.2 Eelgrass and Macroalgae Disturbance

Simenstad et al. (1999) describes the potential effects of propeller wash on eelgrass. Flume studies have shown that current velocities of 20 to 31 inches per second (50 to 80 centimeters per second [cm/sec]) may be sufficient to cause sediment disturbance around eelgrass and that velocities of 71 inches per second (180 cm/sec) can cause severe erosion of eelgrass patch edges. However, eelgrass patches in Puget Sound thrive in currents of up to 79 inches per second (200 cm/sec) (Thom et al. 1996, in Nightingale and Simenstad 2001b). The effect of vessels used during installation of overwater structures on eelgrass and macroalgae depends on local current and sediment conditions, as well as on maximum current velocity at the sediment surface. In addition to the direct effects of propeller wash on submerged vegetation, propeller wash can entrain bubbles and suspend sediment, causing reduced light availability that can indirectly affect eelgrass and, to a lesser extent, macroalgae (Simenstad et al. 1999).

Thom et al. (1996), in studying the impacts of passenger-only ferries at the Vashon Island terminal, found that at 187 feet (57 meters) from the boat, it is likely that the propeller wash has little effect on existing eelgrass. Thom et al. (1996) also concluded that currents with a velocity above 2.46 feet/second (0.75 meters/second) damaged eelgrass by eroding away overlying sediment and that currents above 3.61 feet/second (1.1 meters/second) caused extensive damage to eelgrass rhizomes. The vertical and horizontal distance at which current velocity may affect eelgrass depends on the size and shape of the propeller. The U.S. Army Corps of Engineers' Regional General Permit No. 6 prohibits the construction or installation of floats or float support pilings within a 4-foot depth elevation between the top of the float stopper and the elevation of the landward-most edge of a macroalgae bed or eelgrass (USACE 2005). This restriction applies to a zone 25 feet wide on both sides of the float projecting waterward horizontally from the float (USACE 2005).

Studies in Florida related to the impacts of boating activity on seagrass indicate that the largest concentration of scarring occurs in waters less than 6.5 feet (2 meters) deep (Sargent et al. 1995, in Dawes et al. 2004). In Florida, many shallow flats and mud banks are severely eroded due to constant scarring, ship groundings, chronic wave action from boats, and water-current scouring (Kruer 1994, in Dawes et al. 2004). Removal of seagrass roots and rhizomes due to prop scarring also destabilizes sediments and resuspension occurs, thereby lowering water transparency and retarding seagrass regrowth into the scar (Durako et al. 1992, in Dawes et al. 2004).

Studies in Florida have also found that fragmentation of seagrass beds caused by propeller scarring did not appear to have any consistent effects on some animal populations over a one-year period, as long as the seagrass patch sizes were greater than 3 square feet (1 square meter) (Bell et al. 2002, in Dawes et al. 2004). The numbers of pinfish (*L. rhomboides*), pipefish (*Syngnathus scovelli*), and eight species of epibenthic shrimp were similar in moderately scarred (6 percent to 31 percent loss of the beds) and non-scarred seagrass beds in Tampa Bay (Dawes et al. 2004). The results of these studies suggest that propeller scars that fragment seagrass beds may enhance certain faunal development caused by edge effects along the cuts, as long as they are not too severe (Dawes et al. 2004). Nevertheless, a recent study of scarring in a *T. testudinum* bed in Puerto Rico revealed a negative effect of scarring on crabs and molluscs up to 16 feet (5 m) from the scar. Also, shrimp species within the scar differed from those in the non-scarred seagrasses. Fish populations did not show an effect from the scarring (Dawes et al. 2004). Further studies are clearly needed to define the effects of moderate scarring compared to those of severe scarring on seagrass productivity (Dawes et al. 2004).

7.12.3 Freshwater Aquatic Vegetation Disturbance

Lagler et al. (1950, in Carrasquero 2001) reported that studies of the effects of outboard motor use have shown that outboard motor propellers clear a swath through aquatic vegetation when within 1 foot (30 centimeters [cm]) of the vegetation. When the installation, use, or maintenance of overwater structures will entail the use of outboard motors in shallow water, some loss of aquatic vegetation could occur.

7.12.4 Noise

The construction or expansion of docks, moorings, and piers can cause increased recreational and commercial boating traffic at the facility and in the general area. Motors, sonars, and depth sounders used on commercial vessels and recreational boats can produce high levels of continuous underwater noise (Scholik and Yan 2001a). Large tankers and naval engines produce up to 198 dB, depth sounders can produce up to 180 dB (Heathershaw et al. 2001, in WSDOT 2006a), and commercial sonar operates in a range of 150 to 215 dB (neither peak nor RMS identified) (Stocker 2002, in WSDOT 2006a). Even small boats with large outboard motors can produce sound pressure levels in excess of 175 dB (neither peak nor RMS identified) (Heathershaw et al. 2001, in WSDOT 2006a). Therefore, fish may experience high levels of underwater sound when boats are present. The impacts to fish from boat traffic noise depend on a variety of factors, including the level of sound generated, the fish species and life stage present, the sound received by fish, and the exposure time. The literature regarding boat motor noise (discussed below) suggests that impacts are most likely to result in behavioral disturbance or sublethal injury.

Scholik and Yan (2001b) exposed a hearing specialist (the fathead minnow) to 2 hours of boat engine noise at 142 dB, which resulted in temporary hearing loss to the fish. Schwarz and Greer (1984, in Scholik and Yan 2001a) examined the reactions of Pacific herring to boat noise and found that abrupt changes in the sound characteristics associated with changes in vessel speed elicited an alarm response. An alarm response to boat noise has also been observed in herring and rockfish (Blaxter et al. 1981, in Scholik and Yan 2001a; Pearson et al. 1992), and Boussard (1981, in Scholik and Yan 2001a) produced an alarm response in two cyprinid species (a roach, *Rutilus rutilus*, and a rudd, *Scardinius erythrophthalmus*) when he exposed them to noise from a 260-horsepower speedboat.

7.12.5 Artificial Light

Although it is reasonable to expect that the construction and operation of overwater structures have potential to add artificial light to the aquatic environment, no literature on the potential impacts of artificial light related to vessel activity was identified.

8 CUMULATIVE IMPACTS OF OVERWATER STRUCTURES AND NON-STRUCTURAL PILING

This section draws on available literature and the authors' professional experience concerning the possible cumulative impacts of the construction and operation of overwater structures and non-structural piling over time or at multiple sites in a limited area.

Only one study (Nightingale and Simenstad 2001b) specifically discusses the cumulative impacts of overwater structure construction. Because this study focused on overwater structures in Washington, its findings are particularly relevant. The authors note that "The bathymetry of Washington's inland waters, that of 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 because of the concentrated zone of potential impact" (Nightingale and Simenstad 2001b). This finding is directly relevant to an ESA analysis, because it identifies the area where cumulative impacts will have a concentrated expression on a limited habitat. The authors then discuss cumulative effects on "rural and natural" as opposed to "urban industrialized" shorelines. For rural shorelines, the authors find that:

> The habitat value of an environment that directly supports the recruitment of fish and shellfish stocks is magnified by its overall importance in stock recruitment. Its value is intrinsic to its location but its loss to stocks and the larger ecosystem reaches beyond its specific location. In short, protection of habitats critical to important survival and recruitment needs of fish and shellfish magnify the importance of controlling any adverse effects to them. Economically, it is far less expensive and more productive to protect existing critically important habitat than to restore lost or degraded habitats. The factors controlling habitat characteristics and the biologic assemblages that have evolved are endemic to the geologic and biologic history specific to a geographic location and region. Perhaps more significantly, the linkages among these ecosystem components are not fully understood (Nightingale and Simenstad 2001b).

This finding is relevant to an ESA analysis because it identifies how cumulative impacts potentially impair habitat essential to reproduction and thus directly affect a species' capacity to sustain and increase its numbers. Such impacts, if sufficiently severe, may jeopardize a species' continued existence.

With regard to cumulative impacts along urban industrialized shorelines, Nightingale and Simenstad (2001b) identify three principal concerns:

- Reduced access to prey resources, compelling juvenile salmon to outmigrate farther and faster than they otherwise would, reducing their metabolic energy resources and potentially exposing them to other risks, such as predation. Although this finding is not directly transferable to other potentially covered species, it is plausible that they too would have to travel farther to access suitable habitat and would also suffer reduced metabolic energy resources and increased exposure to other stressors.
- Reduced autochthonous productivity due to limited light availability, an impact that could be reduced by incorporating design features to reduce shading by overwater structures.
- Landscape-scale effects (such as fragmentation) that could be minimized by landscape-scale habitat treatments, enhancing habitat in refuge areas such as beaches.

One cause of cumulative impacts that is generally not addressed in the literature but that applies to all overwater structures and non-structural piling regardless of impact mechanism is accidents. Accidental chemical spills, accidental concrete spills, accidental erosion of material stockpiles, and various other kinds of accidents that occur during use of structures constructed under the HPA authority all constitute impacts that likely would not have occurred but for the issuance of an HPA. Such accidents can be predicted only in a statistical sense, and WDFW would likely not have legal liability for these accidents, but the impacts could still occur and therefore could affect populations of potentially covered species. This impact would be considered by the federal agencies in their decision to issue an Incidental Take Permit.

8.1 Shading

The studies reviewed do not identify cumulative impacts of shading that differ from the direct and indirect impacts of single-structure shading, i.e., decreased primary productivity, loss of eelgrass beds with impacts to the associated food chain processes, and changes in the migration patterns of salmonids. There are data to suggest that the cumulative loss of habitat resulting from the shading of multiple structures can affect fish abundance and species richness within a region (Carrasquero 2001; Kalher et al. 2000; Fayram 1996; Williams and Thom 2001).

The cumulative impacts of even narrow residential piers can be detrimental in a freshwater environment (Carrasquero 2001). It has been suggested that the cumulative impact of an increase in the number of docks around the Lake Washington shoreline, where approximately 4 percent of shallow-water habitats are covered by overwater structures (Kalher et al. 2000), might have caused the observed decrease in freshwater survival of juvenile sockeye salmon over time (Fayram 1996). Although individual shoreline structures may not impose significant impacts on salmon species, populations, or stocks, the cumulative impacts of dense, contiguous shoreline modifications are likely contributors to the present decline of several Puget Sound salmon species and may inhibit the success of recovery actions (Williams and Thom 2001).

The shading of eelgrass beds that serve as important nursery habitat for many species can also greatly affect numbers of marine biota within a region, including salmonids, crab, herring, and important epibenthic crustaceans. Given the strong association of important fish prey resources with eelgrass, the shading out of eelgrass by numerous overwater structures poses a potential risk of reduced prey resources for fish, affecting fish populations.

8.2 Littoral Vegetation

Installation of overwater structures in the nearshore has the potential to cause local losses of littoral vegetation. It logically follows that the cumulative impact of structures that shade littoral vegetation or otherwise inhibit growth would be a reduction in littoral vegetation cover, as can be seen in the case of eelgrass at individual piers (Nightingale and Simenstad 2001b). Large-scale eelgrass monitoring in the inland waters of Washington State (2001 through 2005) indicates that an equal number of sites appear to have increasing or decreasing eelgrass coverage (Dowty et al. 2005). However, because eelgrass coverage is affected by many variables in addition to the cumulative impacts of development, the results observed by Dowty et al. (2005) do not indicate a clear cause and effect of overwater structures or other development on overall patterns of eelgrass coverage. The real implications of cumulative changes in eelgrass distribution and cover are unclear, because it is not known how dependent many potentially covered species are on eelgrass. For instance, herring spawn on eelgrass, but there are extensive areas of eelgrass where no herring spawn, so changes in eelgrass cover alone would be a poor predictor of future herring spawning success. Similarly, young salmon forage extensively in eelgrass, but foraging habitat may not be a limiting factor for juvenile salmon in Puget Sound (Haas et al. 2002). Much human impact on eelgrass and macroalgae takes the form of habitat fragmentation, but although such fragmentation is in principle an adverse impact, it remains unclear just how that impact is delivered to affected species (Haas et al. 2002). Thus, our understanding of cumulative impacts on eelgrass and macroalgae is limited by major data gaps.

8.3 Freshwater Aquatic Vegetation

Individual overwater structures can reduce the overall coverage and density of freshwater aquatic plants in lakes and ponds with developed shorelines (Radomski and Goeman 2001). This could be significant to the ecological functions of aquatic systems where human development occurs. For example, Radomski and Goeman (2001) found that because of reduced aquatic vegetation, the most highly developed lakes are lacking in physical habitat structure compared to less developed lakes, which was reflected in a correlation between the occurrence of floating leaved and emergent plants and (warm-water) fish biomass.

8.4 Riparian and Shoreline Vegetation

Although there have been numerous evaluations on the effects of large-scale removal of riparian habitat to aquatic habitats, few studies reviewed for this white paper specifically addressed cumulative impacts from the localized removal of riparian and shoreline vegetation (as could occur during installation of overwater structures). It is expected that permitting multiple activities within a watershed can have cumulative impacts on riparian/shoreline vegetation, including increased likelihood that the impacts will be measurable and thus more likely to have an adverse impact on aquatic species and habitat. Additionally, cumulative impacts are likely to be more significant in smaller watersheds. The threshold at which a group of activities will have an adverse impact on aquatic species and habitat at the watershed scale cannot be quantified, because each watershed has unique characteristics, such as riparian/shoreline vegetation and the contribution such habitat makes to the quality of specific aquatic habitat.

8.5 Noise

Cumulative noise impacts may result from the accumulation of exposure energy that fish receive from multiple pile drives (Popper et al. 2006), increased numbers of boats or boating use (Scholik and Yan 2001a), and increased use of construction equipment. In speaking of cumulative noise impacts to marine mammals, Dr. Sylvia Earle, former chief scientist at NOAA, has stated that "each sound by itself is probably not a matter of much concern," but taken together, "the high level of [ocean] noise is bound to have a hard, sweeping impact on life in the sea" (Holing 1994, in Radle 2005). However, the cumulative impacts of noise on fish physiology and behavior are unknown at this time.

8.6 Water Quality

Although natural turbidity-causing mechanisms may vary greatly in magnitude and duration, they are more likely to occur in an isolated fashion and affect different portions of the stream network at different times (Bash et al. 2001). This variation allows fish to use refuge areas that might otherwise be impacted by these events (Bash et al. 2001).

Professional experience has shown that anthropogenic sediment disturbance is often different; such events are more likely to occur simultaneously in many scattered areas or in overlapping time frames across a watershed, causing secondary impacts and lingering effects with greater potential to affect larger portions of a stream network at any given time. In addition, anthropogenic disturbances may more frequently result in temporary barriers to fish movement, which could reduce the existence of or limit accessibility to refugia (Bash et al. 2001).

Turbidity impacts may not be the only source of stress to aquatic life in a system (Bash et al. 2001). The potential of an activity to increase turbidity should be evaluated in the context of other environmental conditions present in the system, such as velocity, water depth or water temperature (Bash et al. 2001). It is also important to note that much of the research on turbidity impacts on salmonids has occurred in controlled laboratory settings and that extrapolation to complex natural systems may require consideration of other factors such as predator and prey abundances (Bash et al. 2001).

Much of the research has focused on smaller projects and little is known about the potential impacts of large projects (>100 pilings) involving the use of treated wood piles in aquatic settings (Poston 2001). It is conceivable that many smaller projects using ACZA- and CCA Type C-treated wood products, if close enough to one another both spatially (with respect to leachate dilution rates) and temporally (in terms of diminishing rates of leaching), could produce effects similar to those of larger projects (Poston 2001).

It is well known that PAHs and metals are significant components of urban stormwater. The risks of PAH and metals contamination from treated wood products should be considered in the context of background PAH and metals concentrations in the surrounding water and sediments, as well as in the context of potential PAH loads from other point and nonpoint sources, such as industrial outfalls and stormwater runoff (Menzie et al. 2002). This may be a difficult undertaking, given that little data are available on the background PAH and metals concentrations in most water bodies and their sediments (Poston 2001).

8.7 Channel Hydraulics

We found no studies specifically addressing the cumulative impacts of channel hydraulic changes on potentially covered species. Generally, the question of cumulative impacts emerges as a data gap. The HPA program itself offers the best means of measuring these impacts, because WDFW has authority to require monitoring of the impacts of authorized projects.

8.8 Littoral Drift

Artificial structures that change longshore drift can alter organic and sediment deposition on beaches and therefore alter biotic assemblages (Thom et al. 1994). However, the overall cumulative impacts of changes in littoral drift due to artificial structures on the system as a whole cannot be predicted at this time (Thom et al. 1994).

8.9 Substrate Modifications

No studies were found analyzing the cumulative impacts of substrate modifications in association with overwater structures or non-structural piling. However, certain changes can be anticipated. As noted in Section 7.10, both permanent and temporary losses of benthic macroinvertebrates are likely to occur as a result of new construction of overwater structures or expansion of existing structures; changes in the representative species assemblages as a result of associated changes in hydraulics and habitat conditions within affected reaches are also likely. Benthic macroinvertebrates, by definition, inhabit the stream bottom; therefore, modification of the streambed will most likely have some effect on the benthic macroinvertebrate community (Waters 1995). It is difficult to ascertain the cumulative impact of changes to benthic macroinvertebrate populations or species diversity and subsequent changes to fish populations or habitat occupancy that may result. Permanent loss of benthic macroinvertebrate numbers or a decrease in species diversity due to permanent loss of habitat will affect foraging opportunities for fish and could affect the population numbers within stream reaches; this may be measurable over time at the watershed scale depending on the size of the watershed and amount of habitat permanently lost.

8.10 Channel Dewatering

No studies examining the cumulative impacts of channel dewatering were found during the literature review. The following discussion is therefore based on the authors' professional experience.

Cumulative impacts of channel dewatering will most likely be associated with fish removal/exclusion methods, disturbance of the bed, and modification of invertebrate habitat and consequent changes in species diversity. Alteration of flow and increased turbidity are temporary and are therefore not likely to have cumulative impacts to aquatic species or habitat.

Fish removal/exclusion will result in the capture and handling of fish, which can cause stress, harm, and mortality. Cumulatively, the impacts to fish populations resulting from multiple permitted activities within a watershed that require fish removal/exclusion could be measurable at the population scale depending on several factors, including watershed and population size. 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 established in the literature, but it seems unlikely that HPA-authorized activities would result in measurable cumulative effects except in the case of rare species where a single project might affect a large fraction of the watershed's population.

Disturbance of the streambed associated with dewatering may result in temporary loss of habitat. The significance of the loss depends on the size of the watershed, the amount of habitat cumulatively lost, and the significance of the habitat lost to the population (i.e., spawning, rearing, or migration habitat). Again, it seems unlikely that HPA-authorized activities would result in measurable cumulative effects except in the case of rare species where a single project might affect habitat critical to a large fraction of the watershed's population.

8.11 Artificial Light

Although it has been shown that juvenile salmonid migrations can be delayed by artificial light in freshwater and marine environments (McDonald 1960, in Tabor et al. 1998; Prinslow et al. 1979, in Nightingale and Simenstad 2001b; Tabor et al. 1998), the implications of this delay are not known. The cumulative impacts of increased artificial light in the aquatic environment have not been investigated. It has been suggested (and, in the case of sockeye fry and sculpin, shown [Tabor et al. 1998]) that rates of predation on juvenile fish increase under artificial light because of changes in migration patterns, congregation of predators, or increased opportunity time for predation. Artificial lighting is often required both for construction and operation of overwater structures, cumulatively adding to light sources over water. However, it is unknown whether losses of threatened and endangered juvenile salmonids could occur due to regional-scale cumulative lighting impacts.

8.12 Vessel Activities

Little is known about the cumulative impacts of construction, commercial, and recreational vessel activities associated with overwater structures, but cumulative impacts from vessel activities have been reported with respect to turbidity. Vessel traffic may cause extended periods of elevated turbidity as boat traffic collectively churns the water, slowing the settling of suspended sediment (Garrad and Hey 1988). In addition, successive passes by vessels may accelerate shoreline erosion; recreational vessel traffic has been observed to cause boat wake-induced levee erosion at rates of 0.0004 to 0.009 inch (0.01 mm to 0.22 mm) per boat pass (Bauer et al. 2002).

Commercial shipping in the Northern Hemisphere has been implicated in a 10-fold to 100-fold increase in oceanic noise levels (Tyak 2000, in Scholik and Yan 2001a), and it has been shown that fish exhibit behavioral and physical responses to vessel noise. However, the cumulative impact of vessel noise on fish has not been specifically studied.

9 POTENTIAL RISK OF TAKE

Table 10 summarizes the risk that potentially covered species may suffer incidental take resulting from the impact pathways discussed in Section 7; the potential that a species may experience incidental take is characterized in Table 10 as Y (yes; potential for take), N (no potential for take), or U (unknown potential for take). The magnitude of the risk is highly dependent on how the impact is expressed, which in turn is highly dependent on the suite of conservation measures employed to minimize the risk of causing take. For species for which there is no potential for take, no additional precautions would be required apart from compliance with existing regulations. For species for which the potential for take is unknown, the data gap precludes reaching a conclusion. The "unknown" category may be the most problematic from the standpoint of ESA compliance, because we lack information needed for the federal agencies to determine whether incidental take would be likely to jeopardize continued existence of affected populations.

Table 10
Summary of Potential for Incidental Take of Potentially Covered Species

Common Name	Scientific Name	Impact Mechanisms											
		Shading	Eelgrass and Macroalgae	Freshwater Aquatic Vegetation	Riparian and Shoreline Vegetation	Noise	Water Quality	Channel Hydraulic Effects	Littoral Drift	Substrate Modifications	Channel Dewatering	Artificial Light	Vessel Activities
Green sturgeon	*Acipenser medirostris*	U	U	Y	Y	U	Y	Y	Y	Y	Y	U	U
White sturgeon	*Acipenser transmontanus*	U	U	Y	Y	U	Y	Y	Y	Y	Y	U	U
Newcomb's littorine snail	*Algamorda subrotundata*	U	Y	N	Y	U	Y	N	Y	Y	N	U	U
Pacific sand lance	*Ammodytes hexapterus*	Y	Y	N	Y	U	Y	N	Y	Y	N	U	U
California floater mussel	*Anodonta californiensis*	U	N	Y	Y	U	Y	Y	Y	Y	Y	U	U
Mountain sucker	*Catostomus platyrhynchus*	U	N	U	Y	U	Y	Y	N	U	Y	U	U
Pacific herring	*Clupea harengus pallasi*	U	Y	N	Y	U	Y	N	Y	Y	N	U	U
Margined sculpin	*Cottus marginatus*	Y	N	Y	Y	U	U	Y	N	U	Y	U	U
Lake chub	*Couesius plumbeus*	U	N	Y	U	U	U	U	N	U	U	U	U

Common Name	Scientific Name	Impact Mechanisms											
		Shading	Eelgrass and Macroalgae	Freshwater Aquatic Vegetation	Riparian and Shoreline Vegetation	Noise	Water Quality	Channel Hydraulic Effects	Littoral Drift	Substrate Modifications	Channel Dewatering	Artificial Light	Vessel Activities
Giant Columbia River limpet	*Fisherola nuttalli*	U	N	U	U	U	Y	Y	N	Y	Y	U	U
Great Columbia River spire snail	*Fluminicola columbiana*	U	N	U	U	U	Y	Y	N	Y	Y	U	U
Pacific cod	*Gadus macrocephalus*	N	Y	N	N	U	Y	N	Y	Y	N	U	U
Western ridged mussel	*Gonidea angulata*	U	N	Y	Y	U	Y	Y	Y	Y	Y	U	U
Northern abalone	*Haliotis kamtschatkana*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Surf smelt	*Hypomesus pretiosus*	U	Y	N	Y	U	Y	N	Y	Y	N	U	U
River lamprey	*Lampetra ayresi*	U	N	N	Y	U	Y	Y	Y	Y	Y	U	U
Western brook lamprey	*Lampetra richardsoni*	U	N	N	Y	U	Y	Y	N	Y	Y	U	U
Pacific lamprey	*Lampetra tridentata*	U	N	N	Y	U	Y	Y	Y	Y	Y	U	U
Pacific hake	*Merluccius productus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Olympic mudminnow	*Novumbra hubbsi*	U	N	Y	Y	U	Y	Y	N	Y	Y	U	U
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	U
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Y	N	Y	Y	Y	Y	Y	N	Y	Y	U	U
Pink salmon	*Oncorhynchus gorbuscha*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Chum salmon	*Oncorhynchus keta*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Coho salmon	*Oncorhynchus kisutch*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Redband trout	*Oncorhynchus mykiss*	Y	N	Y	Y	Y	Y	Y	N	Y	Y	U	U
Steelhead	*Oncorhynchus mykiss*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Sockeye salmon	*Oncorhynchus nerka*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Chinook salmon	*Oncorhynchus tschawytscha*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Lingcod	*Ophiodon elongatus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Olympia oyster	*Ostrea lurida*	Y	Y	N	Y	U	Y	N	Y	Y	N	U	U
Pygmy whitefish	*Prosopium coulteri*	U	N	U	U	Y	U	Y	N	U	Y	U	U

Common Name	Scientific Name	Impact Mechanisms											
		Shading	Eelgrass and Macroalgae	Freshwater Aquatic Vegetation	Riparian and Shoreline Vegetation	Noise	Water Quality	Channel Hydraulic Effects	Littoral Drift	Substrate Modifications	Channel Dewatering	Artificial Light	Vessel Activities
Leopard dace	*Rhinichthys falcatus*	U	N	U	U	U	U	Y	N	U	Y	U	U
Umatilla dace	*Rhinichthys Umatilla*	U	N	U	U	U	U	Y	N	U	Y	U	U
Bull trout	*Salvelinus confluentus*	U	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Dolly Varden	*Salvelinus malma*	U	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	U
Brown rockfish	*Sebastes auriculatus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Copper rockfish	*Sebastes caurinus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Greenstriped rockfish	*Sebastes elongates*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Widow rockfish	*Sebastes entomelas*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Yellowtail rockfish	*Sebastes flavidus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Quillback rockfish	*Sebastes maliger*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Black rockfish	*Sebastes melanops*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
China rockfish	*Sebastes nebulosus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Tiger rockfish	*Sebastes nigrocinctus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Bocaccio rockfish	*Sebastes paucispinis*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Canary rockfish	*Sebastes pinniger*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Redstripe rockfish	*Sebastes proriger*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Yelloweye rockfish	*Sebastes ruberrimus*	U	Y	N	N	U	Y	N	Y	Y	N	U	U
Longfin smelt	*Spirinchus thaleichthys*	U	Y	N	Y	Y	Y	Y	Y	U	Y	U	U
Eulachon	*Thaleichthys pacificus*	U	Y	N	Y	Y	Y	N	Y	Y	N	U	U
Walleye pollock	*Theragra chalcogramma*	U	Y	N	N	U	Y	N	Y	Y	N	U	U

Note: Species listed in alphabetical order by scientific name.

The following decision rules explain most of the content of Table 10:

- Marine species are not at risk of take due to impacts to channel hydraulics, or freshwater aquatic vegetation.

- Species that spend all of their lives in freshwater are not at risk of take due to impacts to eelgrass and macroalgae.
- For most species except salmonids, the effects of noise, artificial light, shading, and vessel activities are largely unknown.

The risk of take of potentially covered species is discussed below by impact mechanism.

9.1 Shading

The evidence reviewed in Section 7.1 supports the following conclusions about impacts potentially amounting to incidental take of potentially covered species:

- The principal impact of shading is reduction in cover and productivity of underwater vegetation. These impacts are detailed in Sections 7.2 and 7.3.
- Most studies of shading are focused on juvenile salmonids. However, available data on light sensitivity suggest that those impacts may reasonably be extrapolated to other small fishes, particularly nearshore marine species. For all other potentially covered species, almost nothing is known about sensitivity to shading.
- In freshwater environments that support significant bass populations, bass are effective, high-level predators that forage from under shade-producing structures.
- Migration of juvenile salmonids is sometimes impeded by shade-producing structures.

WAC 220-110-300(3) states that overwater structures and associated moorings "shall be designed and located to avoid shading of eelgrass (Zoestra spp.)." WAC 220-110-300(5) states that mitigation measures for overwater structures and associated moorings "shall include, but not be limited to, restrictions on structure width and/or incorporation of materials that allow adequate light penetration (i.e. grating) for structures located landward of -10.0 feet MLLW." Additionally, WAC 220-110-300(6) states that overwater structures and associated moorings "shall be designed and located to avoid adverse impacts to Pacific herring spawning beds and rockfish and lingcod settlement and nursery areas," and WAC 220-110-300(7) states that overwater structures and associated moorings "shall be designed and located to avoid adverse impacts to juvenile salmonid migration routes and rearing habitats." The language in WAC 220-110-300 is vague in that the WAC does not provide any specific information regarding how to avoid shading of eelgrass, what adequate light penetration is or how to achieve adequate light penetration, or how to avoid adverse impacts to Pacific herring spawning beds, rockfish and lingcod settlement and nursery areas or juvenile salmonid migration routes or rearing habitats. Thus, it is difficult for an applicant for an HPA to design and locate a structure to avoid such impacts and, therefore, there is a moderate potential risk for take of the potentially covered species.

NMFS (2005b) identified incidental take of juvenile Puget Sound Chinook resulting from shading by a wharf and moorage float in Swinomish Slough, which may impede longshore movement during certain times of the day, and from a reduction in primary productivity and consequent reduction in food resources. Based on the shading footprint, the extent of take (identified as harm in this biological opinion) was determined to be any juvenile Puget Sound Chinook rearing and outmigrating within less than 1 acre around the structure.

In a freshwater environment, NMFS (2006c) determined that the shading and structure resulting from the proposed expansion of a marina in the Columbia River will likely result in increased predation of listed juvenile salmon by a number of piscivorous fish species found in the area, although NMFS was unable to quantify the number of salmon expected to be killed.

9.2 Eelgrass and Macroalgae

Generally, the federal agencies have treated loss or reduced density of eelgrass as equivalent to loss of essential habitat for listed species known to occur in the area. As such, it constitutes a take of listed species such as salmon and bull trout. A similar perspective has been adopted by state jurisdictional agencies, including WDFW and the Washington Department of Natural Resources (WDNR). Overwater structures and non-structural piling can sometimes be sited to avoid eelgrass and macroalgae, but some structures must be sited within a narrowly defined area, and in some areas eelgrass and/or macroalgae are very common, thus some over water structures and/or non-structural piling are likely to directly impact eelgrass and/or macroalgae.

Accordingly, compensatory mitigation has been required, typically including consideration of temporal impacts related to the time between impact and full eelgrass recovery. An example of such a requirement is WAC 220-110-100(7) and WAC 220-110-300(4), "Kelp. . .

and intertidal wetland vascular plants. . . shall be replaced using proven methodology." Additionally, WAC 220-110-300(3) states that overwater structures and associated moorings "shall be designed and located to avoid shading of eelgrass (Zostera spp.)," but does not provide any guidance on design or locational parameters to accomplish this. Based on the regulatory background, the federal agencies are almost certain to evaluate eelgrass loss as resulting in incidental take of potentially covered species that use eelgrass. Those species include anadromous salmonids, anadromous and marine forage fishes, and certain larval pelagic fishes.

Notwithstanding WAC 220-110-100(7) and WAC 220-110-300(4), the federal agencies have generally not regarded impacts to macroalgae as amounting to incidental take. The macroalgae most critical to potentially covered species are kelps that chiefly occur in areas of rocky substrate, often in deep water, and will not often be permanently impacted by overwater structures and/or non-structural piling.

9.3 Freshwater Aquatic Vegetation

Based on the discussion in Section 7.3, overwater structures can impair the growth of freshwater aquatic vegetation by a variety of mechanisms. WAC 220-110-060(8) requires that "removal of aquatic vegetation shall be limited to that necessary to gain access to construct the project." This requirement provides some assurance that impacts are minimized, but makes no provision for recovery or restoration of the impacted vegetation. Moreover, WAC 220-110-331 through 338 provide extensive regulation of aquatic plant removal measures but provide no consideration of the ecological role of the affected vegetation. Since the specified measures do not exclusively apply to designated noxious aquatic weeds, it is entirely possible that they could be used to regulate activities impacting potentially covered species that are dependent on aquatic vegetation. Certain potentially covered species, including freshwater molluscs and an array of fishes, have a strong association with freshwater aquatic vegetation and would be at relatively high risk of incidental take from projects that remove or reduce such vegetation within their habitat. Sessile organisms and larval fishes would also be at high risk of mortality caused by vegetation-clearing operations.

The impacts of noxious aquatic weeds are indirect, deriving mainly from their accidental introduction during the construction and use of artificial structures. Noxious weed introductions have a high probability of causing incidental take of ESA listed fish species, because noxious weeds can potentially out-compete native vegetation and alter water quality and food web interactions (WNWCB 2006).

9.4 Riparian and Shoreline Vegetation

The hydraulic code includes provisions that minimize but do not avoid impacts to riparian and shoreline vegetation. For instance, WAC 220-110-070(1)(c) provides that in bridge construction, "disturbance of bank or bank vegetation shall be limited to that necessary to construct the project" and that "the banks shall be revegetated within one year with native or other approved woody species", except that "the requirement to plant woody vegetation may be waived." WAC 220-110-060(2) contains similar language for freshwater docks, piers, floats and the driving or removal of piling in freshwater environments. However, the ambiguous language and the lack of binding provisions regarding replacement of ecological function render the WAC provisions inadequate in that they do not provide assurance that loss of riparian and shoreline vegetation is effectively minimized, let alone compensated. Thus, there is a moderate to high risk that take of fish could occur. WAC 220-110-300 does not contain any language related to the disturbance of bank or bank vegetation.

In its biological opinion for a bridge replacement on an Oregon river, NMFS (2006a) determined that the take caused by habitat-related effects of a project could not be accurately quantified (i.e., as a number of fish) because the relationship between habitat conditions and the distribution and abundance of those individuals in the action area was imprecise, and nearshore areas damaged by construction would require years to recover characteristics favorable for rearing and migration.

In such instances, NMFS uses the causal link established between the activity and the change in habitat conditions affecting the listed species to describe the extent of take as a numerical level of habitat disturbance, rather than stating an expected amount of take (50 Code of Federal Regulations 402.14(i)). NMFS (2006a) found that the best available indicators for the extent of take is the area of riparian habitat that will be permanently modified by the action, because it is directly proportional to long-term harm attributable to the project. In another instance, NMFS (2006b) indicated that the risk of take associated with the removal or disturbance of riparian/shoreline vegetation should be described in terms of acres of riparian/shoreline or miles of stream affected.

9.5 Noise

It is well established that impact pile driving can result in incidental take of fish. NMFS and USFWS biological opinions commonly identify such take and quantify it based on the area of habitat affected by sounds above the threshold levels cited in Section 7.5 and the duration of pile driving activities. However, the sound sensitivity of individual species is not well known. In addition, species that lack internal gas-filled voids (such as swim bladders) appear to be less vulnerable to noise impacts than are fish that have gas-filled voids, such as salmonids. These include potentially covered invertebrate species and certain fishes identified in Table 5. For such species, the risk of take is somewhat lower than it is for salmonids; however, species-specific studies would be required to quantify the difference in risk. Standard measures to minimize such take are discussed in Section 11.5. The WACs do not provide any avoidance or minimization measures related to underwater noise. WAC 220-110-270(12) does state that "if a fish kill occurs or fish are observed in distress, the project activity shall immediately cease and the department granting the HPA shall be notified immediately." However, this does not provide any avoidance of underwater noise related impacts for the covered species, and thus there is a high risk of take associated with underwater noise generated by pile driving activities.

Construction noise and activity associated with the La Conner Wharf and Float Project was thought to cause forage fish to temporarily leave the vicinity, which would temporarily reduce the prey base for Chinook and other fish species (NMFS 2005b); project effects on other predators, such as those eating young Chinook, were not addressed. However in the consultations reviewed, NMFS has not assigned quantifiable incidental take associated with construction noise other than pile driving.

9.6 Water Quality

Many aspects of water quality can be impacted by overwater structures, with varying degrees of impact on potentially covered species. With respect to suspended solids, the take risk to potentially covered fish species increases in proportion to the magnitude and duration of the impact; vulnerability of the affected life-history stage; inability of the fish to avoid the impact through avoidance behavior; physiological, developmental, and behavioral impairments suffered by the fish; and indirect mechanisms such as exposure to predation. Fine sediment deposition also poses an incidental take risk to invertebrates, as discussed in Section 7.7.

Incidental take risk associated with dissolved oxygen impacts is probably quite low. Because the potential impact of pH change from uncured concrete is normally avoided via compliance with the hydraulic code (e.g., WAC 220-110-070(1)g and WAC 220-110-270(3)), the risk of incidental take from pH change is near zero.

Risk of incidental take of potentially covered species due to the use of treated wood appears to be related to factors that include proximity, dilution by the water body, and type of treatment. PAH releases from creosote pilings may pose a significant risk, given that many types of organisms have significant PAH sensitivities at low exposure levels (e.g., fishes studied by Incardona et al. 2004 and Incardona and Scholz 2006). Potentially vulnerable species include molluscs and mussels that may be sessile on the treated wood or in adjacent sediments, or to juvenile fish that consume epibenthic prey inhabiting those sediments. ACZA-treated wood appears to be somewhat less harmful, with most impacts expected during initial leaching (up to 10 days, per Poston 2001), although recent investigations (Baldwin et al. 2003; Linbo et al. 2006) indicate that juvenile salmonids may have substantially higher sensitivities to dissolved copper (the primary active ingredient of ACZA) than previously suspected. That sensitivity includes an impaired sense of smell with potential sublethal effects including reduced foraging efficiency and reduced predator avoidance ability. The hydraulic code provides for minimizing but not entirely avoiding this risk in salt water (WAC 220-110-060(4) and WAC 220-110-270(9)) by requiring that "materials treated with preservatives shall be sufficiently cured to minimize leaching into the water or bed" and by prohibiting creosote and pentachlorophenol-treated wood use in lakes.

There are few data on the stormwater vulnerability of potentially covered species other than salmonids. WAC provisions (WAC 220-110-070(1)(f), (2)(f) and (3)(i) and WAC 220-110-100(3)(b)) require avoidance of direct stormwater delivery to streams during construction, but indirect effects arising during operation of bridges or commercial/industrial piers may still occur resulting in some potential risk for take.

Based on the discussion above, it can be concluded that activities that allow significant increases in suspended sediment have a high risk of causing incidental take of potentially covered fish species exposed to this condition. The risk of take increases in proportion to:

- The magnitude and duration of the impact
- The vulnerability of the affected life-history stage
- The inability of the organism to avoid the impact through avoidance behavior
- The physiological, developmental, and behavioral impairments suffered by the fish
- Indirect mechanisms such as exposure to predation

9.7 Channel Hydraulics

Impacts to potentially covered species may result when a vulnerable life-history stage of a species is exposed to an impact directly or indirectly caused by an overwater structure. In this context, a direct impact arises when an overwater structure alters the process of sediment transport, and an indirect impact arises when the change in sediment transport causes further habitat changes, such as bank erosion and loss of riparian vegetation. In the following discussion, indirect impacts are mentioned only briefly; they are detailed elsewhere in Section 7 where channel dewatering, water quality, and freshwater aquatic and riparian vegetation are evaluated.

Potential impacts of changes in channel hydraulics on potentially covered species are summarized in Table 11 and further discussed below (excepting riparian vegetation, which is discussed in Sections 7.4 and 9.4).

WAC 220-110 places great emphasis on minimizing impacts attributable to channel hydraulic changes. WAC 220-110-070 notes the benefits of avoiding impacts by placing bridges rather than culverts; WAC 220-110-070(1)(a) recommends placing bridge piers back of the OHWL; and WAC 220-110-070(1)(h) requires that bridge components have the least effect on channel hydraulics. Such provisions discourage, but do not prohibit construction of bridges that could have significant impacts on channel hydraulics, including the impacts discussed below. However, the use of qualifying language diminishes the effectiveness of such provisions in avoiding incidental take. Examples of such language include "shall be avoided, where practicable" (WAC 220-110-070 preamble); "disturbance ... shall be limited to that necessary" (WAC 220-110-070(2)(d) and (3)(d)); and "the requirement ... may be waived" (WAC 220-110-070(2)(h) and (3)(d)). Some provisions, though, are not ambiguous and effectively avoid potential impacts; such provisions are noted below, where applicable.

Table 11
Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species

Impact	Potentially Affected Species
No impact identified	Marine species or marine life stages of estuarine and anadromous species
Habitat destruction due to siting of structure	Species potentially occupying the affected stream
Embedding due to reduced sediment transport capacity or indirectly as a result of bank erosion	Species potentially occupying the affected streambed: gravel spawners and benthos
Scour due to locally increased transport capacity	Species potentially occupying the affected streambed: gravel spawners and benthos
Deposition downstream of scour areas	Species potentially occupying the affected streambed: gravel spawners and benthos
Loss of riparian vegetation due to bank erosion	Species potentially occupying the affected stream. This impact is detailed in Section 7.4.

9.7.1 No Impact

Localized scour or deposition could occur around anchors or pilings. Such impacts would be minor, local, and not significantly different from similar impacts associated with natural structures on the seafloor, such as boulders or rock outcrops. Thus, there is a low risk of incidental take due to channel hydraulic effects in a marine setting.

There are also many sites in Washington where few, if any, of the potentially covered species are known to occur. Most of the freshwater-only species have very limited distributions (summarized in Table 2). Outside of those distribution areas and upstream of anadromous passage barriers, the western brook lamprey and freshwater-only varieties of the trout and char species are the principal species vulnerable to impact. These species, however, are vulnerable to almost all impacts detailed below. Thus, there are few HPA-jurisdictional waters in Washington where all potentially covered species can confidently be dismissed as absent.

9.7.2 Habitat Destruction

For the purpose of this white paper, habitat destruction is defined as the replacement of habitat with an artificial structure. Habitat destruction includes temporary and permanent elements. Temporary habitat destruction occurs when an area of habitat is inaccessible during or for a time following construction but becomes accessible within a reasonable time after construction, typically by the time work on the site concludes. Permanent habitat destruction occurs when an area of habitat remains inaccessible for the service life of the structure or longer. Permanent destruction of channel habitat occurs when fill is placed in the channel, usually to raise an area above the OHWL or to support an overwater structure (such as pilings or piers). Temporary channel habitat destruction includes both of these mechanisms when they are not permanent, as well as channel dewatering (Section 7.10) resulting from the diversion of flow or flow exclusion via structures such as cofferdams. Habitat destruction necessarily entails loss of habitat for any potentially covered species that utilize the affected habitat. As such, habitat destruction presents a high potential risk of incidental take; the risks are related to use of the habitat by potentially covered species, the area affected, the time frame during which the area is affected, and how potentially covered species respond to the loss or degradation of habitat.

Additionally, the process of placing fill may cause harm to individual animals. However, in-water placement of fill generally requires isolating and dewatering the work site, the impacts of which are discussed in Sections 7.10 and 9.10.

9.7.3 Embedding

Embedding is an issue principally in moderate-gradient channels that normally have a gravel or cobble bed, i.e., plane-bed and pool-riffle channels. Steeper channels have sufficient stream power that the "fines" consist of coarse sand and gravel, which do not substantially impair habitat quality. The less steep regime channels have fine-grained bed materials (generally defined as particles smaller than 0.04 inch [1 mm] in diameter) that are vulnerable to deposition (discussed below) rather than embedding. This circumstance is partly due to a research and management emphasis on gravel-bedded streams, which provide optimum spawning habitat for salmonids (Montgomery et al. 1999). There are fewer data on spawning habitat for other potentially covered fish species. Salmonids chiefly spawn in beds with a substrate size between 0.8 and 4.7 inches (2 and 12 cm) in diameter (Raleigh et al. 1986, in Bjornn and Reiser 1991), and artificial spawning channels have generally employed gravels 0.8 to 1.5 inches (2 to 3.8 cm) in diameter (Bjornn and Reiser 1991). Lamprey, in contrast, spawn primarily in channels with fine gravel and sand substrates (Wydoski and Whitney 2003, pp. 33-39), and Olympic mudminnow spawn in submerged vegetation and primarily occur in regime channels (Mongillo and Hallock 1999).

Normally, spawning salmon winnow the fines from their redds, mobilizing fine sediment into the water column and in the process coarsening the bed in the immediate vicinity of the redd (Kondolf et al. 1993; Montgomery et al. 1999). In streams that support substantial populations of spawners, this process can be as effective as annual floods at mobilizing bed sediment and scouring fines from the bed, and thus significantly enhances hyporheic upwelling and downwelling (Gottesfeld et al. 2004). Hyporheic flows create a hydraulic gradient across redds that conveys waters having relatively high dissolved oxygen concentrations through the redd (Geist 2000a, 2000b). However, fine sediments can be deposited again after redd construction, filling pore spaces between gravel particles in and over the redd with fine sediment.

The probability of this phenomenon increases if the sediments are particularly fine, the sediment supply is large, and the streamflows are relatively low (Bjornn and Reiser 1991). The process may also be exacerbated by downwelling hyporheic flows, which often occur at salmonid spawning sites in Pacific Northwest rivers (Tonina and Buffington 2003, 2005). Consequences of this embedding include reduced water flow around the eggs, reduced dissolved oxygen uptake by developing embryos, and reduced flushing of metabolic waste, which can result in reduced embryo survival (Bjornn and Reiser 1991). Reduced survival occurs due to three mechanisms: reduced hydraulic conductivity through sediments, reduced intragravel oxygen concentrations due to the oxidation of organic particles in the gravel, and impaired oxygen exchange efficiency due to clay particles on the egg membrane (Greig et al. 2005). Redds of large salmonids are usually buried beneath at least 6 inches (15 cm) of gravel (DeVries 1997) and are often more than 12 inches (30 cm) deep (Bjornn and Reiser 1991). Fine sediment does not need to penetrate to that depth to impact eggs and alevins (fry that have not yet emerged from the gravel); near-surface deposits of fine sediment may be sufficient to reduce water flow through the redd, causing mortality due to reduced dissolved oxygen, and the embedded surface layer may prevent alevin emergence (Everest et al. 1987; Bjornn and Reiser 1991). In addition to effects on redds, eggs, and alevins, embedding also reduces prey for foraging juveniles by promoting a shift from epibenthic to benthic infaunal macroinvertebrates, which are not easily preyed upon by young salmonids (Bash et al. 2001, pg. 25; Suttle et al. 2004). Thus, embedding has a high risk of causing incidental take if it affects sediments used for spawning.

9.7.4 Scour

Scour is potentially an issue in all channel types, although it is most often a concern in plane-bed and pool-riffle channels, which have a relatively mobile bed. The term “scour” is usually used to refer to flow-driven excavation of the streambed, but it can also occur along stream margins and result in bank erosion. Overwater structures, such as bridges can cause scour when the structure has not received correct hydraulic design, but such errors are unlikely in view of requirements that bridges “be aligned to cause the least effect on the hydraulics of the watercourse” (WAC 220-110-070(1)(h)). Thus, a bridge is only required to minimize such impacts. Since there are no guarantees that a bridge design or the installation will completely avoid scour, such activities implemented according to the WACs will have some associated low to moderate risk of scour, which could impact suitable habitat for potentially covered species. Non-structural piling and piling associated with other overwater structures (i.e., piers) could also potentially cause scour in marine or estuarine areas with strong tidal currents, or riverine environments with strong currents.

Scour chiefly occurs in conjunction with high-flow events that account for the largest fraction of annual sediment transport. Such flows can mobilize all spawning-sized substrates in step-pool and cascade channels, with the result that salmonids in such channels preferentially spawn in microsites with low scour potential (Montgomery et al. 1999). Conversely, the depth of bed mobilization is somewhat less in pool-riffle and plane-bed channels. In these sites, salmon normally excavate their redds deep enough to avoid scour during years with normal peak flows (Montgomery et al. 1999). However, scour that occurs in areas where it has previously been rare may result in the loss of redds with eggs or of gravels containing fry or the benthic invertebrates that constitute part of the prey base for fish in the stream. Such scour events are particularly likely around hard structures placed in the channel (e.g., pilings), because shear stresses, and therefore energy available to mobilize sediments, are exceptionally high near such structures (Yager et al. 2004). The opposite effect is observed in the vicinity of aquatic vegetation (Bennett et al. 2002), raising the possibility that aquatic vegetation plantings may help to decrease scour around structures at some sites. Freshwater mussels are particularly vulnerable to scour because they are long-lived, sessile organisms. Mussels are commonly found on relatively coarse (gravel to boulder) substrates in microsites that constitute flow refugia with low risk of scour (Cuffey 2002; Brim-Box et al. 2004).

Scour can potentially result in incidental take via several mechanisms. Impacts to eggs and fry of potentially covered species (e.g. salmonids), or to sessile organisms such as mussels, constitute the potential for incidental take of animals. Impacts to the prey base can be interpreted as incidental take if the food supply is a limiting factor on fish productivity. The literature review did not specifically identify scour impacts on other potentially covered species, but such impacts are likely for sessile species and for species that spawn in benthic habitats.

The WACs do not provide specific guidance or measures to avoid or minimize impacts from scour associated with overwater structures or non-structural piling. WAC 220-110-070(1)(h) does require that bridges "be aligned to cause the least effect on the hydraulics of the watercourse" but does not necessarily require that bridges be designed appropriately or footings or other support structures be placed in such a way as to avoid or minimize impacts to hydraulic processes of a watercourse. The generally vague language presented in the WACs will minimize the potential risk for take of potentially covered species, but will not eliminate it.

9.7.5 Deposition

Deposition may occur in slackwater areas created downstream of an artificial structure, or it may occur farther downstream when sediment mobilized by scour is redeposited. Deposition can have a variety of effects, depending on the amount of sediment and its particle size distribution. Deposition of large quantities in a localized area results in the creation of bedforms, discussed below. Deposition of somewhat smaller quantities that do not significantly modify bedforms may still result in burial of redds and benthic organisms such as mussels. Moderate deposition of a few centimeters of coarse-grained material may not harm redds and may even help to protect them from scouring flows (Montgomery et al. 1999), but deposition of greater thicknesses may result in reduced dissolved oxygen levels in redds, causing mortality of eggs or alevins, as detailed above in the discussion of embedding. As with scour, deposition impacts are most likely when an overwater structure and associated support structures and non-structural piling are installed and have not received proper hydraulic design. While significant amounts of deposition (i.e., amounts potentially causing measurable incidental take) are not likely to occur from the installation of an overwater structure or non-structural piling, some localized deposition may occur as a result of changes in hydraulics in the immediate vicinity of the structure. The same WAC provision cited above (WAC 220-110-070(1)(h)) as minimizing scour-related impacts, will also serve to minimize depositional impacts. Implementation of the WAC as written will likely minimize the risk of take but not eliminate it.

The potential risk of take from deposition related to hydraulic changes resulting from an overwater structure and non-structural piling is relatively minor. However, fine sediment deposition can impair the growth and feeding efficiency of filter feeders (Bash et al. 2001). For example, deposition of fine sediment can adversely impact freshwater mussels, but the mechanisms and quantities involved are not well understood, and different mussel species show varying responses to fine sediment inputs (Box and Mossa 1999). Deposition can affect mussels by burying them or altering their habitat. Burial under fine sediment (silt) can suffocate animals (Tucker and Theiling 1998). Ellis (1936, in Tucker and Theiling 1998) experimentally showed that as little as 0.25 inch (6.35 mm) of silt covering the substrate caused death in about 90 percent of the mussels examined. Siltation also is detrimental to young mussels and reduces their survival (Scruggs 1960, in Tucker and Theiling 1998). Habitat alteration harms mussels by filling interstitial spaces in gravel and cobble bed channels inhabited by mussels. Flow through the gravel is inhibited and algal and microbial communities change (Tucker and Theiling 1998). Juvenile survival (even of hardy species) may be reduced in silt-impacted mussel beds, which can limit recruitment in the entire bed (Tucker and Theiling 1998). Potential impacts from deposition associated with installation of an overwater structure or non-structural piling would be localized and relatively minor with a low potential risk for take of the covered species.

Both coarse and fine sediment deposition can present potential for incidental take by burying animals living in the bed, such as eggs and alevins in redds and invertebrate infauna, and/or impairing habitat by reducing access to necessary resources such as prey and well-oxygenated water.

9.8 Littoral Drift

The littoral drift processes of wave action and littoral current affect benthic substrate and vegetation and therefore influence species assemblages (Thom et al. 1994). Primary productivity, organic matter flow, nutrient dynamics, benthic biota, and the entire local food web may also respond to alterations in littoral drift (Thom et al. 1994). The following discussion focuses on direct and indirect impacts to potentially covered finfish and shellfish species in response to these habitat alterations that may result from overwater structures and non-structural piling.

Pacific salmon, Pacific herring, surf smelt, sand lance, and a variety of other fish may be affected by habitat changes caused by structures that affect littoral drift (Thom et al. 1994). Suitable surf smelt spawning areas were adversely impacted by littoral drift alterations resulting from bulkheads along the Hood Canal (Penttila and Aguero 1978, in Nightingale and Simenstad 2001b). Typical spawning substrates consist of fine gravel and coarse sand, 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, altering substrate composition in surf smelt spawning areas can affect surf smelt spawning or reduce egg survival.

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 are susceptible to deleterious effects of littoral alterations because they rely on a certain beach profile and specific substrate compositions.

Any species that depends on eelgrass, such as Pacific salmon or Pacific herring, is susceptible to changes in littoral drift. Eelgrass typically grows in sand and mud substrates in sheltered or turbulent waters (Phillips 1984), and Pacific herring spawn on the blades of eelgrass and other macroalgae (WDNR 2006a). It is consistently documented that the vegetation assemblages associated with eelgrass support increased numbers of juvenile salmonid epibenthic prey species (Nightingale and Simenstad 2001b). Studies of eelgrass communities in Padilla Bay show that a specific group of copepods (*Harpacticus uniremis* and other copepods of the genera *Zaus* and *Tisbe*) is unique to the eelgrass epiphyte assemblage and the principal prey of juvenile chum salmon, Pacific herring, Pacific sand lance, and surf smelt (Nightingale and Simenstad 2001b). Pacific herring are also a direct food source of larger predators, including adult Chinook salmon, bull trout (Nightingale and Simenstad 2001b), Pacific hake (Bailey 1982; NMFS 1990; Quirollo 1992; McFarlane and Beamish 1986, in NRC 2001), Pacific lamprey, rockfish (WDNR 2006a), and many other species (WDNR 2006a).

Benthic communities, including invertebrate populations, are impacted by sediment alterations (Nightingale and Simenstad 2001b). For instance, the Olympia oyster is an epibenthic filter feeder found throughout the inland waters of Puget Sound, as well as in Willapa Bay and possibly Grays Harbor (WDNR 2006b). Olympia oysters occupy nearshore areas on mixed substrates with solid attachment surfaces and are found from approximately 1 foot (0.3 m) above MLLW to approximately 2 feet (0.6 m) below MLLW; their larvae settle onto hard substrate such as oyster shells and rocks (West 1997, Baker 1995, both in WDNR 2006b). Olympia oysters are adversely impacted by siltation and do best on firm substrates (WDNR 2006b). Therefore, it follows that local impacts to littoral drift can alter preferred substrate or smother oysters beneath silt.

The WACs do not address impacts to littoral drift from overwater structures or non-structural piling or provide any guidance or measures to avoid or minimize potential impacts associated with littoral drift.

To conclude, impacts to littoral drift may change beach substrate characteristics and sediment deposition. Changes to these processes can alter benthic and epibenthic communities, fish spawning and rearing habitat, and vegetation (Thom et al. 1994).

9.9 Substrate Modifications

Based on the studies cited in Section 7.9, it appears that the primary direct impact of placing structures is to create hard substrates in settings where such substrates did not previously occur, increasing habitat diversity. This change would likely benefit rockfish and any other potentially covered species that use hard or rocky substrates. However, the indirect impact of increased shellhash deposition can harm productive natural habitat types, specifically eelgrass and macroalgae communities. In that case, the risk of incidental take will be the risk of adversely impacting eelgrass and macroalgae, as discussed in Section 9.2.

WAC 220-110-300(1) states that "floats and rafts shall not ground on surf smelt, Pacific herring, Pacific sand lance and rock sole spawning beds. In all other areas, no more than twenty percent of the float or raft within the beach area shall ground at any time. Those portions of the float or raft that will ground shall be constructed to align parallel to the shore and provide a minimum of eight inches clearance between the beach area and nongrounding portions of the float." WAC 220-110-300(2) states that "floats, rafts, and associated anchoring systems shall be designed and deployed so that the bed is not damaged." WAC 220-110-060(2) states that "excavation for and placement of the footings and foundation shall be landward of the ordinary high water line unless the construction site is separated from state waters by use of an approved dike, cofferdam, or similar structure." The language in the WACs will avoid impacts to forage fish and rock sole spawning beds, but does provide for direct impacts to other areas, where twenty percent of a float or raft may ground at any time or where excavation may occur landward of the ordinary high water line, which will impact habitat that may be considered designated critical habitat under the ESA, or could be designated in the future, providing for a moderate to high potential risk for take of the potentially covered species. Additionally, installing a cofferdam or other similar structure may require fish handling in some situations, which has a high potential risk for take of the potentially covered species.

9.10 Channel Dewatering

The primary risks of incidental take associated with channel dewatering result from the capture and handling of fish, the loss of small fish (particularly salmonid fry) that seek refuge in the substrate of the dewatered bed, and the use of pumped bypass systems. This conclusion is based on a review of several biological opinions, specifically the take calculations and the incidental take statements presented in these documents, as cited below.

The hydraulic code provides few assurances that incidental take will be minimized during dewatering activities. For construction of overwater structures and driving and removal of piling in freshwater, WAC 220-110-060(1) states that "excavation for and placement of the footings and foundation shall be landward of the ordinary high water line unless the construction site is separated from state waters by use of an approved dike, cofferdam, or similar structure." WAC 220-110-120 provides the most restrictive code language, but it only applies to "game and food fish" (implicitly excluding many potentially covered species) and only states that they must be captured or moved – there is no discussion of ways to manage the dewatered work area so as to minimize the need to handle fish. WAC 220-110-060(1) does not indicate whether the isolated work area must be dewatered or fish removal is required. Assuming the isolated work area must be dewatered and fish removal is required, there is no requirement that the operation be performed by trained personnel, nor that it comply with any recognized protocol. There is a relatively high risk of take for dewatering activities in fish-bearing waters because the WAC does not focus on "all fish," methodologies for removal could result in stranding fish, and fish could be harmed through mishandling. The efficiency of capturing fish is also strongly correlated to site conditions. Areas with large, complex substrate, deep pools, complex woody debris, overhanging and submerged vegetation and other features that provide hiding places and hinder visibility can decrease the efficiency of fish capture and removal efforts.

Capture-related take, such as injury or mortality from electrofishing, varies from 2 percent (no distinction between injury and mortality) (NMFS 2006a) to 30 percent (25 percent injury and 5 percent mortality) (NMFS 2006b) of fish captured using electrofishing equipment. Some biological opinions did not distinguish between methods of capture (e.g., volitional movement of fish from the project site during slow dewatering, capture by seining or dip-netting, capture by electrofishing). One biological opinion estimated take due to stranding (i.e., fish not captured and removed and thus remaining in the work area to be dewatered) at 8 percent (NMFS 2006b). All such injury and mortality represent incidental take directly attributable to a project.

NMFS biological opinions also routinely identify impacts attributable to increases in turbidity and suspended solids. These include indicators of major and minor physiological stress, habitat degradation, and impaired homing behavior. These effects are sublethal, but are still considered take under the ESA (NMFS 2006b). The effects of increased suspended solids concentrations are discussed in Sections 7.6 and 9.6.

9.11 Artificial Light

Incidental take of listed fish species as a result of artificial light during construction or operation of overwater structures has not been quantified in past biological opinions and corresponding incidental take statements. The studies cited above indicate that artificial light has mixed effects; many of these effects are detrimental, and all of them represent a change from natural patterns of behavior. This suggests that, although artificial light responses are unknown for most potentially covered species, there is a significant risk that nighttime illumination of the water surface may contribute to incidental take. However, such impacts can generally be minimized, as discussed in Section 11.11.

The WACs do not provide any guidance or specific requirements to avoid or minimize impacts relating to artificial light.

9.12 Vessel Activities

Vessel activities may result in incidental take of potentially covered species via several mechanisms, including:

- Physical disturbance of sediment, organisms (Haas et al. 2002), and submerged vegetation through grounding or water turbulence caused by propeller wash, potentially resuspending sediment, physically dislodging vegetation and organisms, or damaging vegetation
- Noise from vessel activity, which would most likely harm organisms by causing them to move from the affected area, potentially impairing foraging or reproductive activities or exposing them to increased risk of predation
- Propeller-wash entrained air bubbles that combine with turbidity increases from disturbed sediment, with the potential consequences resulting from increased turbidity discussed in Section 9.6 and the consequences resulting from decreased light availability discussed in Section 9.1.

The WACs do not provide any guidance on vessel operation during construction of an overwater structure or installation of non-structural piling. There are no provisions for avoiding or minimizing potential impacts to the potentially covered species relating to the grounding of vessels, propeller-wash, or noise associated with work vessels.

9.13 Risk Evaluation

Table 12 presents a brief summary of the incidental take risk analysis presented above. Given the uncertainties described above, this risk evaluation is at best a qualitative assessment and is based strongly on professional experience of the analysis team in the context of their work in ESA implementation. The risk evaluation summarized in Table 12 assumes that potentially covered species are present when the described impact occurs; thus, impacts may be avoided by performing the activities when or where covered species are absent.

Table 12
Conclusions of the Risk Evaluation

Activity	Low Risk	Moderate Risk	High Risk
Freshwater structures per WAC 220-110-060	• Structures located in areas lacking submerged aquatic vegetation; • Structures causing little increased shading, either due to size or incorporation of grating or other light penetrating features • Pile-driving activities with peak sound <150 dB; • Structures in areas with little sediment transport; • Structures not increasing the volume of untreated stormwater; • Placing small areas of non-conforming substrate; • Activities avoiding the impacts potentially causing “moderate” or “high” risk.	• Structures removing riparian vegetation; • Structures that require removing LWD in lentic waters; • Pile-driving activities with peak sound between 150 and 180 dB; • Structures increasing the volume of untreated stormwater due to increased impervious surface; • Structures comprised of CCA- or ACZA-treated wood; • Structures that measurably alter channel hydraulics or littoral drift; • Structures causing nighttime illumination of the water surface.	• Structures in areas of submerged aquatic vegetation that are used by dependent species (e.g., Olympic mudminnow); • Structures that require removing LWD in lotic waters; • Pile-driving activities requiring hammer pile driving with peak sound >180 dB; • Structures that substantially alter channel hydraulics; • Placing large areas of non-conforming substrate; • Activities that require dewatering of the work area; • Activities requiring substantial in-water operation of mechanized equipment. • Structures in riverine environments that use creosote treated wood;
Saltwater structures per WAC 220-110-300	• Structures located in areas lacking submerged aquatic vegetation; • Structures causing low shade; • Pile-driving activities with peak sound <150 dB; • Structures in areas with little sediment transport; • Placing small areas of non-conforming substrate; • Activities avoiding the impacts potentially causing “moderate” or “high” risk.	• Structures removing riparian vegetation; • Pile-driving activities with peak sound between 150 and 180 dB; • Structures discharging stormwater; • Structures requiring CCA- or ACZA-treated wood; • Structures measurably altering littoral drift; • Structures causing nighttime illumination of the water surface.	• Structures located in areas of eelgrass or macroalgae; • Structures shading large areas; • Structures requiring hammer pile driving with peak sound >180 dB; • Structures that require creosote-treated wood; • Placing large areas of non-conforming substrate; • Activities that require dewatering of the work area; • Activities requiring substantial in-water operation of mechanized equipment.
Non-structural or structural piling	• Pile-driving activities with peak sound <150 dB; • Structures that avoid the impacts potentially causing “moderate” or “high” risk.	• Pile-driving activities with peak sound between 150 and 180 dB • Structures requiring CCA- or ACZA-treated wood.	• Piling located in areas of eelgrass or macroalgae; • Structures requiring hammer pile driving with peak sound >180 dB. • Structures requiring creosote-treated wood.

10 DATA GAPS

This section identifies information gaps in the available literature about the 12 impact pathways (presented in Section 7) associated with the construction and operation of overwater structures and non-structural piling and describes the data needed to fill those gaps.

10.1 Shading

As stated in the WDFW white papers on overwater structures (Nightingale and Simenstad 2001b; Carrasquero 2001), significant gaps and uncertainties remain in the extent of scientific knowledge about the impacts of overwater structures and shading on the aquatic environment and biota. Some of these gaps are basic to understanding the ecology and life history of potentially impacted species, such as those defining the extent and ecological dependence of shoreline habitat use by certain biota. Since the publication of the two WDFW white papers cited above, a few studies have been completed regarding shoreline habitat use of aquatic biota. Toft et al. (2004) reported on fish distribution, abundance, and behavior in nearshore habitats along the marine shoreline of the City of Seattle, and Tabor et al. (2006) studied nearshore habitat use by juvenile Chinook salmon in the Lake Washington basin. One data gap identified by Nightingale and Simenstad (2001b), which is to determine the conditions for and the significance of avoidance of shoreline structures by migrating juvenile salmon, has been studied in greater detail since the publication of the white papers. Southard et al. (2006) studied conditions for, and the significance of, avoidance of shoreline structures by migrating juvenile salmon in *Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines*. This study supported other findings that identified shading of overwater structures as the mechanism for salmonid avoidance (Weitkamp 1982, Pentec 1997, in Nightingale and Simenstad 2001b; Shreffler and Moursund 1999) and recommended ways to minimize impacts of ferry terminals on juvenile salmonids. Furthermore, Haas et al. (2002) suggest that additional research is necessary to determine the thresholds at which epibenthic biota become affected by the shading of vegetation.

Additional data gaps include the effects of temporary shading associated with vessel operations during construction of overwater structures or installation of non-structural piling. However, in general vessels required for the construction of overwater structures and installation of non-structural piling will operate during the approved in-water work window, which will minimize potential impacts associated with shading. Additional data gaps relate to the operation of commercial and recreational vessels which may be moored at an overwater structure or non-structural piling, and may occur at various times of year and therefore affect covered species.

10.2 Littoral Vegetation

Numerous significant data gaps preclude a clear understanding of how human activities cumulatively impact littoral vegetation. Relatively little work has been done on macroalgae. For eelgrass, the following gaps are particularly significant:

- Factors governing the extent of eelgrass coverage, including local and large-scale changes in eelgrass coverage, are just beginning to be researched (Dowty et al. 2005).
- How large-scale changes in eelgrass cover resulting from overwater structures vary in conjunction with other large-scale changes, such as climate variability, has not been determined.
- More research is needed to determine the causes of local declines in eelgrass coverage observed in Washington State (Dowty et al. 2005).
- It is not known how strongly many potentially covered species depend on eelgrass. For instance, young salmon forage extensively in eelgrass, but foraging habitat may not be a limiting factor for juvenile salmon in Puget Sound (Haas et al. 2002).
- Much human impact on eelgrass and macroalgae takes the form of habitat fragmentation, but although such fragmentation is in principle an adverse impact, it remains unclear just how that impact is delivered to affected species (Haas et al. 2002).

10.3 Freshwater Aquatic Vegetation

It is not known at what point the cumulative impact of overwater structures on aquatic vegetation becomes significant to most potentially covered freshwater species. Most of these species are thought to be affected by the loss of aquatic vegetation through indirect impact pathways that could vary from one location to another. To assess the relative merits of aquatic plant conservation and mitigation measures, the importance of aquatic vegetation in different systems and for all of the potentially covered species needs to be better understood. Of the potentially covered species, current data have shown a clear and consistent dependence on freshwater aquatic vegetation only for the Olympic mudminnow, although it is expected that freshwater aquatic vegetation is important for other potentially covered species as well, which is why this is identified as an important information gap.

10.4 Riparian and Shoreline Vegetation

Most of our understanding of the role of riparian and streamside vegetation as a mediator of instream habitat condition has grown out of concern over its role in providing salmonid habitat. Although the reviewed literature addresses many ecosystem functions affected by riparian vegetation, such as shading, LWD recruitment, and allochthonous nutrient inputs, there is little discussion of how these changes may affect species other than salmonids. Knutsen and Naef (1997) indicate that nutrient inputs from riparian vegetation are important for suckers, whitefish and minnows, which feed directly on such detritus. Riparian habitat is also important for terrestrial wildlife.

10.5 Noise

Data on the effects of exposure to sound from pile driving on specific fish or invertebrates are few, and although the few studies completed provide some information about exposures to pile-driving sounds, there is little that can be definitively concluded (Hastings and Popper 2005). Hastings and Popper (2005) stress that because monitoring data show that sound pressure levels do not necessarily decrease monotonically with increasing distance from the pile, it is important that received sound levels be measured in future experiments to develop exposure metrics that correlate with mortality and different types of damage observed in fish exposed to pile driving. Hastings and Popper (2005) conclude that it is important to initiate experimental studies that start with basic questions about the effects on fishes from exposure to pile-driving sounds. Recommended studies from Hastings and Popper (2005) are presented in Table 13. Two data gaps are particularly significant: the cumulative impact of sound to fish and the effects of noise on the behavior of fish and the consequent impact to species survival and recovery.

In addition to data gaps on the hearing capabilities of fish and how fish are injured by pile-driving noise, uncertainties also exist on how fish react to other anthropogenic noises caused by vessels, construction, and other sources. It is also important to develop information on ambient noise levels for particular areas, because ambient noise levels influence the area of effect (attention to ambient), and fish reaction to sound likely varies depending on the "loudness" of ambient conditions.

Table 13
Research Questions on the Impact of Pile Driving on Fishes

Project Title	Project Objectives	Significance	Relationship to Other Studies	Relationship to Pile Driving Needs
Characterize Pile Driving Sounds				
Define acoustic dose for exposure to pile driving sound	Develop ways to express exposure to pile driving sounds in terms of total energy received and the degree of temporal variation in the waveform, and to define the acoustic particle velocity within the sound field	This will provide a series of “standard” pile driving sounds in water and substrate for use as the stimuli with which to do studies on representative species	This study is fundamental to investigations of effects on fishes because it provides laboratory signals that would be representative of the range of pile driving stimuli in different locations	Without this standardization it will be impossible to generalize between studies done in different locales and with different piles
Structural acoustic analysis of piles	Develop structural acoustics models of piles to investigate how modifications to piles and hammering could alter the sounds and potentially incur less damage to animals	This could result in potential modifications to the structure, hammer, and/or process that could reshape the temporal characteristics of the pile driving stimulus without changing structural integrity	Would need to test modified sounds on animal models	This analysis will help provide ways to mitigate some effects of pile driving on aquatic organisms
Define characteristics of the underwater sound field	Develop underwater sound propagation model and integrate with pile structural acoustics models to estimate received levels of sound pressure and particle velocity in the vicinity of pile driving operations and verify with field measurements of underwater sound pressure measurements	This is the only way to define zones of impact on fishes because the sound energy received by a fish depends on not only the pile-driving source, but also the size, shape, and properties of the underwater environment.	Would be able to map the impact of pile driving sounds on the underwater environment based on results of tests of pile driving sounds on animal models	Received levels of sound pressure and acoustic particle velocity must be known underwater in the region surrounding the pile to calculate appropriate metrics related to observed effects and define the zone of impact
Characterize injury of fish exposed to pile driving sounds				
Hearing capabilities of Pacific Coast fishes	Determine hearing capabilities (using Auditory Brainstem Response [ABR]) of representative species. Determine in terms of both pressure and particle motion.	Useful for prediction of detection range of pile driving sounds and potential effects on hearing capabilities	Previous behavioral studies did not use any Pacific Coast fishes or elasmobranches	Studies would be on species that are particularly germane to those affected by pile driving

Project Title	Project Objectives	Significance	Relationship to Other Studies	Relationship to Pile Driving Needs
Mortality of fishes exposed to pile driving	Determination of short and long term effects on mortality of representative species as a result of pile driving. Measure pathology (using necropsy studies) of the effects on fishes of received sounds representative of different distances from the source	Provide baseline data on effects of pile driving and the effects of such signals of different levels and spectral components	Studies of this type have, heretofore, not be done under controlled situations	Provide mortality data as well as pathology as to the effects of pile driving and determination of the cause of immediate and long-term mortality
Effects of pile driving on non-auditory tissues	Using the precise same paradigm as for effects on the ear, examine other tissues using standard fish necropsy techniques to asses gross, cellular, and molecular damage to fish. Furthermore, determine stress effects on fish using appropriate stress measures (e.g., hormone levels). Do for representative species.	Provide insight into how the sounds affect fish, even when there is no immediate mortality	The only comparable data are from blasts, which suggests significantly different effects depending on fish size and species.	Direct measure of potential long-term damage to fishes.
Effects of pile driving on hearing capabilities	Determine temporary threshold shifts and permanent threshold shifts on representative species.	Provide insight into hearing loss and possible recovery as a result of different sound levels and sound types	No studies of this type have been done using pile-driving sounds	Data that will help understand the sound levels and other parameters that could result in the loss of the ability of different species types to detect sounds, and thus detect biologically critical signals
Effects of pile driving on fish eggs and larvae	Determine mortality, growth rates, and pathological changes in developing fishes of representative species with exposure at different times during the development cycle	Since eggs and larvae do not move from the sites of spawning, determine if long-term pile driving could affect fish populations	No studies done on any fish system are relevant to this investigation	If fish spawn in the vicinity of pile driving sites, or cannot be kept from spawning during pile driving operations, effects on eggs and larvae could be considerable

Project Title	Project Objectives	Significance	Relationship to Other Studies	Relationship to Pile Driving Needs
Behavioral responses of fish to pile driving	Observe, in large-scale cages, the short-term behavioral responses of representative species to pile driving sounds. Do fish attempt to swim from the source? Do they react to the sounds? Do they "freeze" in place?	In knowing behavioral responses, it may be possible to predict which species would remain in an area of pile driving vs. species that could be expected to leave the area after the initial pile driving activity.	None have been done to date.	This may help limit the number of species that would need to be "protected."
Long-term behavioral effects of pile driving on fish	Attempt to do field studies that would provide insight into movement patterns of fishes and normal behaviors and how these might be affected, in the long-term, by the presence of continuous pile driving.	While there may be few or no apparent effects on immediate behavior (e.g., rapid swimming), physiology (e.g., hearing, effects on other organs), or mortality, there may be longer-term behavioral effects such as those from continual sounds from pile driving preventing fish from reaching breeding sites, finding food, hearing and finding mates, etc. This could result in long-term effects on reproduction and population survival.	None have been done to date.	Pile driving may not have an immediate impact on fishes, but continual pile driving may have longer-term effects that could significantly alter fish populations in the areas in which pile driving takes place.
Effects of pile driving on the ear and lateral line	Determine morphological changes over time for representative species on sensory cells of the ear and lateral line, and whether such changes are reversible	If there is loss of sensory cells there is a loss in hearing ability or the ability of the lateral line to be used in hydrodynamic reception. If there is recovery of these cells, fishes may be able to survive (assuming they did not die prior to recovery).	A few studies suggest that exposure to high sound pressure levels will affect the sensory cells of the ear, but almost nothing is known about the lateral line. However, no studies were done with sounds comparable to those from pile driving	Loss of hearing capabilities, even for a short period of time, could dramatically affect survival of fishes.
Effects of multiple pile driving exposures on fish	For the appropriate experiments cited above, determine effects of multiple exposures, over time, of pile driving	Some fishes may stay in the pile driving area, or go between areas that have different time tables for pile driving. Thus, there may be multiple exposures over time	No data in the literature.	If fish remain in an area over time, there may be cumulative effects that need to be understood

Source: Hastings and Popper 2005

10.6 Water Quality

There is still much work to be done to understand the impacts of suspended sediment and turbidity on potentially covered species. Most of the reviewed literature discussed impacts only with respect to salmonid species. Many of the studies were conducted in the laboratory in the absence of complex interactions that occur in natural systems. While the laboratory work is useful for describing interactions around which a study has been designed, additional field data would help to verify laboratory-derived conclusions. In addition, many data gaps identified by Bash et al. (2001) still appear to be gaps. For instance, a lack of background water quality data for most waters in Washington, exposure thresholds for sublethal effects, the effects of short-term sediment pulses, species responses to varying sediment particle sizes and shapes, the effect of fine sediment deposition on hyporheic mechanisms, and how these affect habitat quality and quantity. This information would help in estimating the potential impacts of aquatic projects by providing a more comprehensive impact analysis in the context of existing conditions and species response thresholds to suspended sediment exposure.

Similarly, many data gaps exist with respect to the potential for treated wood applied to aquatic settings to impact potentially covered species. Little work has been done to evaluate the potential impacts of treated wood applications in large projects on water quality and sediment and dose responses of potentially covered species to PAH and metals concentrations in water and sediment (Poston 2001). Poston (2001) reported a lack of knowledge on bioaccumulation and pathways of exposure of potentially covered species to PAHs and metals, as well as microbial and physical degradation processes of PAHs and metals. These processes are still not well described in the literature. Recent work has called into question the reduction in PAH leaching rates achieved by current BMPs for creosote treatment (Poston 2001). This information would allow for better estimates of take.

10.7 Channel Hydraulics

Relatively few studies specifically address questions about the effects of overwater structures on potentially covered species other than salmonids. Instead, this white paper relies on studies that address water crossing effects on habitat features, such as scour or sediment composition, and on studies that address the effects of changes in habitat features on potentially covered species. We have high confidence that this approach suffices to identify potential impacts on potentially covered species, although there are few case studies demonstrating quantitative impacts on animals or their habitat. The existing studies are often of limited use because they focus on "legacy" effects, i.e., impacts that occurred because of practices that are rarely, if ever, authorized under current regulations.

Nearly all studies that specifically look at impacts to potentially covered species address only impacts on salmonids listed under the ESA (i.e., Pacific salmon and bull trout). Some studies address effects on resident salmonids, sturgeon, lamprey, or mussels, but the literature is largely barren for all other potentially covered species. For many potentially covered species, the literature does not provide sufficient information to estimate how a given alteration in physical habitat might affect the species, because their life histories and habitat requirements are imperfectly understood. For such species, which include most potentially covered warm-water fish and invertebrate species (except mussels), this lack of information makes it difficult to estimate take potential.

10.8 Littoral Drift

Littoral drift cells can change over time with natural and human-caused alterations in shoreline configuration, sediment sources, and other variables. Mapped shoreline sediment sources and the location and direction of littoral currents and drift cells should be updated periodically to help users avoid adversely affecting important aquatic habitat characteristics and the potentially covered species that depend on them.

10.9 Substrate Modifications

The literature on substrate modifications is limited. Most studies of substrate changes have examined changes in a hydraulically active environment, which in this white paper is treated in Sections 7.7 and 7.8 on channel hydraulics and littoral drift. Hydraulically passive environments are mainly deep marine and deep lake environments, where substrates are seldom altered except by point and linear structures such as pilings. Relevant studies focus on the marine environment. No data were identified as applicable to lake environments, where the potentially covered species include sturgeon and, to a lesser degree, suckers and mature salmonids. Conducting interviews and reviewing agency documents might provide further detail on the impacts of structures in hydraulically passive environments, but seems impracticable in view of the small risk of incidental take associated with such structures.

10.10 Channel Dewatering

No data that would allow quantification of the amount of habitat lost due to placement of footings located below the OHWL or MLLW associated with piers or ramps or temporarily disturbed each year as a result of the construction of overwater structures were identified. Such data would make it possible to improve estimates of take and cumulative impacts.

Relatively few studies have directly compared the susceptibility of different species to electrofishing-induced spinal injuries and muscular hemorrhages, especially within or among non-salmonids, including potentially covered species. However, injury frequencies reported for specific species are highly variable among and often within investigations and sometimes appear to be contradictory. Differences in rates and degree of injury, especially between investigations, are often difficult to attribute to species, fish size, fish condition, environment (including water conductivity and temperature), field intensity, or other current or field characteristics. Still, most existing data support Salmonidae as the fish taxon most susceptible to electrofishing injury (Snyder 2003).

10.11 Artificial Light

Extensive gaps exist in our understanding of how artificial light impacts aquatic organisms. As discussed in Section 7.11, impacts to fish resulting from artificial light are often related to changes in nighttime behaviors such as migration, activity, location (Nightingale and Simenstad 2001b), and potentially schooling behavior in juvenile salmonids (Ali 1959, 1962, in Simenstad et al. 1999). Further studies on the qualitative effects of predator/prey relationships associated with artificial light, and investigations focused on the consequences of behavioral changes in aquatic organisms in a natural environment, are necessary to better understand the impacts associated with nighttime artificial light.

10.12 Vessel Activities

Relatively little is known about the potential impacts of vessel activities on potentially covered species. Although some work has been done with respect to turbidity, much of the research to date has focused on freshwater environments. More work is needed with respect to impacts of smaller vessels on turbidity in estuarine and marine environments. Much work is also needed to assess the noise impacts of small vessels operating at varying speeds, so that noise levels specific to conditions created by a particular project can be estimated. Similarly, potential impacts of small vessels on eelgrass and aquatic vegetation are not well known, and more work is needed to support impacts to these resources. Haas et al. (2002) recommends determining thresholds of disturbance for epibenthic communities affected by varying degrees of vessel activity. No literature was identified describing the potential impacts of vessel activities with respect to artificial light.

11 HABITAT PROTECTION, CONSERVATION, MITIGATION, AND MANAGEMENT STRATEGIES

If the impacts described in Section 7 occur within habitat used by a potentially covered species, the result may be incidental take of aquatic animals through either physical harm to the animals or reduced capacity of the habitat to serve essential life functions, such as reproduction, foraging, and migration. The ESA requires that such impacts be avoided or, if unavoidable, minimized to the maximum extent practicable. This analysis assumes that all overwater structures and non-structural piling are conditioned under the HPA authority in accordance with the Hydraulic Code rules (WAC 220-110) and other local, state, and federal regulations. Additional measures for further avoiding or minimizing the risk of incidental take are identified below. These measures include one that was not specified in any of the documents reviewed for this white paper: modifying in-water work windows to be protective of spawning and incubation by any potentially covered species that could be present in the area affected by a proposed project.

11.1 Shading

Nightingale and Simenstad (2001b), Carrasquero (2001), and Thom et al. (1995, in Haas et al. 2002) provide impact minimization measures for the design, construction, and revetment of a variety of overwater structures. WDFW might want to consider following the guidance provided by these authors, such as:

- Increasing the height of overwater structures to allow light transmission under the structures
- Decreasing structure width to decrease the shade footprint
- Aligning the structure in a north-south orientation to allow the arc of the sun to cross perpendicular to the structure, which reduces the duration of light limitation each day
- Using the smallest number of pilings possible, allowing more light beneath the structure
- Using grated surfaces or including openings in the deck surface to pass light, as opposed to prisms. Gayaldo and Nelson (2006) found that grating (with 37 to 58 percent open space) transmits 10 times more light under piers than do acrylic prisms. In addition, light that passes through open grating penetrates the water evenly under the pier, whereas light transmitted though prisms concentrates beams

of light that do not always reach the water surface. The U.S. Army Corps of Engineers Regional General Permit for residential overwater structures in inland marine waters within Washington State (USACE 2005) requires ramps to be grated, and floats are required to have grating account for a minimum of 30 percent of the surface area; the grating must have 60 percent open area and be oriented to maximize light penetration (USACE 2005). Additionally the Regional General Permit for residential overwater structures in inland marine waters prohibits pier widths greater than 6 feet, float widths greater than 8 feet and lengths greater than 20 feet, and the construction of new or the modification of existing fingers, "ells," and T structures onto floats (USACE 2005).

Southard et al. (2006) provides additional recommendations on minimization measures specific to shading impacts on juvenile salmonids, and Kahler et al. (2000) provides recommendations for lakes, as outlined below:

- To minimize the shade-related impacts to migrating juvenile salmonids created by ferry terminals, overwater structures should be designed and constructed to allow incidental light to penetrate as far under as possible, while still providing the necessary capacity and safety considerations necessary to support their intended function. The physical design (e.g., dock height and width, dock orientation, construction design materials, piling type and number) will influence whether the shadow cast on the nearshore covers a sufficient area and level of darkness to constitute an impediment. Construction of closely spaced terminal structures should be avoided to minimize the potential cumulative impacts of multiple overwater structures on juvenile salmonid migration (Nightingale and Simenstad 2001b).
- Experiment with technologies and designs that can soften the light-dark edge to minimize potential temporary inhibition of movement.
- The incorporation of light-enhancing technologies in the design of overwater structures is likely to maintain light levels under overwater structures greater than what is required by juvenile salmonids for feeding and schooling (i.e., estimated at between 0.0001 and 1 foot-candles, depending on age and species). To encourage daytime movement under terminals and other overwater structures, it would be beneficial to decrease the dark-edge effect as much as possible. Providing even a small amount of light in a regular pattern under a dock may encourage fish to swim

underneath. Natural lighting for fish could also be enhanced if the underside of the dock were reflective.

- Continued research is needed to improve our understanding of the relationship between overwater structures and the behavior of migrating juvenile salmonids. Acoustic tagging-tracking technology should be further used to address the data gaps in our knowledge.
- Fish feeding behavior during temporary delays of movement should be investigated. If prey resources and refuge habitat are adequate, fish may benefit from holding in an area adjacent to a terminal.

Kahler et al. (2000) recommends the following measures to mitigate or avoid the undesirable impacts of overwater structures on salmonids in lakes:

- No net increase in overwater coverage should occur in the Lake Washington system — permits for new construction should be contingent on permits for replacement structures. Only replacement structures that demonstrate a reduction in overwater coverage should be permitted. The amount of overwater coverage eliminated from the replacement pier could be held in a "surface area mitigation bank," which new piers would have to draw from. Gradually lower the total net coverage over local lakes.
- All piers, both new and replacement structures, should be restricted to a 3.5-foot-wide cantilever bridge that spans the nearshore area to a narrow moorage structure of the minimum size necessary to moor the applicant's boat.
- Cantilever bridge structures should be grated and as high off the water as practicable, and moorage structures should be no less than 24 inches above OHWL. Floating structures should have maximum light penetration and be removed annually after boating season.
- Prisms and grating should be studied to determine their efficacy at providing sufficient ambient light for macrophyte production under piers. The best products should be utilized in all new or replacement overwater structures to minimize losses of primary productivity.

11.2 Littoral Vegetation

Mitigation of impacts to littoral vegetation is best achieved through avoidance. If overwater structures are designed and located so that they do not reduce available light below approximately 325 $\mu M/m^2/sec$, then eelgrass impacts may be avoidable (Thom et al. 1996, in Simenstad et al. 1999). Where projects result in a direct loss of eelgrass during in-water construction, revegetation can be achieved through natural regrowth or transplanting (Thom et al. 2001); however, transplanting eelgrass is not always successful and the science is still developing. For one project in the San Juan Islands, post-disturbance monitoring of eelgrass beds indicates that where substrate, depth, light availability, and currents are suitable and adjacent eelgrass remains intact, natural revegetation can recolonize disturbed areas at a rate of greater than 1 foot per year (Jones and Stokes 2005).

In Washington, transplanting has been used with some success to revegetate eelgrass beds, although a review of eelgrass restoration projects concluded that eelgrass restoration is "possible, with difficulty" (Thom et al. 2001). New eelgrass beds can be established where conditions that prevent eelgrass from growing (e.g., shade, depth, substrate, or current velocity) are remedied (Thom et al. 2001).

Where conditions are suitable for eelgrass growth, impacts of overwater structures should be avoided or minimized by use of the following measures:

- Avoid impacts by locating structures away from eelgrass beds whenever possible.
- Minimize the area of impact by using the best available installation methods.
- Minimize shading by using the lowest possible number of pilings.
- Space pilings to minimize shade to areas suitable for eelgrass.
- Minimize dimensions of the structure to reduce shade.
- Incorporate design elements such as grated decks or deck openings to reduce shade.
- Whenever possible, orient structures to reduce the shade in habitat that is otherwise appropriate for eelgrass growth (e.g., structures oriented east-west cast a shadow on a single area for a longer period of the day than do structures oriented north-south).
- Locate the structure as high above the water as practical to reduce shade.
- Encourage shared-use docks to minimize cumulative impacts.
- Remove floats during off season and store at an upland location.

- Avoid vessel impacts to eelgrass by maximizing the vertical and horizontal distance between vessel propellers and eelgrass to the extent practicable, maintaining a minimum clearance of 1 foot below the propeller.

Adopting these measures would likely result in avoidance and minimization of eelgrass and macroalgae impacts to the greatest extent practicable. However, it is likely that some projects would still require compensatory mitigation to completely offset temporal loss of eelgrass function and site-specific and cumulative impacts on eelgrass.

11.3 Freshwater Aquatic Vegetation

Mitigation of impacts to aquatic vegetation should focus on ecosystem functions (Hruby et al. 1999). Although all non-noxious aquatic plants are considered beneficial, replacement of vegetation lost or disturbed during project installation may be less beneficial than other ecosystem renovation methods, depending on the plant coverage, density, species, and setting involved. For example, guidance on assessing the functions and values of riverine flow through wetlands in Western Washington (Hruby et al. 1999) does not include aquatic vegetation as a variable in evaluating the functions and values to anadromous or resident fish. Likewise, the matrices of ecosystem functions and pathways for making ESA determinations of effect at the watershed scale (NMFS 1996; USFWS 1998) do not include aquatic vegetation as an indicator of ecosystem function. However, this is partly because both of these evaluation systems are largely designed to address salmonid habitat requirements; re-evaluation is warranted for many potentially covered species having a stronger dependence on freshwater aquatic vegetation (e.g., Olympic mudminnow or California floater). In many settings, aquatic vegetation can recolonize through natural seeding and vegetative growth if conditions are suitable. Depth, substrate, shade, and competition among plant species are all factors that determine which species of plants colonize and survive (Chambers et al. 1999).

Using the functional approach to assessing potential impacts to aquatic vegetation (Hruby et al. 1999), which is an important habitat component for many of the potentially covered species (e.g., Olympic mudminnow and California floater), and determining appropriate mitigation for the loss of freshwater aquatic vegetation are likely to result in minimal potential for incidental take related to aquatic vegetation loss.

11.4 Riparian and Shoreline Vegetation

The following measures could help avoid and minimize incidental take arising from impacts to riparian and shoreline vegetation:

- Prepare revegetation plans for projects that temporarily disturb vegetation during construction. The revegetation plans should identify areas to be replanted with native riparian vegetation when construction is complete. Replanted vegetation should be monitored for a three-year period, and the project proponent should be required to ensure 100 percent survival of all plantings (considered viable and healthy) at the end of one year and 80 percent survival of all plantings (considered viable and healthy) by the end of the three-year monitoring period. These recommendations are based on provisions in WAC 220-110 and on general conditions provided by the Corps, NMFS, and USFWS for Corps ESA Section 7 programmatic consultations.
- Submit monitoring reports to WDFW as part of the revegetation plan. Similar to the requirement of the Corps for ESA Section 7 individual and programmatic consultations, two monitoring reports should be required, one to be submitted one year after project completion and the other to be submitted three or five years after project completion. The monitoring reports must include information on the percentage of plants replaced, by species and achieve specific performance standards related to survival rates (i.e., 100 percent at the end of year one and 80 percent at the end of the monitoring period). Monitoring reports should also state the cause of any plant failure, a provision generally required by the Corps, NMFS, and USFWS for Corps ESA Section 7 programmatic consultations.
- Recommend that vegetation (specifically large trees and root wads) removed for the project be saved for later use in restoration efforts. This condition has often been required in recent individual and programmatic Section 7 consultations. Even if the material is not specifically useful for the permitted action, a WDFW area habitat biologist will generally know of ongoing or pending restoration projects in need of LWD and root wads.
- To the extent practicable, do not permit removal or disturbance of riparian vegetation in areas with high erosion hazard (Knutson and Naef 1997). If such removal or disturbance is permitted, require replanting with native riparian vegetation or other appropriate erosion control measures.

- Require performance bonds for projects disturbing large areas of riparian vegetation.
- Projects that require extensive in-water work, which may require extensive access and which have high-quality riparian habitat, should have work performed entirely within the wetted channel to avoid impacts to riparian vegetation. The short-term impact to a stream channel may be of less consequence than the long-term impact that may be incurred to riparian vegetation, due to the respective rate of recovery.

Brennan and Culverwell (2004) recommend the following for consideration as part of any coastal management strategy and development of shoreline regulations associated with marine riparian habitat:

- Use the precautionary principle: "Do No Further Harm" — Preventing additional losses is both critical and cost-effective. Once riparian functions are lost, they are difficult and expensive to restore, if restoration is possible at all.
- Fill data gaps — The lack of empirical data for Northwest coastal ecosystems and limited recognition of riparian functions have led to poor management practices and protection standards for coastal resources. Research and documentation are critical to establish a scientific foundation for creating adequate policies and practices for protection and restoration.
- Establish appropriate buffers and setbacks — Buffers and setbacks are essential, functional, and cost-effective tools for preserving important processes and functions, preventing environmental degradation, and protecting valuable coastal resources.
- Maintain and/or restore riparian vegetation for human health and safety — Flooding, storm, and erosion hazards are common problems in coastal areas and become a greater threat when shoreline development does not consider the functions and values of maintaining riparian vegetation buffers.
- Identify, evaluate, and incorporate multiple functions into a management strategy — Any management strategy should be based on maintaining all natural processes and functions, determined by an evaluation of the specific requirements for maintaining individual and collective functions over space and time (e.g., LWD recruitment; life history requirements of multiple species of fishes and wildlife).
- Use a multidisciplinary approach in developing riparian management zones — Experts in a wide range of natural sciences should collaborate on an integrated and multidisciplinary assessment.

- Maintain and/or restore riparian vegetation for pollution abatement and soil stability — Vegetative buffers would likely be of benefit by reducing contaminants in runoff and reducing costly reactionary measures to clean up waterways.
- Maintain and/or restore riparian vegetation for fish and wildlife — It is clear that as vegetation is eliminated, the food supply, and thus the carrying capacity of the coastal ecosystem, is reduced.
- Protect marine riparian areas from loss and degradation — Riparian areas provide a wide range of functions that are beneficial to humans, fish, and wildlife. Every effort should be made to preserve remaining marine riparian areas from further degradation, fragmentation, and loss.
- Increase public education and outreach — It is critical that decision makers and the general public be educated about the outcomes of their actions, especially those who have the greatest influence on outcomes (i.e., those who live, work, and play along our shorelines).
- Develop and implement conservation programs — Use ecological principles to guide actions and incorporate multiple functions and processes in developing goals and objectives for conservation actions.
- Develop incentives for conservation programs — Land acquisition, tax incentives, regulatory incentives, and other measures have been used and should be considered in the development of conservation programs.

11.5 Noise

Several noise reduction devices have been developed for pile driving, including air bubble curtains, fabric barriers, pile caps, and cofferdams. Air bubble curtains infuse the area surrounding the pile with air bubbles, creating a bubble screen that reduces peak underwater sound pressure levels. Results on the effectiveness of bubble curtains for reducing sound pressure waves vary and range from 0 dB_{RMS} to 30 dB (neither peak nor RMS identified) (Reyff et al. 2003, Vagle 2003, both in WSDOT 2006a). Proper design and implementation of a bubble curtain are key factors in the effectiveness of this strategy (WSDOT 2006a). Based on the literature, NMFS and USFWS usually assume there will be a 15 dB_{peak} and RMS reduction in sound levels when using a bubble curtain (WSDOT 2006a). For steel piling 14 inches or less in diameter, as well as concrete and wooden piling, such a reduction would reduce noise levels to below injury thresholds established by NMFS and USFWS (as described in Section 7) at a distance of 33 feet (10 meters).

Fabric barriers and cofferdams are also used to attenuate sound levels from pile driving by creating another interface through which sound travels. The concept is similar to that behind the use of bubble curtains (WSDOT 2006a).

Pile caps have also been shown to effectively reduce underwater sound levels. Laughlin (2006) reduced sound levels by 27 dB with a wood pile cap when driving a 12-inch-diameter steel pile, which would reduce noise levels to below those established for injury (at 33 feet [10 meters]) by NMFS and USFWS. Conbest, Micarta, and Nylon pile caps have also been shown to reduce sound levels (Laughlin 2006).

Under certain conditions, a vibratory hammer can be used to reduce noise impacts. Vibratory hammers vibrate the pile into the sediment by oscillating the pile into the substrate. The vibratory action of this hammer causes the sediment surrounding the pile to liquefy so that the pile can be driven (WSDOT 2006a). Peak sound levels for vibratory hammers can exceed 180 dB; however, the sound from these hammers has a relatively slow rise, produces sound energy that is spread out over time, and is generally 10 to 20 dB lower than pile driving using an impact hammer (WSDOT 2006a). However, it is frequently necessary to proof a piling driven with a vibratory hammer with an impact hammer to ensure the integrity of the piling.

In addition to the prevention measures discussed above, construction activities should be timed to occur when sensitive life stages (e.g., spawning, incubation, emergence) of potentially covered species are less likely to be present (NMFS 2003a).

11.6 Water Quality

The following mitigation measures regarding suspended sediment are based on those proposed by Bash et al. (2001):

- Prior to project construction, determine suspended sediment concentrations and collect information on particle size and shape as indicators of the nature of existing turbidity.

- When evaluating cumulative impacts from turbidity, consider information from existing assessments of watershed condition to account for point and nonpoint source pollution loads from watershed sources other than the project, as well as legacy impacts of the system.
- Once existing turbidity and sources have been determined, WDFW may be able to establish allowable/acceptable increases to background turbidity associated with project-related activities, similar to those established in the Implementing Agreement between the Washington State Department of Transportation (WSDOT) and Ecology (WSDOT and Ecology1998), which states that:

    > All work in or near the water, and water discharged from the site shall meet the State's Water Quality Standards, WAC 173-201A. A mixing zone for turbidity is authorized within WAC 173.201A-030 during and immediately after necessary in-water or shoreline construction activities that result in the disturbance of in-place sediments. Use of a turbidity mixing zone is intended for brief periods of time (such as a few hours or days) and is not an authorization to exceed the turbidity standard for the entire duration of the construction. Use of the mixing zone is subject to the constraints of WAC 173-201A-100(4) and (6), requiring an applicant have supporting information that indicates the use of the mixing zone shall not result in the loss of sensitive or important habitat, substantially interfere with the existing or characteristic uses of the water body, result in damage to the ecosystem, or adversely affect public health. The mixing zone is authorized only after the activity has received all other necessary local and state permits and approvals, and after the implementation of appropriate best management practices to avoid or minimize disturbance of in-place sediments and exceedances of the turbidity criteria. Within the mixing zone, the turbidity standard is waived, and all other applicable water quality standards shall remain in effect. The mixing zone is defined as follows:
    >
    > 1) For waters up to 10 cfs [cubic feet per second] flow at time of construction, the point of compliance shall be 100-feet downstream of project activities.

2) For waters above 10 cfs up to 100 cfs flow at time of construction, the point of compliance shall be 200-feet downstream of project activities.
3) For waters above 100 cfs flow at the time of construction, the point of compliance shall be 300 feet downstream of project activities.
4) For projects working within or along lakes, ponds, wetlands, estuaries, marine waters or other non-flowing waters, the point of compliance shall be at a radius of 150-feet from the activity causing the turbidity exceedance.

- Set stockpile areas back from the bank and include erosion prevention BMPs, such as silt fencing and tarp covers.

Many of the following mitigation measures regarding aquatic applications of treated wood are based on those suggested by Poston (2001).

- Use alternative materials such as metal, concrete, or composites, or for temporary projects use untreated wood.
- If possible, install immersed treated wood products when potentially covered species are not present near the site. This measure is based on information on rapidly diminishing leaching rates reported by Poston (2001).
- Pre-soak treated wood in confined water to reduce impacts by capturing the initial surge of most concentrated leachate, particularly in the case of ACZA- and CCA Type C-treated products, for which leaching rates appear to drop dramatically after a few days.
- Phase and stagger the installation of ACZA- and CCA Type C-treated structures by a few weeks or more, which may dramatically reduce the concentration of leached metals in surrounding water and the instantaneous extent of the area of impact. This measure is based on information on rapidly diminishing leaching rates reported by Poston (2001).
- Use semi-transparent, water-repellent stain, latex paint, or oil-based paint on above-water portions of treated wood structures, which may reduce leaching of arsenic, chromium, and copper into stormwater generated by that portion of the structure (Lebow et al. 2004).

Adopting these measures would greatly reduce, and in some cases eliminate, the risk of incidental take due to water quality impairments.

11.7 Channel Hydraulics

It is difficult to programmatically quantify the risk of incidental take attributable to any structure that modifies a stream channel because of the great variety of site-specific factors at work. However, the review performed for this white paper indicates that habitat impacts are approximately defined by the area of habitat affected, the number of species affected, and the importance of the habitat to each species.

The area of habitat affected is the area of habitat destruction, which can be determined from project plans, plus the area of habitat subject to embedding, scour, or deposition, which can be determined via hydraulic modeling of the structure using a common sediment transport model (appropriate models are described by Miller et al. 2001).

The number of species affected can be determined at the site scale via surveys or from an inventory database, such as the Streamnet database, the Priority Habitats and Species database, the distribution maps developed for the WDNR Aquatic Lands HCP effort, or the Forest Practices HCP. For certain species, these resources identify species use as well as presence, e.g., spawning, migration, or rearing habitat.

The importance of a habitat can be estimated by the principle of limiting factors: The resource that is most limiting to a population's growth will be the principal control on that population. For example, if the fish in a given stream are most limited by insufficient spawning habitat, then a project that destroys spawning habitat will result in greater harm than one that destroys an equivalent area of foraging habitat. Baseline data on limiting factors for some species are available from watershed councils and have been prepared for most WRIAs that contain habitat accessible to anadromous salmonids; a current inventory and summaries of limiting factors are available from the Washington State Conservation Commission website at http://salmon.scc.wa.gov. However, these summaries are rarely informative enough to make a determination about which habitat elements are directly limiting for fish production. For salmonids, quantitative analysis has estimated limiting factors for most streams in Washington using the Ecosystem Diagnosis and Treatment model; further information is available at http://www.mobrand.com/edt/.

Additional measures that could minimize impacts from artificial structures include finding an alternative to building the structure; siting the structure as far as possible outside of the active channel; minimizing the structure's footprint; and generally designing the structure to have the least possible effect on channel hydraulics (Bates 2003).

WDFW could consider requiring that HPAs for any structure that will place fill within the OHWL include a hydraulic model of probable structure effects on sediment transport and channel hydraulics to ensure that impacts such as scour, deposition, and embedding due to fine sediment deposition are avoided or minimized to a quantitatively ascertainable degree. Such a requirement would ensure that effects of the structure on the channel, and by extension on potentially covered species, are as well understood as practicable. The results of such studies can be summarized to provide an indicator of the quantitative impact of authorized projects on channel hydraulics. Such results would be useful in estimating cumulative impacts of the HPA program, incidental take, and identifying appropriate compensatory mitigation measures.

11.8 Littoral Drift

Impacts to littoral drift can be avoided or minimized by avoiding or reducing those features that interfere with littoral transport processes (see Section 7.8) through the following measures:

- Design pile-supported structures with maximum open space between pilings to allow waves, currents, and sediment to pass beneath (MOEE 1995).
- Minimize certain impacts from floating structures placed perpendicular to shorelines, which dampen wave action and prohibit natural shoreline erosional processes, by minimizing the dimensions of these types of structures.
- Utilize floating breakwaters or ramps in place of breakwater walls to reduce effects on littoral drift (Nightingale and Simenstad 2001b).
- Do not allow floats to ground at low tide.

The effects of these measures are site-specific, and thorough study of the littoral drift cell and potential habitat affected should be conducted on projects that could affect the system's littoral currents and wave action. Avoiding or minimizing alterations in littoral processes would allow shoreline sediment conditions to change at the scales and rates that match those that potentially covered species have evolved to adapt to, minimizing the potential for incidental take through alterations in shoreline substrate distribution and consistency.

11.9 Substrate Modifications

In the nearshore environment, where overwater structures alter the benthic environment via shellhash deposition and establishment of invertebrate communities on pilings, use of fewer and more widely spaced pilings will help to reduce sea star and crab bioturbation of the benthos (Thom et al. 1995, in Haas et al. 2002).

Prohibiting overwater structures from grounding out during low tide events will avoid potential impacts such as affecting aquatic organisms by directly crushing the organisms or changing the character of the substrate. The U.S. Army Corps of Engineers prohibits the grounding of floats on tidal substrates at any time in their Regional General Permit No. 6 (USACE 2005).

11.10 Channel Dewatering

The following actions could be taken to minimize the impacts of channel dewatering on potentially covered species:

- Adopt guidance/protocols for fish removal and exclusion. Specifically, this refers to guidance/protocols for fish capture (including seining and electrofishing), fish handling, and reporting on the number and types of fish captured, fish injured, injuries observed, and mortality. An example protocol is provided by WSDOT (WSDOT 2006b).
- Develop guidelines for channel dewatering and stream bypasses. Adopt a protocol for review/approval of proposed dewatering and stream bypass plans.
- Define the qualifications of a "qualified fish biologist" or "qualified personnel" who can perform fish capture and handling activities or develop an appropriate training or qualification process for biologists. In addition, maintain a list of qualified fish biologists who can perform fish removal and exclusion activities.

- Initiate volitional fish removal activities before isolating and dewatering the work area and have qualified fish biologists present to oversee the fish removal activities.

In addition, Snyder (2003) recommends the following measures to minimize the harmful effects of electrofishing on fish:

- Use the lowest power output that still provides for effective electrofishing (sufficiently large field for taxis and narcosis).
- Use the least damaging current available (direct current; do not use alternating current). However, the occurrence of brands (i.e., burn-type marks caused by electrofishing) and extended tetany (tonic spasm of muscles) indicates harmful effects are still a problem, even when using currents designed to be less harmful.
- Use spherical electrodes and vary the number and size of spheres according to water conductivity and desired size and intensity of the field. Personal communications cited in Snyder (2003) suggest that while spherical electrodes are theoretically superior to cables, no significant difference in catch rate or the incidence of brands was observed between the two; that spherical anodes and cable cathodes appear to be the best combination; and that anodes should be kept high in the water to draw fish to the surface, where they can be easily netted.
- Minimize exposure to the field and specimen handling by rapidly netting fish before they get too close to the anode and quickly, but gently, placing them in oxygenated holding water.
- Change the holding water frequently to ensure adequate dissolved oxygen and to avoid excessive temperatures on hot days; process the fish frequently to reduce crowding.

11.11 Artificial Light

Kahler et al. (2000) recommends that to reduce impacts on salmonid predation, additional shoreline or pier lighting on lakes should not be permitted, and Tabor et al. (1998) suggests that reducing artificial light in the Cedar River would benefit emigrating sockeye salmon. Tabor et al. (1998) also observed that any reduction in artificial lighting must be balanced with safety and other public concerns.

11.12 Vessel Activities

Issues related to vessel activities include vessel grounding in sensitive habitats (such as eelgrass), the effects of propeller wash, the risk of accidental spills of fuel or other contaminants, and the risk of introducing noxious weeds. Vessel grounding impacts can be minimized by adopting WDFW's HPA provisions that prohibit the grounding of vessels in areas of eelgrass, macroalgae, or forage fish spawning (e.g., "Eelgrass and kelp shall not be adversely impacted due to project activities [e.g., vessels shall not ground, anchors and spuds shall not be deployed, equipment shall not operate, and other project activities shall not occur in eelgrass and kelp"]). It may also be appropriate to require construction vessel operation plans for larger projects or projects located in particularly sensitive habitat to ensure that the potential for vessel and construction activity impacts to sensitive habitats and species is minimized. To reduce vessel impacts to the nearshore environment at the Clinton ferry terminal, Thom et al. (1995, in Haas et al. 2002) recommended constructing a longer deck that keeps vessels in deeper water. HPA standard provisions should include provisions to clean propellers before putting boats into the water to reduce the spread of noxious weeds, file a spill prevention plan, and maintain the vessel on a routine basis as well as prior to its use on the construction site. Residential/recreational floats should be sited in deeper water to reduce the potential impacts associated with propeller wash.

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APPENDIX A

STANDARD HPA PROVISIONS

Chapter 220-110 WAC

Last Update: 6/22/05

Hydraulic code rules

Chapter Listing

WAC Sections

220-110-060	Construction of freshwater docks, piers, and floats and the driving or removal of piling.
220-110-300	Saltwater piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings.

220-110-060
Construction of freshwater docks, piers, and floats and the driving or removal of piling.

All pier, dock, float, and piling construction projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. The following technical provisions shall apply to freshwater dock, pier, and float construction projects and the driving or removal of piling:

(1) Excavation for and placement of the footings and foundation shall be landward of the ordinary high water line unless the construction site is separated from state waters by use of an approved dike, cofferdam, or similar structure.

(2) Alteration or disturbance of the bank and bank vegetation shall be limited to that necessary to construct the project. All disturbed areas shall be protected from erosion, within seven days of completion of the project, using vegetation or other means. The banks shall be revegetated within one year with native or other approved woody species. Vegetative cuttings shall be planted at a maximum interval of three feet (on center), and maintained as necessary for three years to ensure eighty percent survival. Where proposed, planting densities and maintenance requirements for rooted stock will be determined on a site-specific basis. The requirement to plant woody vegetation may be waived for areas where the potential for natural revegetation is adequate, or where other engineering or safety factors preclude them.

(3) Removal of existing or temporary structures shall be accomplished so that the structure and associated material does not reenter the watercourse.

(4) All piling, lumber, or other materials treated with preservatives shall be sufficiently cured to minimize leaching into the water or bed. The use of wood treated with creosote or pentachlorophenol is not allowed in lakes.

(5) Skirting or other structures shall not be constructed around piers, docks, or floats unless specifically approved in the HPA.

(6) Floatation for the structure shall be enclosed and contained, when necessary, to prevent the breakup or loss of the floatation material into the water.

(7) All work operations shall be conducted in such a manner that causes little or no siltation to adjacent areas. If at any time, fish are observed in distress, a fish kill occurs, or water quality problems develop as a result of a pier, dock, float, or piling project, construction operations shall cease and the permittee or authorized agent shall immediately contact the department.

(8) Removal of aquatic vegetation shall be limited to that necessary to gain access to construct the project.

[Statutory Authority: RCW 75.08.080. 94-23-058 (Order 94-160), Â§ 220-110-060, filed 11/14/94, effective 12/15/94; 87-15-086 (Order 87-48), Â§ 220-110-060, filed 7/20/87. Statutory Authority: RCW 75.20.100 and 75.08.080. 83-09-019 (Order 83-25), Â§ 220-110-060, filed 4/13/83.]

220-110-300
Saltwater piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings.

Piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated mooring projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. The following technical provisions apply to piers, pilings, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings in saltwater areas. In addition, these projects shall comply with technical provisions and timing restrictions in WAC 220-110-240 through 220-110-271.

(1) Floats and rafts shall not ground on surf smelt, Pacific herring, Pacific sand lance, and rock sole spawning beds. In all other areas, no more than twenty percent of the float or raft within the beach area shall ground at any time. Those portions of the float or raft that will ground shall be constructed to align parallel to the shore and provide a minimum of eight inches clearance between the beach area and nongrounding portions of the float.

(2) Floats, rafts, and associated anchoring systems shall be designed and deployed so that the bed is not damaged.

(3) Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located to avoid shading of eelgrass (Zostera spp).

(4) Kelp (Order laminariales) and intertidal wetland vascular plants (except noxious weeds) adversely impacted due to construction of piers, docks, floats, rafts, ramps, boathouses, and houseboats shall be replaced using proven methodology.

(5) Mitigation measures for piers, docks, floats, rafts, ramps, and associated moorings shall include, but are not limited to, restrictions on structure width and/or incorporation of materials that allow adequate light penetration (i.e., grating) for structures located landward of -10.0 feet MLLW.

(6) Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located to avoid adverse impacts to Pacific herring spawning beds and rockfish and lingcod settlement and nursery areas.

(7) Piers, docks, floats, rafts, ramps, boathouses, houseboats, and associated moorings shall be designed and located to avoid adverse impacts to juvenile salmonid migration routes and rearing habitats.

(8) Floatation for the structure shall be fully enclosed and contained to prevent the breakup or loss of the floatation material into the water.

(9) Boathouses and houseboats and covered moorages shall not be located landward of -10.0 feet MLLW.

[Statutory Authority: RCW 75.08.080. 94-23-058 (Order 94-160), Â§ 220-110-300, filed 11/14/94, effective 12/15/94. Statutory Authority: RCW 75.08.012, 75.08.080 and 75.20.100. 84-04-047 (Order 84-04), Â§ 220-110-300, filed 1/30/84. Statutory Authority: RCW 75.20.100 and 75.08.080. 83-09-019 (Order 83-25), Â§ 220-110-300, filed 4/13/83.]

APPENDIX B

MAPS: TRAs AND WRIAs

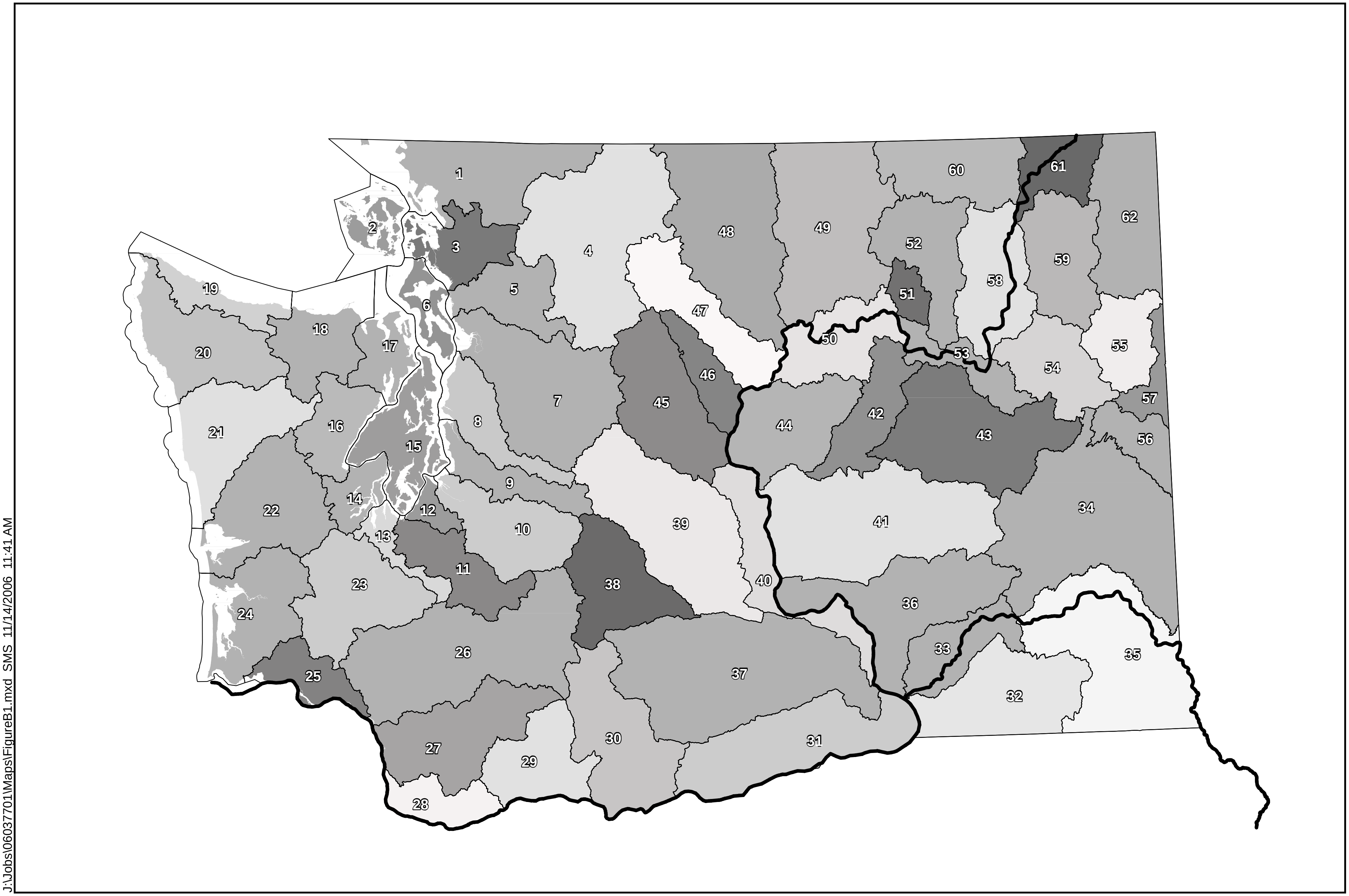

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Figure B-1
Water Resource Inventory Areas

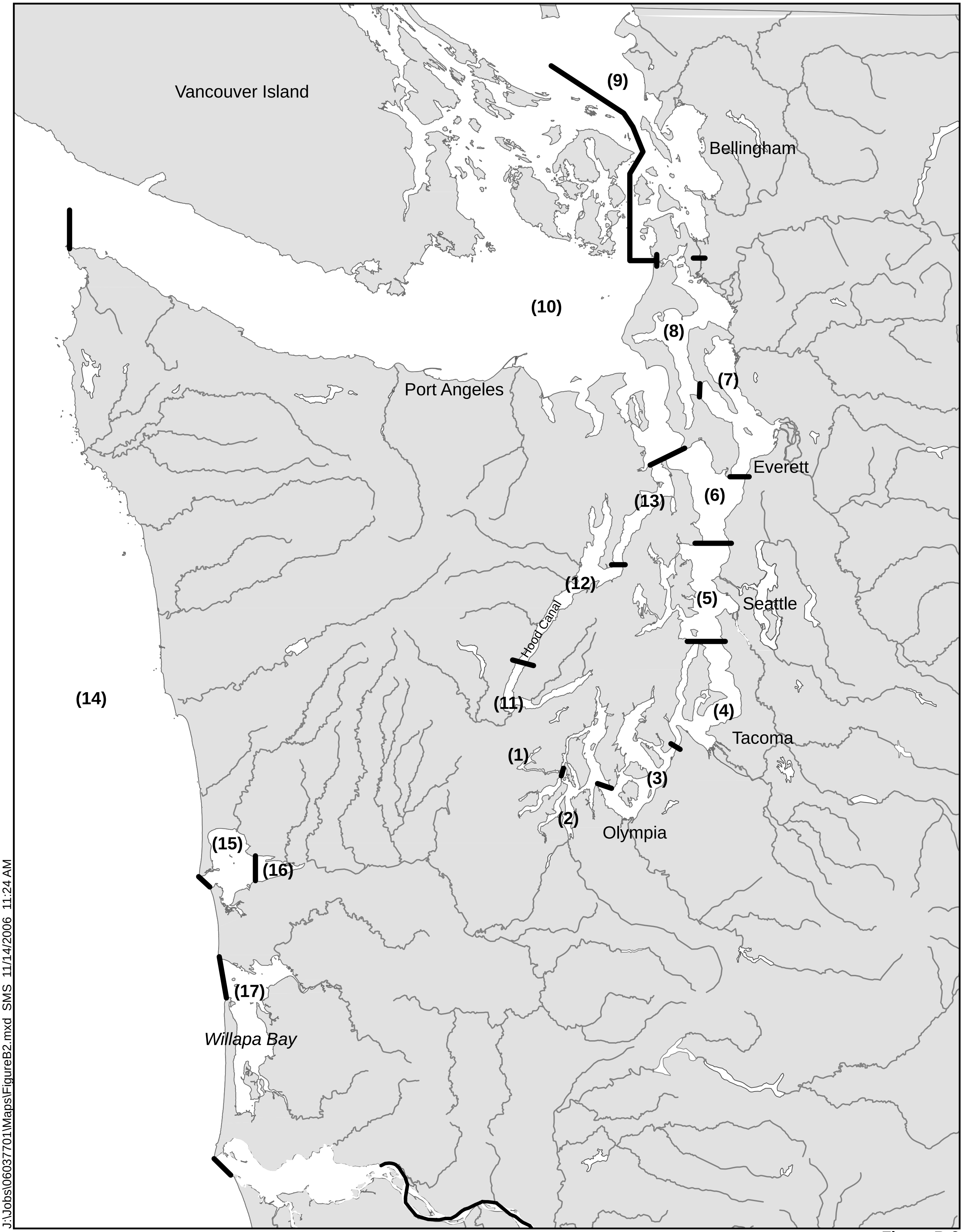

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Figure B-2
Tidal Reference Areas