WATER CROSSINGS WHITE PAPER

Prepared for

Washington Department of Fish and Wildlife
600 Capitol Way North
Olympia, Washington 98501-1091

Prepared by

Jones & Stokes Associates
11820 Northup Way, Ste E300
Bellevue, Washington 98005

In association with

Anchor Environmental, L.L.C.
1423 Third Avenue, Suite 300
Seattle, Washington 98101

R2 Resource Consultants
15250 NE 95th Street
Redmond, Washington 98052

December 2006

EXECUTIVE SUMMARY ES-1
Overview ES-1
Species and Habitat Use ES-2
Risk of Take and Potential Mitigation Measures ES-3
Channel Dewatering ES-3
Channel Hydraulics ES-3
Littoral Drift ES-4
Substrate Modifications ES-4
Water Quality ES-4
Eelgrass and Macroalgae ES-5
Freshwater Aquatic Vegetation ES-5
Riparian and Shoreline Vegetation ES-6
Noise ES-6
Artificial Light ES-6
Shading 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 Channel Dewatering 7-1
7.1.1 Fish Removal and Exclusion 7-2
7.1.2 Fish Entrainment 7-3
7.1.3 Alteration of Flow 7-3
7.1.4 Disturbance of the Streambed 7-4
7.1.5 Loss of Invertebrates 7-4
7.1.6 Elevated Turbidity During Rewatering 7-6
7.2 Channel Hydraulics 7-6
7.2.1 Controlling Factors in Channels 7-6
7.2.2 Habitat Structure in Channels 7-9
7.3 Littoral Drift 7-15
7.3.1 Wave Action 7-16
7.3.2 Littoral Currents 7-18
7.4 Substrate Modifications 7-19

7.5 Water Quality 7-20
7.5.1 Suspended Solids 7-21
7.5.2 Contaminated Sediment Impacts 7-26
7.5.3 Dissolved Oxygen Impacts 7-26
7.5.4 pH Impacts 7-27
7.5.5 Treated Wood-Related Impacts 7-27
7.5.6 Stormwater and Nonpoint Source Water Quality Impacts 7-36
7.6 Eelgrass and Macroalgae 7-37
7.6.1 Ambient Light 7-39
7.6.2 Direct Disturbance and Displacement 7-41
7.6.3 Vessel Interactions 7-41
7.7 Freshwater Aquatic Vegetation 7-42
7.7.1 Ambient Light 7-43
7.7.2 Direct Disturbance During Installation 7-44
7.7.3 Vessel Interactions 7-44
7.7.4 Introduction of Noxious Weeds 7-44
7.8 Riparian and Shoreline Vegetation 7-45
7.8.1 Shading and Water Temperature Regime 7-45
7.8.2 Streambank/Shoreline Stability 7-47
7.8.3 Altered Allochthonous Input 7-47
7.8.4 Groundwater Influence 7-48
7.8.5 Habitat Conditions 7-49
7.9 Noise 7-50
7.9.1 Pile Driving 7-50
7.9.2 Noise from Construction Vessels and Equipment 7-54
7.10 Artificial Light 7-54
7.11 Shading 7-57
7.11.1 Shading and Fish/Invertebrates 7-58
7.11.2 Prey Abundance, Feeding, and Growth 7-61
7.11.3 Migration and Distribution 7-62
7.11.4 Predation 7-65
7.12 Vessel Activities 7-67
7.12.1 Sediment Disturbance 7-67
7.12.2 Eelgrass and Macroalgae Disturbance 7-68
7.12.3 Freshwater Aquatic Vegetation Disturbance 7-68
7.12.4 Noise 7-69
7.12.5 Artificial Light 7-70

8 CUMULATIVE IMPACTS OF WATER CROSSINGS 8-1
8.1 Channel Dewatering 8-1
8.2 Channel Hydraulics 8-2
8.3 Littoral Drift 8-3
8.4 Substrate Modifications 8-3

8.5 Water Quality 8-4
8.6 Eelgrass and Macroalgae 8-5
8.7 Freshwater Aquatic Vegetation 8-5
8.8 Riparian and Shoreline Vegetation 8-6
8.9 Noise 8-6
8.10 Artificial Light 8-6
8.11 Shading 8-7
8.12 Vessel Activities 8-8

9 POTENTIAL RISK OF TAKE 9-1
9.1 Channel Dewatering 9-4
9.2 Channel Hydraulics 9-5
9.2.1 No Impact 9-6
9.2.2 Habitat Loss 9-7
9.2.3 Embedding 9-8
9.2.4 Scour 9-10
9.2.5 Deposition 9-12
9.2.6 Rapid Channel Change 9-14
9.3 Littoral Drift 9-16
9.4 Substrate Modifications 9-18
9.5 Water Quality 9-20
9.6 Eelgrass and Macroalgae 9-21
9.7 Freshwater Aquatic Vegetation 9-22
9.8 Riparian and Shoreline Vegetation 9-22
9.9 Noise 9-23
9.10 Artificial Light 9-24
9.11 Shading 9-24
9.12 Vessel Activities 9-25
9.13 Conclusions of the Risk Evaluation 9-26

10 DATA GAPS 10-1
10.1 Channel Dewatering 10-1
10.2 Channel Hydraulics 10-2
10.3 Littoral Drift 10-2
10.4 Substrate Modifications 10-2
10.5 Water Quality 10-3
10.6 Eelgrass and Macroalgae 10-3
10.7 Freshwater Aquatic Vegetation 10-4
10.8 Riparian and Shoreline Vegetation 10-4
10.9 Noise 10-4
10.10 Artificial Light 10-5
10.11 Shading 10-5
10.12 Vessel Activities 10-6

11 HABITAT PROTECTION, CONSERVATION, MITIGATION, AND MANAGEMENT STRATEGIES 11-1
11.1 Channel Dewatering 11-1
11.2 Channel Hydraulics 11-2
11.3 Littoral Drift 11-5
11.4 Substrate Modifications 11-5
11.5 Water Quality 11-6
11.6 Eelgrass and Macroalgae 11-7
11.7 Freshwater Aquatic Vegetation 11-8
11.8 Riparian and Shoreline Vegetation 11-9
11.9 Noise 11-10
11.10 Artificial Light 11-11
11.11 Shading 11-11
11.12 Vessel Activities 11-12

12 REFERENCES 12-1

List of Tables

Table ES-1 Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species ES-3
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 During Construction and Operation of Water Crossing Structures 6-2
Table 5 Effects Thresholds for PAHs in Surface Water 7-31
Table 6 U.S. Water Quality Criteria for the Protection of Aquatic Life ("aquatic life criteria") for Water Soluble Chemicals Used in Treating Wood 7-34
Table 7 Threshold Effects Concentrations (TECs) for Freshwater Sediment 7-35
Table 8 Probable Effects Concentrations (PECs) for Freshwater Sediment 7-36
Table 9 Hearing Categories for Potentially Covered Fish Species 7-52
Table 10 Summary of Potential for Incidental Take of Potentially Covered Species 9-2
Table 11 Potential Impacts of Changes in Channel Hydraulics on Potentially Covered Species 9-6
Table 12 Conclusions of the Risk Evaluation 9-27

List of Figures

Figure 1 Conceptual Framework for Assessment 6-1
Figure 2 Juvenile Salmon Behavior Patterns Related to Light Intensity 7-60

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
BMP	best management practice
CCA	chromated copper arsenate
CCC	criterion chronic concentration
CFR	Code of Federal Regulations
CMC	criterion maximum concentration
Corps, the	U.S. Army Corps of Engineers
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
HCP	Habitat Conservation Plan
HPA	Hydraulic Project Approval
HPDD	high-pressure directional drilling
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
SSC	suspended sediment concentration
TEC	threshold effects concentration
TRA	Tidal Reference Area
TSS	total suspended solids
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
cm	centimeter
cm/sec	centimeters per second
dB	decibel
F	Fahrenheit
JTU	Jackson turbidity unit
m	meter
m^3	cubic 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/L	milligrams per liter
mg/kg	milligrams per kilogram
mm	millimeter
mm/hour	millimeters per hour
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 the HPA program complies with the Endangered Species Act (ESA), the WDFW is considering 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.

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 one such HPA activities, water crossings. Water crossings are defined by WDFW as "structures that facilitate the movement of people, animals, or materials across water from bank to bank; such structures include bridges, culverts, fords, cable cars, tunnels, conduits (regardless of what a conduit conducts), and similar structures."

The literature review conducted for this white paper identified 12 impact mechanisms associated with the construction and operation of water crossings 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:

- Channel dewatering

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

Water crossings may also impact fish passage; however, that impact is not addressed herein because it will be the focus of a separate white paper.

Following a brief description of water crossing activities and potential impact mechanisms, the 52 aquatic species being considered for coverage under the HCP are described. Based on this information, the risk 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 water crossing. 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.

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.

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 (primarily fill placement) 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
Rapid channel change via migration or channel avulsion due to accidental flow obstruction, particularly flow blockage, from an artificial structure	Species potentially occupying the habitats that may be dewatered or buried by the impact
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. A variety of measures could be employed to minimize or avoid such incidental take.

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 "Eelgrass and Macroalgae."

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

- Design pile-supported structures with open space between pilings.
- Minimize the width of water crossing structures.
- Use hydraulic analysis and design to determine how a structure is likely to impact littoral drift.

Substrate Modifications

The principal risk of incidental take due to substrate modification is the loss of habitat resulting from the placement of fill. Substrate modifications can be minimized by proper hydraulic design of bridges and culverts.

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 often 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 avoid the impact through avoidance behavior; 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.

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. 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 eelgrass and macroalgae 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, NOAA Fisheries 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.
- Save vegetation (specifically large trees and root wads) removed for a 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 water crossings 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.

Artificial Light

Incidental take of listed fish species as a result of artificial light to build or operate water crossings 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.

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 structures (or the diameter of culverts) to allow more light to reach the water surface
- Decreasing structure width to decrease the shade footprint
- Using the smallest possible number of pilings or piers, allowing more light beneath the structure

Vessel Activities

Vessel activities associated with the installation and operation of water crossings 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 habitat to ensure that the potential for vessel and construction activity impacts to sensitive habitats and species is minimized.

1 INTRODUCTION

In Washington State, construction or performance of work that will use, divert, obstruct, or change the natural bed[1] or flow of state waters requires 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 (known as 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 U.S.C. 1532(19)).

To ensure that the activities conducted under the HPA authority comply with the ESA and to facilitate ESA compliance for citizens 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 outline conservation measures 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.

[1] Bed is defined as the land below the ordinary high water line of the state waters, but does not include irrigation ditches, canals, 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.

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.

This white paper addresses the availability of scientific information on one such HPA activity, water crossings. Water crossings are defined by WDFW as "structures that facilitate the movement of people, animals, or materials across water from bank to bank; such structures include bridges, culverts, fords, cable cars, tunnels, conduits (regardless of what a conduit conducts), and similar structures." 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 water crossings. 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
Longfin smelt	*Spirinchus thaleichthys*	SPHS	Anadromous
Eulachon	*Thaleichthys pacificus*	FC/SC	Anadromous

Common Name	Scientific Name	Status	Habitat
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.

A review of WDFW's Hydraulic Project Management System database, which tracks HPAs issued, revealed that since 1998, 93 percent of HPAs issued for water crossings have been for bridges, culverts, or conduits. This white paper therefore focuses on bridges, culverts, and conduits, which are the structures for which WDFW would benefit by securing programmatic coverage under the ESA.

The remainder of this white paper is organized as follows:

- Section 2 – Objectives
- Section 3 – Methodology
- Section 4 – Permitted water crossing activities
- Section 5 – Distributions and habitat use of the potentially covered species

- Section 6 – Conceptual framework for assessing impacts
- Section 7 – Analysis of direct and indirect impacts
- Section 8 – Analysis of cumulative impacts
- Section 9 – Analysis of the potential risk of take
- Section 10 – Identified data gaps
- Section 11 – Strategies and management recommendations to offset potential impacts
- Section 12 – Publication details for the references cited

2 OBJECTIVES

The objectives for 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 water crossings 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 water crossings
- 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 of potentially covered species.

3 METHODOLOGY

The following five principal tasks were performed in preparing this white paper:

1. Existing WDFW rules and guidance were reviewed to identify current knowledge and practices relevant to the analysis of water crossing impacts on potentially covered species. WDFW guidance relevant to water crossings includes (a) *Design of Road Culverts for Fish Passage*, referred to here as the culvert manual (Bates 2003); (b) the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003), and (c) the *Stream Habitat Restoration Guidelines* (Saldi-Caromile et al. 2004).
2. A literature review was conducted to compile information reflecting the current state of knowledge regarding potential impacts from water crossings on potentially covered species. The compiled literature set included (a) relevant previous white papers prepared by WDFW; (b) copies of HPAs for marine and freshwater projects, which were 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 that address various water crossing projects in Washington and Oregon. The principal keyword search strategy was to look for documents linking terms describing the species (i.e., common and scientific names of potentially covered species) with terms describing water crossing structures or pathways of impact associated with the construction and operation of such structures. In addition, some documents were identified through the bibliographies contained in documents identified through the searches described above.
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 other than salmonids were also identified 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 pathways and for each of the principal water crossing types.
5. A draft version of this white paper was prepared and reviewed by technical specialists on the consultant team, then submitted to WDFW for comments. The white paper was

amended based on the comments provided by WDFW and the white paper was finalized.

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." Water crossings, although not defined in the RCW, are defined by WDFW as "structures constructed to facilitate the movement of people, animals, or materials across water from bank to bank. These structures include bridges, culverts, fords, cable cars, tunnels, conduits (regardless of what the conduit is conducting), etc." Based on discussions with WDFW, this white paper has a slightly narrower focus on water crossings in the form of bridges, culverts, or conduits, which collectively represent 93 percent of all water crossing HPAs issued by WDFW between 1998 and 2006.

The complete legal description of water crossing structures is contained in Washington Administrative Code (WAC) 220-110, the *Hydraulic Code Rules*, and is particularly detailed in WAC 220-110-070, *Water crossing structures*. Additional WAC provisions relevant to water crossings include WAC 220-110-100, *Conduit crossing*, and WAC 220-110-310, *Utility lines*. Appendix A reproduces the full text of these WAC sections.

For the purposes of this analysis:

1. A culvert is defined as a hydraulic project conveying waters of the state through a fill.
2. A bridge is defined as a hydraulic project conveying goods or materials from one bank to another across waters of the state.
3. A conduit is defined as a hydraulic project conveying goods or materials beneath waters of the state (tunnels usable by humans were not included in this analysis).

Practical examples of culverts and bridges are abundant. Examples of conduits authorized under HPAs include sewer lines, pipelines, and cables trenched or tunneled across streams and comparable structures trenched, tunneled, or laid on the bottom in marine waters. Conduits can also be attached to bridges, but there are no significant ESA-related risks associated with such installations, and bridge-attached conduits are therefore not analyzed in this white paper.

For this white paper, water crossings are defined as hydraulic projects that comply with all provisions specified in WAC 220-110-070, WAC 220-110-100, or WAC 220-110-310. The analysis presented in this white paper addresses the impacts of lawful activities, which are the 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 water crossings authorized by WDFW.

Most water crossings also affect waters of the United States. Thus, their construction also requires a permit from the U.S. Army Corps of Engineers (the Corps) 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 the 52 potentially covered species listed in Table 1 by noting their 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

Common Name	Scientific Name	Water Resource Inventory Area*	Tidal Reference Area (see list below)*
Coho salmon	*Oncorhynchus kisutch*	1-42, 44-48, 50	All
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*	N/A	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
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)

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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; larger individuals feed on detached, drift algae (NMFS 2004; Gardner 1981; West 1997; In: WDNR 2006b; Jamieson 1999)	Spawning: Broadcast spawners; release pelagic gametes that develop into free-swimming larvae; mature larvae settle on crustose coralline algae
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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; require: 1) soft mud substrate, , 2) little or no flow, and 3) dense aquatic vegetation; prefer bogs and swamps; 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
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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; Myers et al. 1998; 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
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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
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

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
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; Bargmann 1998)	Spawning: November to April 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

Water crossing structures 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 a water crossing structure. The 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 species of interest.

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 water crossing structures 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 During Construction and Operation of Water Crossing Structures

Impact Pathway	Description
Channel dewatering	Changes that result from altered flow, principally from dewatering that occurs due to stream diversion during culvert work or bridge construction.
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).
Water quality	Changes in water quality, chiefly in turbidity, but also in temperature, pH, dissolved oxygen content, and metallic or organic toxins.
Eelgrass and macroalgae	Artificial changes in submerged 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.
Artificial light	Artificial light used during construction or operation of a structure.
Shading	All shading of waters, whether by natural or artificial means.
Vessel activities	Changes resulting from the operation of vessels during construction or other operations that occur during construction of the water crossing structure.

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. For each pathway, the risk that construction or operation of water crossings may result in incidental take, as well as the potential severity of such take, is evaluated. 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 7.9). In the following impact analysis, such areas of overlap are identified by cross references.

7.1 Channel Dewatering

Channel dewatering occurs primarily in freshwater streams and is typically associated with the need to work "in the dry" during installation, construction, or replacement of culverts and bridges. Review of numerous biological opinions prepared by NOAA Fisheries 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.

7.1.1 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 and a cofferdam and slowly dewatering the construction area. It has been suggested that reductions in flow of 80 percent result in the greatest number of fish (approximately 50 to 75 percent) volitionally moving out of the dewatered construction area (NMFS 2006g). 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 downstream to a point beyond the construction area, where dewatering will not occur. Another 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 all fish have been removed from the construction area being dewatered (NMFS 2003b).

Captured fish are typically released downstream of the construction area. Depending on the number of fish captured and the size of the stream, 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. These effects represent the potential for incidental take. 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). However, adverse effects are minimal 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, including 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).

7.1.2 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 dewater residual pools within a portion of the dewatered channel, the hose or pipe pulling water from the channel is typically fitted with a mesh screen to prevent aquatic life from being entrained into the intake hose/pipe of the pump (WSDOT 2006a).

7.1.3 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 the dewatering of 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 water crossing structures on stream channels are discussed in more detail in Section 7.2.

7.1.4 Disturbance of the Streambed

Disturbance of the streambed associated with channel dewatering can be extensive, depending on the purpose of the dewatering. If a water crossing 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) may occur, such as when a new roadway requires installation of a new stream crossing structure. The effects of such substrate disturbance are discussed in greater detail in Section 7.2.

7.1.5 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 dewatering during construction (summarized in Waters 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 (Waters 1999). Blinn et al. (1995, in Waters 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 Waters 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, i.e., exceeding 79 degrees Fahrenheit (F) (26 degrees Celsius [C]). This area was exposed for at least 20 days before being inundated again.

Exposure to cold air may be equally lethal (Waters 1999). Nagel (1987, in Waters 1999) believed mussels were more sensitive to cold water during frosts than to warm water during temporary droughts. Blinn et al. (1995, in Waters 1999) 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 desiccation, excavation, installation of water crossing structures, and placement of associated 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 disturbance to the channel results in permanent loss of habitat (i.e., installation of a new water crossing structure). Once flow is returned to the dewatered portion of the channel, benthic macroinvertebrates that drift from unaffected areas upstream, as well as insects from allochthonous sources (material that is produced in one area and consumed in another), will begin to recolonize the previously dewatered channel. 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 2003a). NMFS (2003a) did not indicate the duration or area of the dewatering that corresponds to the one-month to 45-day time frame for recolonization.

7.1.6 Elevated Turbidity During Rewatering

To dewater a channel, a bypass system must be in place 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 pumped 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, but excavating and operating a temporary channel bypass can result in temporarily increased turbidity. 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 dewatered channel. Then the upstream cofferdam is removed, and flow is slowly returned to the channel to minimize resuspension of fine sediments and increases in turbidity. The impacts of increased turbidity are further addressed in the discussion of water quality in Section 7.5.

7.2 Channel Hydraulics

7.2.1 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 here 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 Shelberg (2001) is also incorporated here 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 Shelberg 2001):

- Channel shortened by straightening (more common with culverts than other structures)
- 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 is "locked," i.e., it loses the ability to migrate over time

Each of these effects constitutes an impact, but collectively these impacts affect channels primarily by altering only one controlling factor: stream power. Stream power 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. A culvert or other non-erodible artificial streambed has a fixed gradient, which may or may not be consistent with channel gradient when the culvert is installed and may later be inconsistent if gradient changes due to other factors. Bates (2003) provides extensive discussion of the role of culvert gradient in determining channel response, particularly for steeper channels and retrofit situations where the culvert gradient is steeper than that of the associated channel. A pipe or other conduit trenched across the bottom of the stream, although customarily placed below the depth of scour, may also function as a gradient control structure if subsequent downcutting occurs.

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, pilings, and abutments and natural structures such as large woody debris (LWD). An example of channel change due to structural roughness 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 connecting the lowest points along a stream bed). This study identified some of the principal channel border roughness elements, such as sediment, vegetation, and artificial elements like riprap and bridge abutments.

Because flow velocity is inversely 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 within a culvert or between abutments, or indirectly, such as when erosion or deposition causes changes in channel geometry. Bridges and culverts tend to confine the channel within artificial bounds and thus generally cause locally reduced channel roughness, potentially causing scour at the structure. 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 increased sediment deposition immediately upstream. Sturm (2004) also found that this effect could be exacerbated in higher flows. This study underscores the importance of modeling the hydraulic effects at channel crossings if locally significant changes in channel structure are to be avoided.

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), ponding upstream of culverts, culvert flow velocities that constitute a fish passage barrier, or a host of culvert structural problems (Bates 2003).

To summarize, the placement of artificial structures in channels can, through a variety of mechanisms, cause increased erosion upstream or downstream 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 complexity, channel slope, channel migration, bed mobility, and bank structure. These potential changes, and their significance to potentially covered species, are described below.

7.2.2 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 water crossing 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. The reviewed literature did not identify significant potential impacts on channel morphology or hydraulics due to water crossing structures in cascade channels.

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 due to the associated disturbance of benthic habitat. More moderate changes in sediment supply would also be expected to alter these channels, primarily by causing a general coarsening or fining of bed materials. Generally, step-pool channels have a high enough gradient and transport capacity that it is feasible to place additional roughness elements, such as baffled or bottomless culverts sized to carry a 100-year flow, 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).

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). 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). Water crossing structures that impair LWD transport in the stream channel, including bridges with in-channel abutments and most culverts, can lead to reduced LWD accumulation in downstream reaches. Artificial instream structures such as abutments and pilings are often local sites for scour in these channels, and scour pools will also commonly develop at the downstream ends of culverts that have not been properly sized and installed. In larger rivers with plane-bed channels, significant scour can occur, particularly in association with LWD accumulations (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 historically constituted the general case for larger Western Washington rivers (Abbe and Montgomery 1996).

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. 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). Such sediment inputs, when caused by water crossing structures, are usually local expressions of a hydraulic change caused by the siting of a bridge abutment within a channel, or deposition due to improper culvert installation. The severity of the impact is dependent upon whether and in what way a sensitive species uses the affected habitat.

Culverts, because they closely confine the channel within a pipe, have some specific impacts on channel hydraulics that are most apparent in step-pool, pool-riffle and plane bed channels, where the stream commonly shows a highly variable capacity to transport its sediment load. The principal impacts are identified by Bates (2003) and include:

- Channel realignment that eliminates natural features such as meanders, spawning riffles, and other diversity in the channel
- Shortened channels that carry flows at higher velocity, causing streambed instability and downstream scour and bank erosion (further discussed in Section 9.2)
- Sediment mobilization that can smother redds downstream (further discussed in Section 9.2)
- Changes in stream base level that can destabilize the channel and cause reduced hydrology in floodplain water bodies
- Upstream bed and bank instability if the culvert is undersized, which causes the repeated formation and draining of an upstream backwater pool
- Blocking the downstream movement of coarse sediment such as boulders and LWD pieces

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). Thus, preservation of riparian vegetation is important when water crossings or overwater structures are sited in regime channels. Water crossing structures have primarily temporary effects on regime channel hydraulics, and the channel equilibrates to local scour or deposition without significant substrate composition changes. However, the equilibration process could still significantly impact sessile species such as freshwater mussels, which could be excavated or buried by local channel form changes.

All channels occur within a landscape context. Principal elements of the context include the floodplain or channel migration zone, which is the area directly influenced by the channel during geologic time frames, and confinement, which is determined by the channel's proximity to neighboring hillslopes. Mountain channels (cascade and step-pool channel types) in Washington are often closely confined with no definable floodplain, but most fish-bearing channels do have a floodplain. Important structural and functional elements of floodplains and channel migration zones are described by Bolton and Shelberg (2001) and include:

- Channel complexity in the form of secondary channels, bars, channel sinuosity, and the way in which these change during floods
- Riparian ecosystems, particularly forested riparian systems that act as LWD sources and are subject to successional changes
- Groundwater and hyporheic components

Water crossing structures can alter each of these functional elements. Channel complexity derives from the channel's capacity to change in response to environmental changes including floods, changes in sediment supply, and delivery of LWD to the stream. Bridges and culverts "lock" the channel by fixing it within artificial bounds set by the culvert walls, bridge abutments, and approach fills located on the floodplain. Also, closed culverts and shallowly buried conduits can lock the channel in the vertical dimension by imposing a fixed base level. This locking prevents the channel from adjusting to flow and sediment supply variability by altering its cross section and gradient; consequently, adjustment occurs by altering channel hydraulics, potentially destabilizing the channel. This effect is most pronounced in the immediate vicinity of the locking structure and results in relatively frequent disturbance of in-channel habitat in the affected area.

The principal effects of channel confinement on groundwater and hyporheic function are identified by Bolton and Shelberg (2001). Effects likely to be observed in connection with water crossing structures include:

- Changes in hyporheic chemistry attributable to altered vegetation in the riparian areas (most likely as a result of the impacts of road approaches, which impact a substantially larger area than bridges and culverts *per se*)
- Reduced hyporheic exchange due to increased sedimentation from various causes (detailed in Section 9.2; likely to be a minor effect for most water crossings)
- Lower base flows attributed to reduced recharge from a straightened channel (likely to be a minor effect for water crossings, which straighten short, isolated sections of channel)

Generally, water crossings are unlikely to result in significant direct alteration of the hyporheic and groundwater environments because they impact short stream reaches. However, if the water crossing contributes to an indirect effect, e.g., by facilitating land use change or floodplain development, then those indirect impacts could have a more substantial impact.

7.3 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 30 to 14,000 cubic meters (m^3) 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 100,000 to 300,000 m^3 per year (MacDonald 1994).

Water crossing structures have the potential to affect littoral drift when they alter the two principal factors of wave action and littoral currents.

7.3.1 Wave Action

Water crossing structures located in the wave zone have the potential to affect wave direction and intensity. The literature on potential impacts is focused on overwater structures such as piers, but the physical processes involved are common to piling- and abutment-supported water crossing structures (chiefly bridges) as well. The effect of pilings on wave action depends 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 could 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 causes 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 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 2000; Thom et al. 1994, all in Nightingale and Simenstad 2001b; Thom et al. 1998; 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 hydrodynamic 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, it is important to remember that changing the type and distribution of sediment will likely alter key plant and animal assemblages (Nightingale and Simenstad 2001b). These changes, as reviewed in the literature, are most pronounced as the cumulative effects of many overwater structures. In comparison, water crossing structures are present at much lower densities on the landscape; thus they would be expected to alter littoral drift patterns locally (i.e. near the structure), but would rarely affect habitat over a large area.

7.3.2 Littoral Currents

In-water structures such as conduits and pilings can 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). Linear features, such as unburied or incompletely buried conduits on the sediment surface, have the potential to collect sediment along the up-current side of the feature (Thom et al. 1994). Pilings also can have this effect when closely spaced (Nightingale and Simenstad 2001b). Where pilings are widely spaced, currents can 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). However, as noted above, this analysis chiefly considered the aggregated impacts due to large numbers of overwater structures; water crossings (chiefly bridges), which are more sparsely distributed on the landscape, would have similar impacts but those impacts would be local, expressed only in the immediate vicinity of the water crossing.

Benthic habitat may be impacted by alterations in natural sediment movement. For instance, Nightingale and Simenstad (2001b) found that a boat ramp interfered with littoral drift cells, potentially impairing the deposition of fine sediments on adjacent beaches that supported beach spawning forage fish, such as surf smelt and sand lance. A similar effect could occur in response to an approach fill for a water crossing structure such as a bridge. 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).

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 (Thom et al. 1994). Such changes would modify beach suitability for forage fish spawning, and might also affect nearshore habitat occupied by critical habitat elements such as eelgrass and macroalgae, with resultant impacts to potentially covered species as detailed in Section 7.6.

7.4 Substrate Modifications

Modifications of substrate caused by channel hydraulic processes are discussed in Section 7.2, and modifications caused by the analogous shoreline process, littoral drift, are discussed in Section 7.3. These include most substrate modifications observed in association with construction and operation of water crossing structures in stream channels and along shorelines. However, there are also substrate modifications that occur in conjunction with water crossings in waters where sediment transport is not a significant habitat-forming process, where the substrate modification is designed to preclude sediment transport, or where the substrate is replaced with an artificial substrate. In such settings, the structure itself constitutes the substrate modification.

Love and York (2005) examined pipelines serving oil wells in the Santa Barbara Channel in California. In this area, the seafloor is mostly comprised of sediments. Along the pipeline, the diversity and number of both fish and invertebrates were much higher than on the adjacent seafloor. The hard substrate of the pipeline was colonized by numerous sessile and motile invertebrates, and fish densities were six to seven times greater than on the adjacent seafloor. Rockfish comprised 84 percent of the fish species and represented 22 species. Most were juveniles or represented species that are small at maturity. Kogan et al. (2003) examined a submarine cable running from Half Moon Bay to Pioneer Seamount in California, a distance of 59 miles (95 kilometers). In the seven years the cable had been in operation, most of the cable had been buried by sediments along the continental shelf, where water depths range up to approximately 390 feet (120 meters [m]), except over areas of rocky substrate. Anemones, echinoderms, and sponges had colonized the cable and were conspicuous in areas where the cable provided the only available hard substrate. In three of nine survey locations, flatfish and rockfish congregated near the cable. The cable had no measurable effect on benthic infauna.

Dock pilings have been found to alter adjacent substrates with increased deposition of shellhash (the shells of dead molluscs that accumulate on the bottom) from piling communities and changes to substrate bathymetry (Shreffler and Moursand 1999, 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).

In freshwater systems, the most common and pervasive substrate modification attributable to water crossings is the placement of pipe (as opposed to bottomless) culverts. Such culverts may acquire a veneer of bed material but usually are bedded by whatever material the culvert is made from, usually metal, plastic, or concrete. Moreover, the culvert usually has a small diameter compared to the functional channel width upstream and downstream of the culvert. The resulting impacts on habitat-providing substrates are described by Bates (2003) and may include:

- Spawning gravels replaced with culvert pipe
- Rearing habitat replaced with culvert pipe
- No streambanks inside the culvert pipe
- No riparian inputs of leaf litter or terrestrial insects along the culvert pipe
- No pool, riffle, or hyporheic (in-gravel) habitat within the culvert pipe
- Few or no benthic invertebrates in the culvert
- No plants growing on substrate within the culvert, because it’s dark
- Culvert straightens the stream, reducing its length as well as width
- Culvert may contribute to loss of off-channel habitat by increasing flow velocity, reducing base level, and simplifying channel form

7.5 Water Quality

Placing constructed features in aquatic settings may adversely impact water quality in several different ways, mainly by causing increases in turbidity or suspended solids, 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.

7.5.1 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 bridge and culvert construction, or stormwater runoff from upland portions of construction sites may increase suspended sediment levels (Bash et al. 2001). Attempts to bore beneath a water body using high-pressure directional drilling (HPDD) also present a risk of sediment disturbance through hydraulic fracturing ("frac-outs") and the release of drilling muds to the surface. Wet, open-trench installation of conduits (consisting of trenching, placing conduit, and backfilling in an inundated water body) typically produces the greatest sediment loads of any conduit installation method, with peak turbidity occurring during trench excavation and backfilling and a rapid return to background levels after backfilling and trench stabilization (Reid and Anderson 1998; Reid et al. 2004). Sediment disturbance can be further increased by instream operation of equipment or storage of excavated material within the floodplain (Reid et al. 2004). Wet, open trenching minimizes disturbance time, because the work can be performed quickly while not blocking fish passage (Reid et al. 2004), and isolating the trenching site by diverting flow around it using a temporary dam and pumps or a flume is effective at limiting turbidity increases and sediment impacts to downstream habitat (Reid et al. 2004).

Changes in stream profile and the presence of submersed structures often cause changes to hydraulic conditions that require redistribution of the energy of moving water, which may cause chronic increases in suspended sediment (NMFS 2005b). The effects of hydraulic alteration are discussed in Section 7.2. 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.

7.5.1.1 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 (SSC). TSS and SSC 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.

7.5.1.2 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).

7.5.1.3 Suspended Solids Impacts on Fish

Physiological effects of suspended sediment on salmonids include gill trauma and altered osmoregulation[3], blood chemistry, reproduction, and growth. Most research

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

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. Gills may be irritated by abrasive suspended sediments. Several laboratory studies have shown gill trauma and increased coughing frequency with increased turbidity. Other studies have shown impacts on 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 while increased turbidity may delay migration, it does not seem to alter homing ability (Bash et al. 2001).

Additional studies have supported the assertion that water clarity affects fish behavior. Avoidance responses and changes in territorial behavior and feeding patterns 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). Evidence of similar development among sand lance has also been reported by 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 National Marine Fisheries Service (NMFS) biological opinions on water crossing 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 of 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).

NMFS has also concluded that, with the implementation of appropriate BMPs, the accidental release of drilling fluid during HPDD is unlikely to occur and so is not likely to adversely impact aquatic species or their habitats (NMFS 2006c). For some projects, however, NMFS concluded that increased turbidity from water crossing projects could have adverse impacts to salmonids due to pulses of increased turbidity from in-water work during construction, as well residual post-construction turbidity pulses generated as the area restabilizes. These effects were evaluated as posing potential threats to juvenile salmonids (NMFS 2006k). 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).

Based on the results described above, it can be concluded that activities that allow significant increases in suspended sediment have a high risk of causing incidental take to 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

7.5.1.4 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). 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.

Note that risk of incidental take attributable to a closely related impact, fine sediment deposition, is discussed in Section 9.2.

7.5.2 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. 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 would ordinarily be required to ascertain and appropriately deal with that risk.

7.5.3 Dissolved Oxygen Impacts

Juvenile salmon are highly sensitive to reductions in dissolved oxygen levels (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 water crossings, 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 water crossing construction and operation, the risk of incidental take associated with this impact mechanism is low.

7.5.4 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 language prohibits fresh, uncured concrete from coming into contact with surrounding water or the bed of the water body, and existing Washington State Department of Ecology (Ecology) regulations also greatly restrict such impacts. Therefore, the risk of incidental take associated with this impact mechanism is low.

7.5.5 Treated Wood-Related Impacts

Some water crossings, such as bridges, may be supported by wood piles. Wood piles are also sometimes used to construct temporary trestles that support equipment during conduit placement and burial; however, temporary piles are generally steel so they can be reused. 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, via 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 (WAC 220-110-060(4)). 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). Two common methods for increasing the resistance of wood to rot are treatment with ammoniacal copper zinc arsenate (ACZA) or chromated copper arsenate (CCA Type C) (Poston 2001).

7.5.5.1 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. Therefore, applying the precautionary principle, cumulative impacts that include a proposed treated-wood project should be evaluated against cumulative impacts without the project.
- 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 relatively mobile,

PAH contamination of sediments is unpredictable in relation to water currents.

- Impacts from CCA Type C- and ACZA-treated wood (primarily the leaching of copper) pose the greatest risk of sediment contamination and direct impacts to organisms that directly colonize treated-wood structures. For immersed structures, the period of greatest risk is the few days to weeks immediately following installation; the period of risk related to stormwater runoff from above-water structures is longer and less predictable.
- Areas with less water circulation and lower pH are at greater risk for contamination, because dilution of higher concentrations occurs much more slowly.
- In studies that evaluated effects in the environment, no adverse biological impacts were reported from sediment toxicity and no community changes were observed. Filter-feeding oysters exhibiting copper accumulation above background levels showed no biological impacts.
- 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 resuspension during the removal of pilings is not well understood at this time.
- The sediment characteristics of percent fines and organic carbon play key roles 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 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 risk of exposure from the consumption of contaminated prey.

Some additional studies not described in 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 increases in 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 (Cooper 1991). PAH leaching rates increase as surface area to volume ratios increase (Colley and Burch 1961; Stasse and Rogers 1965; Gjovik 1977; Miller 1977, all in Cooper 1991).

Table 5 summarizes several studies on biological effects thresholds for PAHs in surface water (Stratus 2005a). These results suggest that observable effects on potentially covered species and certain of their prey species may occur at PAH concentrations as low as 0.6 micrograms per liter (µg/L).

Table 5
Effects Thresholds for PAHs in Surface Water

Organism	Exposure Source	Toxicity Endpoint	Concentration in µg/L	Citation
Mysidopsis bahia	Elizabeth River, Virginia, sediment extracts	24-hr LC50	180	Padma et al. 1999
Rhepoxynius abronius	Eagle Harbor, Washington, sediment extracts	96-hr 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

EC50 = Exposure concentration of a material that has a defined effect on 50 percent of the test population.
LC50 = 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
Source: Stratus 2005a

Many studies have investigated thresholds for biological effects of PAH concentrations in sediment. Several effects thresholds have been determined using NOAA Fisheries' 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 2005a).

7.5.5.2 ACZA- and CCA Type C-Treated Wood

Recent work on contaminant leaching from ACZA- and CCA Type C-treated wood not described in Poston (2001) was also identified. A 2004 study of arsenic, copper, and zinc concentrations in sediment, water, and shellfish near four ACZA-treated wood structures on the Olympic Peninsula showed insignificant increases in these substances 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 reduced biomass and diversity of sessile epifaunal communities have been observed on treated wood panels than on untreated wood panels, but these effects dissipated over time, reaching negligible levels after three months of exposure (Weis et al. 1992; 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 feet (1 m) but diminished to background levels at 10 feet (3 m) from the bulkheads. Polychaete worms collected within 3 feet (1 m) of a 1-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 feet (1 m) from bulkheads (Weis et al. 1998, in Stratus 2005b). Presumably, comparable impacts would occur if the treated wood were part of a water crossing structure such as a bridge.

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 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 semi-transparent water-repellent stain, latex paint, or oil-based paint to greatly reduce 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 to protect aquatic life (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 (Table 6). In both fresh water and salt water, invertebrates appear to be 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).

There does not appear to be a pattern of sensitivity among species with respect to chromium III, but the ALC, although only established for fresh water, appears 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 is 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, 1968; Black and Birge 1980, both 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).

Table 6
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)[f]	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 model for calculating freshwater criteria based on site-specific water chemistry.

Notes: CMC = criterion maximum concentration

CCC = criterion chronic concentration

Source: USEPA 2002, except as noted, as taken from 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 7 and 8 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 7
Threshold Effects Concentrations (TECs) for Freshwater Sediment

		Concentration (mg/kg dry wt)					
Name	**Definition**	**Basis**	**As**	**Cr**	**Cu**	**Zn**	**Reference**
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 8
Probable Effects Concentrations (PECs) for Freshwater Sediment

Name	Definition	Basis	Concentration (mg/kg dry wt)				Reference
			As	Cr	Cu	Zn	
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 mediana	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

7.5.6 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. Water crossings 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 Ecology under the federal Clean Water Act (33 United States Code [USC] §§ 1251-1387). The Ecology regulations are subject to USEPA review and Section 7 requirements of the

ESA (16 USC 1531-1544). Generally, the federal agencies have found that full compliance with applicable Ecology and Washington State Department of Transportation (WSDOT) stormwater treatment guidance is sufficient to support a determination that stormwater generated from a project will not result in incidental take of listed species. However, there are few data on the stormwater vulnerability of potentially covered species other than salmonids.

7.6 Eelgrass and Macroalgae

Impacts to habitats and species may occur through the loss of eelgrass and macroalgae resulting from construction of new water crossings 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) designate eelgrass and kelp as saltwater habitats of special concern and require that hydraulic projects result in no net loss of the productive capacity for fish and wildlife. Furthermore, the hydraulic code rules require that overwater structures that support water crossings be designed or located to avoid shading or other impacts that could result in the loss of eelgrass and kelp habitat (WAC 220-110-240 through 330).

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 conditions in many portions of Puget Sound typically limit the lower elevation to the range of -8 feet to

-12 feet MLLW. Macroalgae have a wider elevation range, and macroalgae 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 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 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, shiner perch, and other 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), 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. 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 can retard current velocity at the sediment-water interface, allowing fine particulates to settle (Phillips 1984). This action can affect sediment dynamics and local sediment characteristics, favoring continued growth and survival of eelgrass (Phillips1984). The vertical structure of kelp forests also affords some dissipation of wave energy (Jackson 1984), which can offer some 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 (Blackmon et al. 2006). Juvenile salmon are found in kelp habitat as well (Blackmon et al. 2006). Rockfish (*Sebastes* sp.) produce planktonic larvae that settle in eelgrass, shallow kelp beds, and floating kelp mats (Blackmon et al. 2006). Likewise, juvenile Dungeness crab (young of the year) are more frequently found in eelgrass and *Ulva* beds than in other habitats, and eelgrass beds are considered valuable nursery habitat for Dungeness crab (Pauley et al. 1989; Blackmon et al. 2006).

HPA-regulated activities in marine waters have the potential to affect eelgrass and macroalgae through the following impact mechanisms:

- Reduced ambient light
- Direct disturbance and displacement during installation
- Vessel interactions

Each of these impact mechanisms is discussed below.

7.6.1 Ambient Light

Light availability is a fundamental requirement for eelgrass and macroalgae growth.[4]

[4] Thom et al. (1998) analyzed the photosynthetically active radiation (PAR) levels at seven Washington State ferry terminal sites and found that no eelgrass was found 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 ($\mu M/m^2/sec$). They also found that the lowest eelgrass shoot densities were found where instantaneous mid-day PAR was less than 150 $\mu M/m^2/sec$. Thom et al. (1998) found that maximum shoot densities required instantaneous PAR of 325 $\mu M/m^2/sec$. PAR intensities less than about 300 $\mu M/m^2/sec$ can be limiting to eelgrass, whereas intertidal macroalgae may be limited by PAR less than 400 to 600 $\mu M/m^2/sec$ (Thom and Schreffler 1996, cited in Simenstad et al. 1999). Subtidal macroalgae can survive lower light levels and may only be limited by PAR less than 100 $\mu M/m^2/sec$ (Luning 1981, cited in Simenstad et al. 1999).

Bridges and culverts would be expected to limit light penetration to the substrate. Such structures would be expected to create shading effects similar to those resulting from the placement of docks, depending on factors such as culvert height, length and width, bridge deck width and elevation off the water, and size and spacing of bridge supports (piers or piles). 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. 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 dock height above the bottom was identified to be the most important dock characteristic correlating to eelgrass bed quality, and a similar effect would be expected for bridges. 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.

Overwater structures have been shown to shade the area underneath and adjacent to the structures. Similar effects are expected for bridges and culverts, which also shade the water surface. The orientation of the structures, density of the structure (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 photosynthetically active radiation (PAR) levels, eelgrass and macroalgae growth will be affected and may be impaired or prevented (Nightingale and Simenstad 2001b; Penttila and Doty 1990). Penttila and Doty (1990) found that fixed and floating docks and structures 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 structure design 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 effect of shade on the eelgrass bed.

7.6.2 Direct Disturbance and Displacement

Aquatic vegetation may be uprooted or displaced during in-water construction of water crossings and the structures that support them; 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. Conduits that are buried through eelgrass generally cause temporary loss of eelgrass along a disturbance corridor (Jones & Stokes 2005; Wones and Cziesla 2004). Pilings that support overwater structures such as bridges 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 is then deposited around the pilings over time, altering the local substrate (Nightingale and Simenstad 2001b). The piling reef habitat provides food for sea stars and the shell bottom is prime settling habitat for juvenile Dungeness crabs (Nightingale and Simenstad 2001b). The burrowing activities of large numbers of crabs can affect the establishment of eelgrass (Nightingale and Simenstad 2001b).

A study of eelgrass recovery at four submarine cable landings in Skagit and San Juan counties demonstrated the disturbance that occurs with conduit (electrical transmission cable) installation and some factors affecting recovery (Jones & Stokes 2005; Wones and Cziesla 2004). This project disturbed eelgrass habitat along a cable route that ranged from 3 to 15 feet in width. Although the upper beaches of these cable landings returned to the pre-excavation appearance within a few weeks through wave action and littoral drift, the disturbance through eelgrass beds required one to four years to fully recover. The sites where eelgrass recovered most rapidly included a site with only a narrow band of eelgrass and a site with an extensive, robust eelgrass bed. Eelgrass was slowest to recover at the deepest extent of eelgrass growth, where light availability may limit the rate of eelgrass recruitment and growth (Jones & Stokes 2002, 2005).

7.6.3 Vessel Interactions

Vessels used during installation of water crossings may physically disturb submerged vegetation as a result of propeller wash (Lagler et al. 1950, in Carrasquero 2001; Haas et al. 2002). In addition, propeller wash may 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.

7.7 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 that occurs 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 1998, 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:

- Reduced ambient light
- Direct disturbance during installation
- Vessel interactions
- Introduction of noxious weeds

Each of these impact mechanisms is discussed below.

7.7.1 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 aquatic vegetation (Chambers et al. 1999). Light limitations can lead to a local reduction in autochthonous (i.e., organic matter produced by aquatic plants within a river or stream) primary production and a reduction in the other functions of aquatic vegetation, including cover, substrate for invertebrate species, and food for herbivores (Hruby et al. 1999). Reduced ambient light occurs beneath bridges and within culverts. The magnitude of light reduction varies with structure geometry and is generally greater for long, low, narrow culverts or for long, wide bridges with decks that are close to the water surface and supported by a large number of closely spaced pilings.

7.7.2 Direct Disturbance During Installation

Human activity associated with the installation of water crossings can result in a reduction of submerged and floating leaved vegetation. In particular, conduits that are buried through aquatic vegetation generally cause temporary loss of the plants along the disturbance corridor. Dewatered channels may also experience loss of aquatic vegetation, depending on the duration of dewatering and the vulnerability of the affected plants to desiccation and drought stress.

7.7.3 Vessel Interactions

The potential impacts of vessel activities on freshwater aquatic vegetation are discussed in Section 7.12. Briefly, vessels used during installation of water crossings 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 used within 1 foot (30 centimeters [cm]) of aquatic vegetation. In addition, propeller use may entrain air bubbles and cause sediment suspension that result in a temporary reduction in light availability.

7.7.4 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 can 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). Activities that could facilitate introduction of invasive aquatic plants include vessel support during the construction or maintenance of water crossings, when an invasive plant could be picked up in one water body and then transported to another. Interlake transfer from boats is thought to be the chief means by which Eurasian milfoil is spread (WNWCB 2005).

7.8 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, 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 of water crossing structures can have several potential impacts to habitat and species in each of these systems, including:

- Reduced shading and altered water temperature regime
- Reduced streambank/shoreline stability
- Altered allochthonous input
- Altered groundwater influence/water quality
- Altered habitat conditions

Each of these impact mechanisms is discussed below.

7.8.1 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 Shelberg 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, specifically 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). Invertebrates, which are also cold-blooded, have a similar temperature dependence.

In lentic (still-water) systems, water temperatures generally change gradually through the year with the seasons, show less change from night to day, and are often stratified vertically. Water temperatures associated with lotic (actively moving) systems 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 F (5.5 to 14.4 degrees 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
- Amplifying effects of toxic substances
- Increasing susceptibility to disease and pathogens
- Increasing potential risk of eutrophication through increased growth of bacteria and algae

[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.

7.8.2 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 7.2 for further information on the impacts to potentially covered species associated with sediment regime changes.

Streambanks and shorelines associated with water crossing structures may be managed so as to impair riparian/shoreline vegetation function. For example, Corps regulations restrict the growth of woody vegetation on dikes, and roads located close to the shoreline may cross or truncate the width of the riparian zone. Such impacts may be attributable to water crossing structures if the dike or road would not have been built (or would not still be maintained) but for the water crossing.

7.8.3 Altered Allochthonous Input

Riparian/shoreline vegetation provides allochthonous inputs 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 to the aquatic environment, which in streams influences channel morphology and habitat complexity, retains organic matter, and provides essential cover for fish (Quinn 2005; Naimen et al. 2002; Knutson and Naef 1997; Murphy and Meehan 1991), as discussed below with regard to altered habitat conditions (Section 7.8.5).

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 for construction or maintenance of water crossings 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).

7.8.4 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). Loss of riparian/shoreline vegetation due to construction of water crossings results in impairment of these ecological functions, contributing to increased flow variability that can contribute to a variety of impacts discussed in other sections of this paper, such as changes in channel hydraulics and increased turbidity.

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

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

depends on many factors, such as stream channel pattern, structure of the alluvial aquifer, and variability in the stream hydrograph (Poole and Berman 2001). The impairment of hyporheic function attributable to water crossings is further discussed in Section 9.2 (channel hydraulics).

7.8.5 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). 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).

7.9 Noise

Underwater noise produced in association with water crosssings 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 impacts to fish and invertebrates from noise produced by these activities.

7.9.1 Pile Driving

Pile driving within the water column is often necessary in the construction and retrofitting of bridges. 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 conducted 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 special 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 taxonically 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 9 outlines the known and presumed hearing categories of potentially covered fish species.

Table 9
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; Hasting 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 translate into instantaneous death or lead to a slow death from injuries (e.g., breakdown of tissues in some organs) (NMFS 2003b).

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). NOAA Fisheries 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 of the accumulation of energy from multiple pile strikes. Discussions on the use of these proposed dual criteria are currently in progress.

7.9.1.1 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.

7.9.1.2 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).

7.9.2 Noise from Construction Vessels and Equipment

This impact is detailed in the discussion of vessel activities in Section 7.12.

7.10 Artificial Light

Artificial lighting may be used during the installation of water crossings, and some bridges carry streetlights, security lighting, or navigational lights. 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)
- Increasing 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 juvenile salmon migrants 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 7.11. 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; 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 waiting, camouflaged against the substrate, on the bottom (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 (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.

7.11 Shading

Water crossings other than bridges and culverts do not generally cause significant shading of aquatic habitat. The information summarized in this section is largely taken from two extensive literature reviews prepared for WDFW: *Marine Overwater Structures: Marine Issues* (Nightingale and Simenstad 2001b) and *Over-water Structures: Freshwater Issues* (Carrasquero 2001). Minimal information is available on shading effects of bridges, but these literature reviews are useful because of the geometric similarities between bridges and docks. 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 and elsewhere. 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 artificial structures when compared to adjacent unshaded, vegetated habitats (Fresh et al. 1995, 2000; Ludwig et al. 1997; Orth and Moore 1983; Parametrix and Battelle 1996; Thayer et al. 1984; Thom et al. 1996, all in Nightingale and Simenstad 2001b and Haas et al. 2002; Thom et al. 1998). Artificial structures can create strong 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 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 could make such fishes vulnerable to a variety of stresses, including predation, starvation, or reduced fitness (Nightingale and Simenstad 2001b).

The effects of reduced underwater vegetation on potentially covered species, and the associated potential for incidental take, are addressed in Sections 7.6 and 7.7, which discuss eelgrass and macroalgae and freshwater aquatic vegetation, respectively. Therefore, the following discussion focuses on the direct effects of shading on potentially covered species.

7.11.1 Shading and Fish/Invertebrates

In addition to affecting aquatic vegetation, shading can affect fish and invertebrates by disrupting normal migration patterns, reducing the ability to avoid predators, and reducing available refuge. To better understand how fish depend directly on light, a discussion of fish vision follows.

Teleost fishes, which include all potentially covered fish species except sturgeon and lamprey, depend on sight for feeding, prey capture, 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).

Light perception depends on the light transmission qualities of the aquatic environment coupled with the spectral qualities of the fish retinal visual pigments (Hoar 1951, Hoar et al. 1957, Ali 1959, McDonald 1960, Brett and Groot 1963, Fields 1966, Ali 1975, McFarland and Munz 1975, Nemeth 1989, Mork and Gulbrandsen 1994, all in Nightingale and Simenstad 2001b). For salmonids, retinal pigment changes as they move from fresh to salt water. These habitat changes trigger changes in their visual sensitivity from the red-yellow hues of freshwater streams to the blue color of estuarine and ocean waters. The time required for such physiologic changes varies across species and life stages. At the juvenile stage, the time required for light-adapted chum and pink salmon to fully adapt to dark conditions was found to range from 30 to 40 minutes. However, the time required for dark-adapted fry to adapt to increased light conditions was found to range from 20 to 25 minutes (Brett and Ali 1958, Protasov 1970, both in Nightingale and Simenstad 2001b). During these periods of transition, the juvenile chum's visual acuity ranges from periods of blindness to a slightly diminished capacity, depending on the magnitude of light intensity contrasts. As the animals become older, the time required for light adaptation generally shortens. The time necessary to adapt to the dark, on the other hand, tends to increase with age. Contrasts in light levels determine the progression of changes the eye undergoes, with previous light levels affecting the speed of transition. Fish previously exposed to higher light intensities become dark-adapted more slowly than do those previously exposed to lower light intensities (Ali 1962, in Nightingale and Simenstad 2001b).

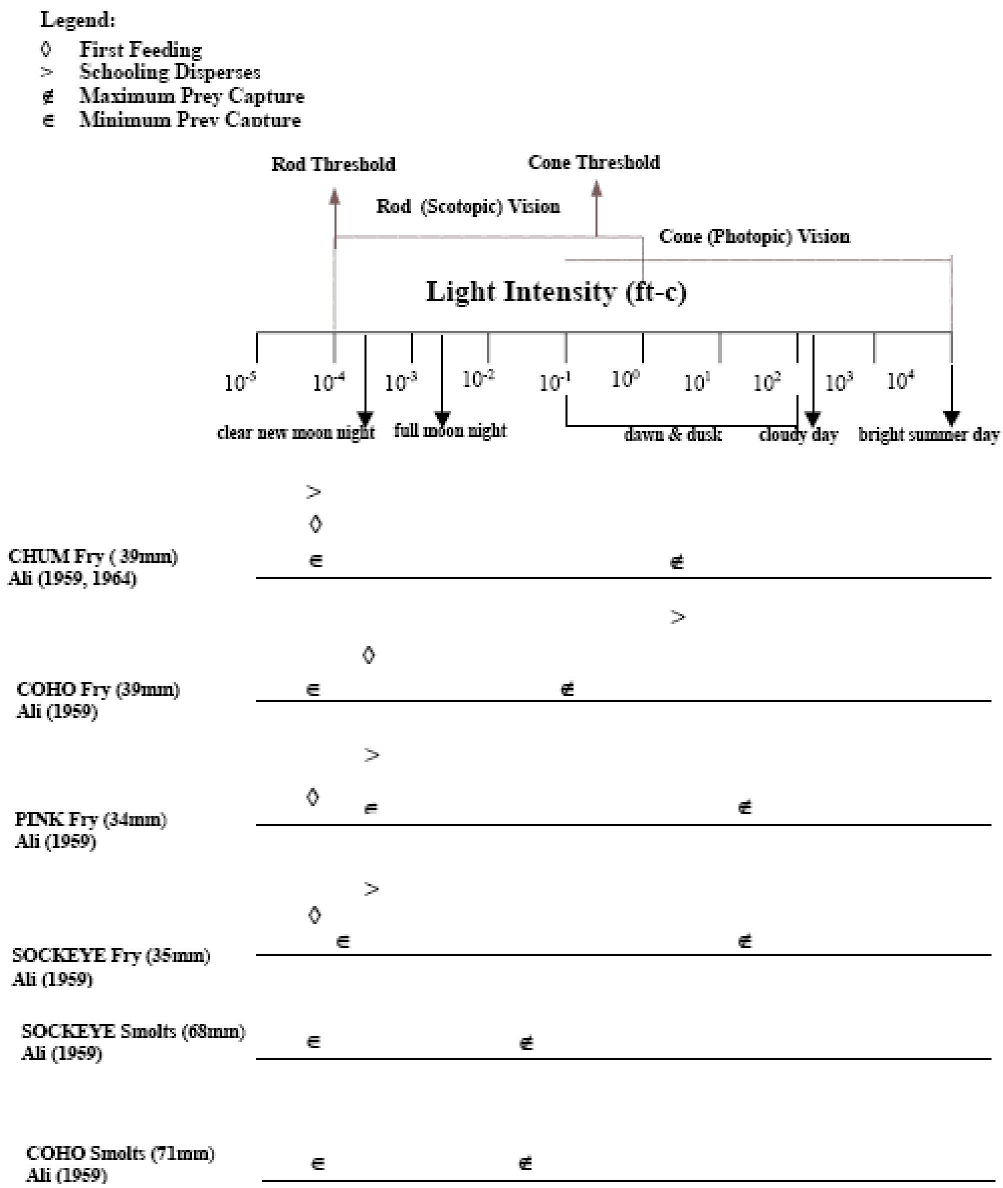


Figure 2
Juvenile Salmon Behavior Patterns Related to Light Intensity
Source: Nightingale and Simenstad 2001b

Figure 2 depicts light conditions related to juvenile salmon behavior such as schooling, predator avoidance, feeding, and migratory behavior.

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.

Similar to salmonids and sand lance, yellow perch have also been found to lose ultraviolet sensitivity with growth. Nightingale and Simenstad (2001b) report this loss of ultraviolet sensitivities to be size-dependent rather than age-dependent and to likely correlate with the time when such fishes move from shallow to deeper water and from feeding on small crustaceans and other zooplankton to feeding on larger food items.

7.11.2 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, potentially 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.

7.11.3 Migration and Distribution

Investigations on shading impacts to fish migration and distribution have primarily focused on impacts to juvenile salmonids. Shading impacts to juvenile salmonids in the marine environment are discussed below. Shadowing has been shown to have different consequences for migration and distribution of some fish in freshwater environments; therefore, fish utilization of overwater structures (e.g., bridges) in freshwater environments is discussed separately.

7.11.3.1 Marine Environment

Changes in ambient underwater light environments pose a risk of altering juvenile salmon migration and distribution and potentially increasing mortality risks. For example, studies have consistently documented a tendency for juvenile salmon to avoid passing beneath shaded habitats (among others, Pentec 1997; Weitkamp 1982; 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 impact 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 overwater structures have been observed variously to pass under the dock, pause and go around the dock, break up from schools, aggregate in the lighted portion of the water column, or pause and eventually go under the dock (Pentec 1997; Weitkamp 1982; Feist 1991, all in Nightingale and Simenstad 2001b; Feist et al. 1992; Southard et al. 2006; Toft et al. 2004; 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 distribution under or around floating piers, although 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 juvenile salmon may move more readily under structures at low tide during the day, when more incidental 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. Additionally, in studies of juvenile salmonid behavior around the Port of Seattle's Terminals 90 and 91, Weitkamp (1982, in Nightingale and Simenstad 2001b) observed predominant distributions of juvenile salmonids occurring in the more sun-exposed west side rather than in darker areas on the east side of the terminals. Salo et al. (1980, in Nightingale and Simenstad 2001b) observed that chum salmon appeared to shift from nearshore migration routes to offshore areas upon encountering a wharf in Hood Canal, and a study in Everett Harbor by Pentec (1997, in Nightingale and Simenstad 2001b) found that when juvenile chum salmon encountered piers, they milled around for periods ranging from 30 minutes to two 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. Similarly, other studies suggest that although very wide or multiple overwater structures likely temporarily impede the movement of juvenile salmon, the cumulative impact is not well understood. Williams and Thom (2001) 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 is likely a contributor to the present decline of several Puget Sound salmon species. These conclusions imply that although overwater structures may cumulatively have notable effects on salmonids, such effects are probably much less for water crossing structures such as bridges, which are relatively sparsely distributed across the landscape of aquatic habitats.

7.11.3.2 Freshwater Environment

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 object, and Kahler et al. (2000) suggests that various in-water structures 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 (2000, pers. comm., in Carrasquero 2001), which explains that both the structures and the shade they cast may provide fishes with physical reference points for orientation.

In contrast to ambush predators, juvenile salmonids respond similarly to overwater structures in both marine and freshwater environments (Tabor et al. 2006). Tabor et al. (2006) found that when migrating Chinook smolts approached piers in Lake Washington, they appeared to move into slightly 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).

7.11.4 Predation

Daytime light reduction caused by shading under overwater structures in the marine nearshore could cause migrating juveniles to move into deeper waters, increasing the risk of predation by larger predators that occupy pelagic waters (Nightingale and Simenstad 2001b; Pentec 1997, in Nightingale and Simenstad 2001b). Predation may also be increased by 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, there is no empirically supported evidence that overwater structures (such as bridges) promote predation by aggregating predators under structures in marine environments (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). Cardwell and Fresh (1979, 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 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. An alternative explanation of fish attraction to on-water and overwater structures is that both the structures and the shade they cast provide fishes with physical reference points for orientation (Fresh pers. comm., in Carrasquero 2001).

Interactions of 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 pilings.
- Smallmouth bass are opportunistic predators that consume prey items as they are encountered and are major predators of juvenile salmonids, likely because of the overlap in their rearing habitat.
- Fish, particularly largemouth bass, seem to be attracted to the shade produced by experimental 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).

7.12 Vessel Activities

Vessel activities associated with the installation and operation of water crossings may adversely impact potentially covered species. Potential impact mechanisms include:

- Physical disturbance of sediment and submerged vegetation through grounding or water turbulence caused by propeller wash, potentially resuspending sediment and physically dislodging 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 from the bed and banks of a water body 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 washing 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 9 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 Hey1988). Recreational vessel traffic has been observed to induce levee erosion at rates of 0.0004 to 0.0087 inch (0.01 mm 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).

7.12.2 Eelgrass and Macroalgae Disturbance

Simenstad et al. (1999) describe the potential effects of propeller wash on eelgrass. Flume studies have shown that current velocities of 1 to 1.5 knots (50 to 80 centimeters per second [cm/sec]) may be sufficient to cause sediment disturbance around eelgrass and that velocities of 3.5 knots (180 cm/sec) can cause severe erosion of eelgrass patch edges. However, eelgrass patches in Puget Sound thrive in currents of up to 3.9 knots (200 cm/sec) (Thom et al. 1996, in Nightingale and Simenstad 2001b). The effect of vessels used during installation of water crossings 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).

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 cm) of the vegetation. When installation of water crossings will require the use of outboard motors in shallow water, some loss of aquatic vegetation could occur.

7.12.4 Noise

Underwater noise is produced by equipment and vessels necessary to dig trenches, place riprap, support equipment over water, and perform other activities associated with the construction of water crossings. Construction equipment tends to produce the same type of slow-rise-time noise, although not vessel-generated, as do motor boats and ship engines. The potential effect of noise generated from vessels used to install water crossings depends 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 related to behavioral disturbance or sublethal injury.

The construction or expansion of water crossing structures can require vessel operations at the facility and in areas between the vessel berths and the work area. Motors, sonars, and depth sounders can produce high levels of continuous underwater noise (Scholik and Yan 2001a). Large 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). Jones & 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 feet (1 m), and Richardson et al. (1995, in Jones & Stokes 2006) estimated that an equipment support vessel produces noise levels at 152 dB_{peak} at 3 feet (1 m). Therefore, fish may experience high levels of underwater sound from vessels or in-water heavy equipment.

The impacts to fish from boat traffic and equipment 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 elicited 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 they were exposed to noise from a 260-horsepower speedboat.

7.12.5 Artificial Light

Although it is reasonable to expect that construction of water crossings, particularly bridges, has the potential to add artificial light to the aquatic environment, the potential for effects is likely to be much less than is associated with operational lighting (discussed in Section 7.10) because these effects are temporary. No literature on the potential impacts of artificial light related to vessel activity was identified.

8 CUMULATIVE IMPACTS OF WATER CROSSINGS

This section draws on available literature and the authors' professional experience concerning the possible cumulative impacts of the construction and operation of water crossing structures over time or at multiple sites in a limited area. No studies that specifically address the cumulative impacts of water crossing structures were located.

One cause of cumulative impacts that is generally not addressed in the literature but that applies to all water crossing structures regardless of impact mechanism is accidents. Accidental chemical spills (chiefly fuels and lubricants), accidental concrete spills, accidental erosion or breach 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, 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 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 streambed, and modification of invertebrate habitat and consequent changes in species diversity. Alteration of flow and increased turbidity during re-watering 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, and cumulative area, timing and duration of dewatering. 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.

Disturbance of the streambed associated with dewatering may result in temporary and/or permanent losses of habitat. The significance of the loss depends on the size of the watershed, whether the loss is permanent or temporary, the amount of habitat cumulatively lost, and the significance of the habitat lost to the population (i.e., spawning, rearing, or migration habitat). The loss of streambed habitat could also affect the prey base available for juvenile and adult resident fish species by reducing the abundance of benthic macroinvertebrates. As noted in Section 7.1, both temporary losses of benthic macroinvertebrates are likely to occur as a result of dewatering associated with new construction of water crossing structures or expansion of existing structures; changes in the representative species assemblages as a result of changes in hydraulics and habitat conditions within affected reaches are also possible. 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. Temporary disturbance of habitat and benthic macroinvertebrate populations is likely to be short term, and benthic macroinvertebrate populations generally recolonize disturbed areas within 45 days (NMFS 2003a).

8.2 Channel Hydraulics

No studies specifically addressing the cumulative impacts of channel hydraulic changes on potentially covered species were found. Bates (2003) cites the importance of proper structure siting and land use practices for minimizing the cumulative impacts of culverts. Bates (2003) recommends as most effective those solutions that avoid the need for a water crossing structure, and states that impacts can be minimized by "consolidating water crossings; employing full-floodplain spanning bridges, by simulating a natural channel through culverts; or removing water crossings."

Water crossings entail an element of risk that catastrophic failure may occur, with dire consequences for affected animals and habitat. Debris flows, dam-break floods, footing scour, and channel avulsions are all relatively common failure scenarios in Washington. Although such failures are not and cannot be authorized by issuance of an HPA, there is a calculable risk that any water crossing structure will fail within a given time frame. The incidence of such failures is presumably a function of the number of structures authorized and the flood event design standard used. In general, the larger and more robust the structure the more tolerant it is of large scale events. Many bridges and culverts were installed to pass the 25- or 50-year event (current standards require passing the 100-year event). Events larger than the design can result in simultaneous failure of many "underdesigned" facilities in the watershed. This constitutes a cumulative impact from the construction of water crossing structures. The impacts of such failures have been observed periodically in Washington in association with major weather/flooding events. Observed impacts include bank and channel erosion, sedimentation of stream gravels and pools, and loss of redds through scour or suffocation. These impacts are somewhat ameliorated by more long-term consequences of the event, which can include beneficial changes such as increased channel complexity, accumulation of debris jams, and introduction of spawning-size gravels. Data are not currently adequate to determine the full effect of such flood events on potentially covered species, and no literature addressing this risk and its magnitude within Washington State was found.

Generally, the question of cumulative impacts of channel hydraulic effects emerges as a data gap. The HPA program itself offers a means of collecting data to help measure these impacts, because WDFW has authority to require monitoring of authorized projects. To date, however, monitoring these types of effects has not been emphasized.

8.3 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).

8.4 Substrate Modifications

No studies were found analyzing the cumulative impacts of substrate modifications in association with water crossings. However, since substrate modification as defined herein largely consists of replacing habitat with nonhabitat in the form of fills, piers, piling, or culverts, it follows that cumulative impacts are roughly proportional, at a watershed scale, to the fraction of aquatic habitat lost to substrate modification.

8.5 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 stressors that may be present in the system (Bash et al. 2001), such as elevated water temperatures, excessive flow variation, reduced cover or reduced prey resources. 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 few data are available on the background PAH and metals concentrations in most water bodies and their sediments (Poston 2001).

8.6 Eelgrass and Macroalgae

Installation of water crossings in the nearshore can cause local loss of eelgrass or macroalgae coverage. It logically follows that the cumulative impact of structures that shade potential eelgrass habitat or otherwise inhibit growth would be a reduction in eelgrass coverage, as can be seen 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 water crossing structures or other development on overall patterns of eelgrass coverage.

8.7 Freshwater Aquatic Vegetation

Individual 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 significantly affect the ecological functions of aquatic systems in the vicinity of water crossing structures. For example, Radomski and Goeman (2001) found that because of reduced littoral 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. The severity of this potential impact is moderated, however, by the low density of water crossing structures in aquatic habitats.

8.8 Riparian and Shoreline Vegetation

Although there have been numerous evaluations of the impacts to aquatic habitats resulting from large-scale removal of riparian habitat, few studies have specifically addressed cumulative impacts from the localized removal of riparian and shoreline vegetation that could occur during installation of water crossings. Permitting multiple water crossings within a watershed can be expected to cumulatively impact to riparian/shoreline vegetation, and as such structures become larger or more common, there is an increased likelihood that the impacts will be measurable and significant. Such impacts may be more significant in smaller watersheds. The threshold at which a group of activities will have an adverse impact to 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.

8.9 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, formerly 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" (Radle [undated]; Holing 1994, in Radle [undated]). Construction of water crossings is only one of several sources of such noise; other major sources include overwater structure construction, large-vessel shipping traffic, military activities, and acoustic profiling for petrochemical and minerals exploration. However, the cumulative impacts of such noise sources on fish physiology and behavior are unknown at this time.

8.10 Artificial Light

Although it has been shown that juvenile salmonid migrations can be delayed by artificial light in freshwater and marine environments (Tabor et al. 1998; McDonald 1960, in Tabor et al. 1998; Prinslow et al. 1979, in Nightingale and Simenstad 2001b), 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. For most water crossings, artificial lighting is temporary during the period of construction, but bridges with installed artificial lighting will cumulatively add to light sources over water. It is possible to speculate that losses of threatened and endangered juvenile salmonids could occur due to regional-scale cumulative lighting impacts.

8.11 Shading

The studies reviewed evaluate cumulative effects of overwater structures, but the effects due to bridges are likely similar. These studies suggest that the cumulative impacts of shading do not differ significantly 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).

No reviewed studies evaluated the cumulative shading effects attributable to culverts.

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 (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). However, no studies have suggested comparable impacts from bridges, which are ordinarily much less numerous than docks even in heavily developed settings.

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. Again, this impact should be much reduced for bridges in comparison to docks and related overwater structures.

8.12 Vessel Activities

Little is known about the cumulative impacts of construction vessel activities associated with water crossings, 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 (Bauer et al. 2002). However, given that such impacts only occur as a result of water crossing construction and maintenance, they are isolated in time as well as in space and cumulatively are unlikely to have any measurable effect on organisms or their habitat.

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.

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, substrate modification, or freshwater aquatic vegetation.
- Freshwater species 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.

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	U	Y	U	Y	Y	Y	Y	Y	U	U
White sturgeon	*Acipenser transmontanus*	U	U	U	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	U	Y	U	U	Y	N	U	Y	U	U
Lake chub	*Couesius plumbeus*	U	N	U	U	U	U	U	N	U	U	U	U
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	N	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	U	Y	Y	Y	Y	Y	Y	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
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Y	N	U	Y	Y	Y	Y	N	Y	Y	U	U
Pink salmon	*Oncorhynchus gorbuscha*	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Chum salmon	*Oncorhynchus keta*	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Coho salmon	*Oncorhynchus kisutch*	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Redband trout	*Oncorhynchus mykiss*	Y	N	U	Y	Y	Y	Y	N	Y	Y	U	U
Steelhead	*Oncorhynchus mykiss*	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Sockeye salmon	*Oncorhynchus nerka*	Y	Y	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Chinook salmon	*Oncorhynchus tschawytscha*	Y	Y	U	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
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	U	Y	Y	Y	Y	Y	Y	Y	Y	U
Dolly Varden	*Salvelinus malma*	U	Y	U	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

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
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.

9.1 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. 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 bypass so as to minimize the need to handle fish. There is no requirement that the operation be performed by trained personnel or that it comply with any recognized protocol. There is a relatively high risk of take for dewatering activities in fish streams because the WAC does not focus on "all fish," methodologies for removal could result in stranding fish, and fish could be harmed through mishandling.

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 are discussed in Section 7.5.

9.2 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 a water crossing structure. In this context, a direct impact arises when a water crossing 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 of this white paper where channel dewatering, substrate modifications, 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 Section 9.8).

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. Similarly, provisions in WAC 220-110-070 related to culvert installation recognize the ways in which culverts may impact channel hydraulics and discourage culvert designs that cause such impacts. 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, however, 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 loss 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
Rapid channel change via migration or channel avulsion due to accidental flow obstruction, particularly flow blockage, from an artificial structure	Species potentially occupying the habitats that may be dewatered or buried by the impact
Loss of riparian vegetation due to bank erosion	Species potentially occupying the affected stream. This impact is detailed in Section 7.8.

9.2.1 No Impact

Nearly all channel impacts discussed in this white paper do not apply to marine settings. Although processes of sediment transport occur in the submarine environment, no literature discussing how these processes could be altered by the placement of artificial structures was located. Although it is possible that localized scour or deposition could occur around anchors (such as for a bridge) or submarine cables, 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. Many of the freshwater-only species have 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.

9.2.2 Habitat Loss

For the purpose of this white paper, habitat loss is defined as the replacement of habitat with an artificial structure. Habitat loss includes temporary and permanent elements. Temporary habitat loss 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 loss occurs when an area of habitat remains inaccessible for the service life of the structure or longer. Permanent loss of channel habitat occurs when fill is placed in the channel or floodplain, usually in the form of fill intended to raise an area above the OHWL (such as when fills are placed around a culvert installed at a new road crossing) or fill placed to support a bridge (such as pilings or bridge abutments). Temporary channel habitat loss includes fill placement when it is not permanent, as well as channel dewatering (Section 7.1) resulting from the diversion of flow or flow exclusion via structures such as cofferdams. Habitat loss necessarily entails loss of habitat for any potentially covered species that utilize the affected habitat. As such, habitat loss presents a high potential risk for 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, because in-water placement of fill generally requires isolating and dewatering the work site, such impacts are discussed in Section 7.1.

Water crossing structures can interrupt hyporheic exchange and groundwater recharge by placing fill and/or impervious surface on previously pervious areas. This impact is particularly severe in the case of full culverts, where both the approach fill and the base of the culvert represent surfaces that impede or prevent infiltration. In bottomless culverts, approach fills impede infiltration, and in bridges, the impact is due to approach fills and areas occupied by pilings or piers. In all cases, though, the impact of impaired hyporheic and groundwater function is generally minor in comparison to the permanent habitat loss represented by the loss of stream channel and floodplain areas overlain by fills, piers, pilings, and culvert bottoms.

9.2.3 Embedding

Increases in fine sediment supply to plane-bed and pool-riffle channels 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. Such fine sediment inputs may occur in association with water crossing construction when a poorly designed structure causes locally increased deposition or locally increased erosion of fine sediments in the bed or banks that may be deposited in gravel-bedded streams farther downstream. Ditches and stormwater discharges associated with the water crossing structure may also contribute fine sediment to the stream. Since water crossing structures often alter channel hydraulics but seldom cause persistent increases in fine sediment supply (an effect more commonly resulting from land use changes), the resulting impacts are normally local, occurring in the immediate vicinity of the structure or at a deposition site a short distance downstream. However, significant incidental take may occur if the affected area includes spawning habitat.

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 ceases.

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. The less steep regime channels have fine-grained[7] bed materials that are vulnerable to deposition (discussed below) rather than embedding. Conversely, the stream power of steeper channels is sufficient that the “fines” consist of coarse sand and gravel, which do not substantially impair habitat quality. Plane-bed and pool-riffle channels provide optimum spawning habitat for salmonids (Montgomery et al. 1999) Salmonids chiefly spawn in beds with a substrate size between approximately 1 and 5 inches (2 and 12 cm) in diameter (Raleigh et al. 1986, in Bjornn and Reiser 1991), and artificial spawning channels have generally employed gravels approximately 1 to 1.5 inches (2 to 3.8 cm) in diameter (Bjornn and Reiser 1991). There are few data on spawning habitat for other potentially covered fish species. Lamprey spawn primarily in channels with fine gravel and sand substrates (Wydoski and Whitney 2003), 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 spawning nest (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

[7] Generally defined as particles smaller than 1 millimeter in diameter.

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). A reduction in 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 impairment of oxygen exchange efficiency due to clay particles adhering to the egg membrane (Greig et al. 2005). Redds of large salmonids are usually buried beneath at least about 6 inches (15 cm) of gravel (deVries 1997) and are often more than about 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; Suttle et al. 2004). Thus, embedding has a high risk of causing incidental take if it affects sediments used for spawning.

9.2.4 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. Water crossing structures 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)) and that "culverts shall be designed and installed to avoid inlet scouring and ... erosion of streambanks" (WAC 220-110-070(3)(f)). Thus, a totally WAC-compliant culvert will avoid scour impacts, but a bridge is only required to minimize such impacts. Since there are no guarantees that a culvert installation will completely avoid scour, both types of water crossings implemented according to the WAC provisions will have some associated low to moderate risk of take of fish.

Scour may be observed upstream or downstream of culverts, around bridge piers or pilings, or in places where hydraulic effects direct streamflow against the bank. Scour effects are normally local, occurring very near the water crossing structure, but the scoured sediments may be transported downstream to contribute to impacts such as embedding and deposition.

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, 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 covered salmonid species, or to sessile organisms such as mussels, constitute the potential for incidental take of animals. Impacts to the prey base can be interpreted as an indirect mechanism for incidental take if 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.

9.2.5 Deposition

Deposition may occur in slackwater areas created upstream or downstream of a water crossing, 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 the structure has not received proper hydraulic design, and significant amounts of deposition (i.e., amounts potentially causing measurable incidental take) are most likely to occur, if they do occur, in the immediate vicinity of the structure. The same WAC provisions cited above as minimizing and avoiding scour impacts will also serve to minimize and avoid deposition impacts. Implementation of the WAC provisions as written will likely minimize the risk of take but not eliminate it.

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).

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

When a conduit is installed, direct impacts on waters can often be minimized by high-pressure directional drilling, a trenchless method of crossing a watercourse using subsurface drilling with a pressurized bore fluid lubricant system (Fisheries and Oceans Canada 2006). HPDD is used to install cables and pipelines for gas, water, telecommunications, fiber optics, power, sewer, oil, and water lines underneath watercourses.[8] WAC 220-110-100 provides little protection against potential habitat impacts arising from boring of conduits, providing only that launch and receiving pits be isolated from the water body and that wastewater from the activity be routed to an area outside the ordinary high water line.

“Frac-outs” constitute a distinctive form of fine sediment deposition that sometimes occurs during HPDD operations. A frac-out is the escape of drilling mud into the environment as a result of a spill, tunnel collapse, or rupture of mud to the surface. Frac-outs are caused when excessive drilling pressure results in drilling fluid propagating vertically toward the surface. The principal constituent of the drilling fluid is clay, specifically bentonite, although a variety of secondary constituents may be added to the fluid.

[8] HPDD involves drilling a pilot borehole underneath the watercourse toward a surface target on the opposite side and back-reaming the borehole to the drill rig while pulling the pipe or cable along through the hole. This process typically uses a freshwater gel mud system to transport drilled spoil, reduce friction, and stabilize the borehole. The gel mud system is typically composed of a mixture of clean, fresh water as the base, bentonite (clay-based drilling lubricant) or an alternative drilling lubricant as the viscosifier, and synthetic polymers (Fisheries and Oceans Canada 2006).

The potential for frac-outs can be limited by careful monitoring, use of appropriate equipment, sufficient depth of conduit placement, appropriate boring pit location, and having response plans ready in the event that a frac-out occurs. In examining the effects of HPDD beneath several major Western Washington rivers, NMFS (2005a) found that "although drilling mud consists of naturally occurring nontoxic materials, such as bentonite clay and water, the release of large quantities of drilling mud into a water body could affect fish or other aquatic organisms by settling and temporarily covering the habitats used by these species." The NMFS analysis examined only effects resulting from the introduction of fine sediment into the water column, not effects on substrate. However, the environmental impact statement for the project found that "the majority of highly mobile aquatic organisms, such as fish, would be able to avoid or move away from the affected area. Other less mobile or immobile organisms, such as mussels and other macroinvertebrates, would incur direct mortality…" (FERC 2005). The environmental impact statement also determined that if redds were affected, "a heavy sediment load dispersing downstream could settle into spawning beds and clog interstitial spaces, reducing the survival to emergence amount of available spawning habitat, which could be a limiting factor in areas of already reduced habitat. When redds are active, eggs could be buried, disrupting the normal exchange of gases and metabolic wastes between the egg and water" (FERC 2005). The potential impacts of such fine sediment deposition are detailed above.

9.2.6 Rapid Channel Change

Many streams in the Pacific Northwest are highly energetic and capable of rapid, sometimes dramatic changes in their channels. Examples of this include debris flows, dam-break floods, channel avulsions, and rapid channel migration.

Debris flows are commonly observed in areas that have experienced severe vegetation loss due to forest harvest, forest fire, or land clearance for development. Death and decay of tree roots on steep soils reduces soil cohesion, resulting in shallow-rapid landslides that usually occur during or shortly after severe rainfall events (Croft and Adams 1950, in Coho and Burges 1994). Shallow-rapid landslides commonly initiate on slopes steeper than the angle of repose (about 77 percent) and mix with streamflow in mountain channels to create debris flows that readily transit channels with gradients steeper than about 10 percent (Swanston 1991; Montgomery and Buffington 1993). Such flows entrain sediment and coarse wood that scour the stream channel, often to bedrock, devastating all habitats in the affected reach (Swanston 1991; Benda and Cundy 1990). Commonly, several years to a decade are required before riparian vegetation, fish populations, and water quality recover from the event.

Debris flows are not ordinarily triggered by water crossing structures in the channel, but their effects may be exacerbated if a dam-break flood occurs. These events happen when a debris flow encounters a dam; flows build up behind the dam, and when the dam fails, the flows resume their passage down the channel with renewed ferocity, commonly continuing downslope until the channel gradient decreases to about 2 to 3 percent (Coho and Burges 1994).

A common cause of debris flow damming is a plugged culvert at a road fill. This is rarely likely to occur at culverts constructed under current regulations, which require that a culvert be sized to carry a 100-year flood and also to pass anticipated debris loading (WAC 220-110-070(3)(c)). Thus, culverts installed according to the WAC have a low risk of take except when debris flows with volumes exceeding 100-year events occur. Current regulations on development and forest practices recognize this risk, and it can be argued that such events are unforeseeable and in no way authorized by issuance of an HPA. Nonetheless, debris flows do occur in response to natural causes, and past experience has shown that some debris flows occur in every severe rainfall event that affects Washington. Such events, because of their burden of LWD and sediment, can easily exceed the calculated 100-year flow volume of the affected stream and thus have a high risk of plugging a culvert and resulting in a dam-break flood, a more severe debris flow, or a channel avulsion (discussed below). Because debris flows can be predicted to occur in vulnerable channels conveyed via culverts, it is appropriate to regard debris flows as a cumulative impact risk resulting from culvert installation. Debris flow or dam-break floods triggered by blockage and subsequent failure of a water crossing have the potential to result in incidental take of any potentially covered species and their habitats in the affected stream reach.

Channel avulsions occur when a stream leaves its old channel and cuts a new one. It has been hypothesized that channel avulsion is the principal mode of channel migration in relatively high-gradient, sediment-rich rivers of Western Washington, such as the Nooksack, the Skykomish, the Green, the Nisqually, and the Queets (Latterell et al. 2006). Channel avulsion is also commonly observed in smaller mountain channels, where it can often be triggered by a debris flow; sediment and wood may fill the original channel and subsequent flows cut a new channel. Channel avulsion is also the dominant channel change process on alluvial fans, where channels are typically transport-limited and avulsion occurs in response to sediment aggradation within the channel. Channel avulsions typically are associated with severe deposition (amounting often to several meters of sediment) in the channel immediately upstream of the avulsion point and dewatering of the channel downstream to the point where the avulsed channel and the initial channel merge. Studies on the Queets River have found that the dewatered channel may be hundreds of meters long (Latterell et al. 2006). Channel avulsions on large rivers are usually not anthropogenic events or are only indirectly caused by human activity, but they may occur in unconfined reaches of smaller streams in response to a culvert becoming plugged by sediment and/or woody debris. As with debris flows, it is appropriate to regard avulsions as a cumulative impact that may result from placement of artificial structures in the channel. Channel avulsions caused by the installation of a water crossing have the potential to result in take, at various levels, of all aquatic habitat and animals in the affected stream reach.

Rapid channel migration occurs when bank cutting allows a channel to move laterally by a distance comparable to or greater than the initial channel width. Although the phenomenon has been observed on rivers in Washington, the literature does not contain examples of it happening in response to placement of an artificial structure in the channel. Therefore, there is likely little risk of take of covered species associated with rapid channel migration in association with the siting or construction of water crossings.

9.3 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 water crossing structures.

Pacific salmon, Pacific herring, surf smelt, sand lance, and a variety of other fish may be affected by habitat changes caused by water crossing structures that affect littoral drift (Thom et al. 1994). 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, any alteration of substrate composition in surf smelt spawning areas may affect surf smelt spawning and egg survival. One study found that suitable surf smelt spawning areas were adversely impacted by littoral drift alterations resulting from bulkheads along the Hood Canal (Penttila and Aguero 1978, in Thom et al. 1994). However, no studies were found identifying comparable changes in association with a water crossing structure; thus there are no data to identify the probability of incidental take via this mechanism.

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, and they are probably about as vulnerable as surf smelt to impacts associated with littoral drift changes due to water crossings.

If water crossings affect littoral drift, they may contribute to changes in the siting and density of eelgrass beds. Any species that depends on eelgrass, such as Pacific salmon and Pacific herring, is thus 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). 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) caused by littoral drift. 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 1 foot (0.3 m) above MLLW to 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 intolerant of 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.

To conclude, changes in beach nourishment and sediment deposition associated with littoral drift can alter benthic and epibenthic communities, fish spawning and rearing habitat, and vegetation (Thom et al. 1994). However, the reviewed literature did not identify cases where water crossing structures altered littoral drift patterns. Thus the probable impacts of water crossings on littoral drift cannot be stated with confidence.

9.4 Substrate Modifications

Based on the studies cited in Section 7.4, it appears that in marine environments, 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 9.6.

In freshwater environments, the principal substrate modifications entail habitat loss due to placing fill within the channel or floodplain, and habitat modification by replacing native substrate with culvert pipe. Provisions of WAC 220-110-070 recognize this risk and require that such impacts be minimized, but it is impractical to entirely avoid such impacts given that certain water crossing structures must be built in order to meet recognized social needs. Even though the WAC requires impacts to be minimized, effects are not likely to be completely eliminated. There is a moderate to high risk of take of fish associated with substrate modifications in freshwater environments, depending on existing conditions at the location of installation and the water crossing design.

Incidental take potential due to habitat loss was discussed in Section 9.2.2. 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. In such instances, NMFS uses the causal link 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 [CFR] 402.14(i)). NMFS (2006a) found that the best available indicator for the extent of take is the area of habitat that will be permanently modified by the action, because it is directly proportional to long-term harm attributable to the project. Thus, incidental take due to fill placement or culvert installation would be assessed as proportional to the area of habitat lost due to fill placement or culvert installation.

Substrate modification due to conduit placement was largely not addressed in the reviewed literature. WAC 220-110-100(2) requires that water crossing conduits "shall be installed at sufficient depth so that subsequent disturbance of the bed of the watercourse is avoided," a requirement that likely avoids any incidental take risk due to substrate modification caused by conduits.

As discussed in Section 9.2, channel hydraulic modifications may also entail substrate modification via placement of fills and structures that alter channel hydraulics or via the hydraulic action of the altered flows. The risk of incidental take due to those sediment effects is discussed in Section 9.2.

9.5 Water Quality

Many aspects of water quality can be impacted by water crossing projects, with varying degrees of impact on potentially covered species. Turbidity may occur during construction due to accidental discharge of HPDD fluids, disturbance of the streambed, or runoff from the work site into the stream, and turbidity may occur during operations if the water crossing structure channels flows to the stream. With respect to turbidity, 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. One of the highest-risk activities, with potential to cause mortality due to short-term acute turbidity exposure, is HPDD. Fine sediment deposition also poses an incidental take risk to invertebrates, as discussed in Section 7.2.

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, and type of treatment. PAH releases from creosote pilings may pose risk of incidental take to some of the covered species, given that many types of organisms have significant PAH sensitivities at low exposure levels (Incardona et al. 2004; Incardona and Scholz 2006). Potentially vulnerable species include molluscs and mussels that may be sessile and 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 [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 the use of creosote- and pentachlorophenol-treated wood 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 culverts may still occur, resulting in some potential for take.

9.6 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). Water crossing structures 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 water crossings 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): "Kelp ... and intertidal wetland vascular plants ... shall be replaced using proven methodology." 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), 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 water crossings.

9.7 Freshwater Aquatic Vegetation

Based on the discussion in Section 7.7, water crossing 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 accidental introduction that could occur during the construction or maintenance of water crossings. 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). However, there are no data that provide a basis for stating the likelihood that this impact might occur.

9.8 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." Similar language constrains temporary (WAC 220-110-070(2)(h)) and permanent (WAC 220-110-070(3)(d)) culvert placement and conduit installation (WAC 220-110-100(8)). 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.

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 CFR 402.14(i)). NMFS (2006a) found that the best available indicator 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.

9.9 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 7.9 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 9. 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 11.9

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.

9.10 Artificial Light

Incidental take for listed fish species as a result of artificial lighting of water crossings has not been quantified in past biological opinions and corresponding incidental take statements. The studies cited in Section 7.10 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 risk that nighttime illumination of the water surface may contribute to incidental take. Data are not adequate to define the magnitude of that risk; however, such impacts can generally be minimized, as discussed in Section 11.10.

9.11 Shading

The evidence reviewed in Section 7.11 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 7.6 and 7.7.
- 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.

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. A similar rationale would apply to an overwater water crossing, such as a bridge, provided it were in a location where longshore movement of juvenile salmon might be affected.

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. Shade cast by bridges may also provide a site for predators to congregate.

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 9.5 and the consequences resulting from decreased light availability discussed in Section 9.11.

9.13 Conclusions of the Risk Evaluation

Table 12 summarizes the foregoing analysis of incidental take risk. Given the uncertainties described above, this risk evaluation is at best a qualitative assessment and is based strongly on the professional experience of the analysis team within the context of their work in ESA implementation. In general terms, activities in the low-risk category appear to be well suited for programmatic approval, whereas activities in the high-risk category would require consideration of project-specific elements (e.g., environmental setting, size, and installation technique) and present a clear need to implement conservation measures to reduce the risk of take. The appropriateness of programmatic approval of activities in the moderate-risk category is debatable and would depend in part on the use of conservation measures. The risk evaluation summarized in Table 12 assumes that potentially covered species or their habitat are present when the described impact occurs; thus, impacts and risk may be avoided by avoiding habitat for potentially covered species and may be minimized by performing the activities when potentially covered species are absent from the site.

Table 12
Conclusions of the Risk Evaluation

Activity	Low Risk	Moderate Risk	High Risk
Water crossing structures per WAC 220-110-070	• Work not requiring channel dewatering; • Work that does not alter channel form; • Structures in areas with little sediment transport; • Structures not requiring fill placement within the channel or floodplain; • Structures that do not use treated wood; • Structures that do not channel runoff to the water body; • Structures located in areas lacking submerged aquatic vegetation; • Structures that do not require removal of riparian vegetation; • Work that does not require production of in-water sound with peak levels more than 150 dB; • Structures that are built and operated without artificial illumination of the water surface; • Structures causing little increased shading of the water surface; • Activities avoiding the impacts potentially causing "moderate" or "high" risk.	• Work not requiring channel dewatering; • Projects that use hydraulic modeling to demonstrate minimal alteration of channel form and minimal modification of the floodway; • Structures requiring little or no fill placement within the channel; • Structures use treated wood; • Structures that channel runoff to the water body, when that runoff is treated in accordance with state and local stormwater treatment requirements; • Structures that have only temporary impacts to submerged aquatic vegetation; • Structures that have only temporary impacts to riparian vegetation; • Work that does not require production of in-water sound with peak levels more than 180 dB; • Structures that are designed to minimize artificial illumination of the water surface; • Structures that are designed to minimize shading of the water surface; • Activities requiring vessel use; • Activities avoiding the impacts potentially causing "high" risk.	• Work requiring channel dewatering; • Projects that do not use hydraulic modeling to demonstrate minimal alteration of channel form and minimal modification of the floodway, or for which hydraulic modeling does not show minimal alteration; • Structures requiring fill placement within the channel; • Structures that channel untreated runoff to the water body, • Structures in areas of submerged aquatic vegetation that are used by dependent species (e.g., Olympic mudminnow, freshwater mussels); • Structures that require removing LWD in lotic waters; • Structures permanently removing riparian vegetation; • Work that requires production of in-water sound with peak levels more than 180 dB; • Structures that fail to minimize artificial illumination of the water surface; • Structures that fail to minimize shading of the water surface; • Activities requiring in-water operation of mechanized equipment other than vessels.
Conduit crossings per WAC 220-110-100	• All provisions above, plus: • Work not requiring HPDD; • Work not requiring trenching "in the wet"	• All provisions above, plus: • Work requiring HPDD but potentially covered species not present (see below); • Work requiring trenching "in the wet" but potentially covered species not present (see below) • Absence of potentially covered species confirmed via survey by qualified biologist.	• All provisions above, plus: • Work requiring HPDD and potentially covered species may be present; • Work requiring trenching "in the wet" and potentially covered species may be present
Utility lines per WAC 220-110-310	• All provisions above; no additional provisions	• All provisions above; no additional provisions	• All provisions above; no additional provisions

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 water crossing structures and describes the data needed to fill those gaps.

Relatively few studies specifically address questions about the effects of water crossings on potentially covered species. 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. There is 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 studies that do exist 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 even provide sufficient information to estimate how a given alteration in physical habitat might affect the species, because their life histories and habitat requirements are so imperfectly understood. For such species, which include most potentially covered warm-water fish and invertebrate species (except mussels), this lack of information may make it difficult for the federal agencies to provide incidental take authorization until the potential impacts on these species are better understood.

10.1 Channel Dewatering

No data were identified that would allow quantification of the amount of habitat disturbed each year as a result of the construction of water crossing structures. Such data would make it possible to better quantify take and estimate 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).

10.2 Channel Hydraulics

Most processes associated with channel hydraulics are reasonably well understood. However, the analysis of the biological effects of those processes on potentially covered species is overwhelmingly dominated by research focused on salmonids, with relatively little research addressing other species. For the majority of the potentially covered species, no relevant studies were identified.

10.3 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 better avoid adversely affecting important aquatic habitat characteristics and the potentially covered species that depend on them. In the absence of such current information, estimation of littoral drift will be difficult for most water crossing projects.

10.4 Substrate Modifications

The literature on substrate modifications is limited. Most studies of substrate changes have examined changes in a hydraulically active environment. Hydraulically passive environments are mainly deep marine and deep lake environments, where substrates are seldom altered except by point and linear structures such as anchors and cables. Relevant studies discussed in Sections 7.3 and 7.4 focus on the marine environment; no data applicable to lake environments, where the potentially covered species include sturgeon and, to a lesser degree, suckers and mature salmonids, were identified. Conducting interviews and reviewing agency documents might provide further detail on the impacts of structures in hydraulically passive environments, but seems impractical in view of the small risk of incidental take associated with such structures.

10.5 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, the effect of fine sediment deposition on hyporheic mechanisms, and how these affect habitat quality and abundance. 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 or to evaluate 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, and 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.

10.6 Eelgrass and Macroalgae

The extent of eelgrass coverage, including local and large-scale changes in eelgrass coverage, are just beginning to be researched (Dowty et al. 2005). The effects of water crossings and climatic variables on large-scale trends in eelgrass coverage have not been determined. Likewise, more research is needed to determine the causes for local declines in eelgrass coverage that have been observed in Washington State (Dowty et al. 2005).

The reviewed literature contained almost no information about the ways in which construction or operation of artificial structures may impact macroalgae or the ways in which those impacts could be minimized or mitigated.

10.7 Freshwater Aquatic Vegetation

It is not known at what point the cumulative impact of water crossings (including bridges and culverts) 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 has to be assessed. Of the potentially covered species, only the Olympic mudminnow and the freshwater mussel have a clear and consistent dependence on freshwater aquatic vegetation.

10.8 Riparian and Shoreline Vegetation

No significant data gaps were identified with regard to the ecological significance of riparian and shoreline vegetation for potentially covered species. However, few studies have specifically addressed the impact of water crossings on riparian and shoreline vegetation, and those studies are focused on the role of such vegetation in supporting salmonid habitat.

10.9 Noise

Data on the effects of exposure to sound from pile driving on specific fish or invertebrates are few; 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 are presented in Section V (Table 5, page 49) of Hastings and Popper (2005). 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 affect the area of effect (attention to ambient), and fish reaction to sound likely varies depending on the “loudness” of ambient conditions.

10.10 Artificial Light

Gaps in knowledge about artificial lighting impacts to aquatic organisms are extensive. Impacts to fish resulting from artificial lighting are often subsequent 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 artificial nighttime lighting.

10.11 Shading

As stated in the WDFW white papers on overwater structures (Nightingale and Simenstad 2001b; Carrasquero 2001), significant gaps and uncertainties exist in the extent of scientific knowledge about the impacts of overwater structures and shading on the aquatic environment and biota. Those data gaps are greater for water crossing structures, which have generally received less study. 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 Nightingale and Simenstad (2001b) and Carrasquero (2001) were published, 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) — 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 (among others, Pentec 1997; Weitkamp 1982, in Nightingale and Simenstad 2001b) and recommended ways to minimize impacts of ferry terminals on juvenile salmonids.

10.12 Vessel Activities

Relatively little is known about the potential impacts of construction 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 and has looked at chronic (recreational and shipping) traffic rather than construction activity. 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 smaller vessels operating at varying speeds, so that noise levels specific to conditions created by a particular project can be estimated. Similarly, potential impacts of smaller vessels on eelgrass and aquatic vegetation are not well known, and more work is needed to support impacts to these resources. No literature was identified describing the potential impacts of vessel-generated artificial light and shading.

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 permitted under the HPA authority are fully compliant with applicable local, state, and federal regulations, particularly including the *Hydraulic Code Rules* (WAC 220-110). 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 Channel Dewatering

The following actions could be taken to avoid or 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 protocol for review/approval of proposed dewatering and stream bypass plans.
- Adhere to performance criteria for fish screens on pumped diversions presented by NMFS (1996a) and WDFW (1998). Compliance will minimize the risk of incidental take due to entrainment.
- Define the qualifications of 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 personnel who can perform fish removal and exclusion 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 direct current.
- Use spherical anodes and cable cathodes and vary the number and size of spheres according to water conductivity and desired size and intensity of the field. 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 – rapidly net fish before they get too close to the anode and quickly, but gently, place them in oxygenated holding water.
- Change holding water frequently to ensure adequate dissolved oxygen and to avoid excessive temperatures on hot days; process fish frequently to reduce crowding.

11.2 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 loss, 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). Impacts resulting from rare and unpredictable events such as debris flows may not have to be analyzed in an ESA context, but if necessary could be estimated within a cumulative effects context using landscape-scale studies such as published watershed analyses.

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, or the distribution maps developed for the WDNR Aquatic Lands HCP effort

(WDNR 2006a, 2006b). 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, where specific WRIA reports can also be ordered. For salmonids, quantitative analysis has estimated limiting factors for most streams in Washington using the Ecosystem Diagnosis and Treatment model, accessible at http://www.mobrand.com/edt/.

WDFW might consider a requirement to assess take risk for each HPA. Estimates of area affected, species affected, and habitat importance would allow unprecedented quantification of habitat impacts on a statewide level and would provide an invaluable tool for adaptive management of the HPA program.

HPAs typically require that structures such as bridges and culverts have capacity to convey flood flows and debris. Additional measures that can minimize impacts 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). Guidance for appropriate design of engineered channels is readily available; the Corps channel rehabilitation manual (Watson et al. 1999) provides a widely used example, and another useful source is the Corps manual *Hydraulic Design of Stream Restoration Projects* (Copeland et al. 2001). WDFW's culvert manual (Bates 2003) also provides excellent design guidance for culvert placement. Procedures for hydraulic design of culverts in steep (greater than 3 percent gradient) channels are detailed by Papanicolaou and Maxwell (2000).

All of these guidance documents emphasize the importance of appropriate hydraulic studies for evaluating a project. 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. The hydraulic model need not be numerical; conceptual or qualitative models may suffice for some settings. Requiring a hydraulic evaluation 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 so as to allow monitoring of the quantitative impact of authorized projects on channel hydraulics. Such results would be extremely useful in estimating cumulative impacts of the HPA program, quantifying incidental take arising from the program, and identifying appropriate compensatory mitigation measures.

Standard procedures for channel isolation and in-water work appear to be largely effective at minimizing channel hydraulic effects associated with work within the OHWL. However, some specialized additional measures may be appropriate for minimizing the risk of frac-outs from HPDD water crossings. Examples of itemized measures intended to minimize the risk of frac-outs and expediently respond to their consequences are provided by Fisheries and Oceans Canada (2006) and California Coastal Commission (2000). WDFW may consider adopting these measures as rule (appropriately, within WAC 220-110-100(3)), periodically reviewing and revising them in consultation with the federal agencies and requiring them for all HPDD projects that need an HPA. In addition to minimizing adverse channel hydraulic impacts, the recommended measures also address substrate modifications and water quality impacts associated with HPDD operations. Compliance with such measures should ensure that incidental take due to frac-outs has been minimized to the greatest practicable extent, thereby meeting the ESA criterion.

Risk of damage from "catastrophic" events such as debris flows, dam-break floods, and rare conventional floods can be minimized by increasing the design standard (e.g., to 500-year flood capacity), using fords rather than culverts at sites where fish passage is not an issue, or siting piers/abutments so as to span the channel migration zone (see Bolton and Shelberg 2001 for discussion of channel migration zones).

11.3 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 7.3) through the following measures:

- Bury conduits so that they do not extend above the sediment surface (MOEE 1995) (currently required under WAC 220-110-100(2)).
- Design pile-supported structures with sufficient open space between pilings to allow waves, currents, and sediment to pass beneath (MOEE 1995).
- Avoid certain impacts from floating water crossings placed perpendicular to shorelines, which dampen wave action and prohibit natural shoreline erosional processes, by minimizing the dimensions of these types of structures.

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.

11.4 Substrate Modifications

The identified impacts of marine substrate modification (as distinct from substrate changes that occur in response to channel or shoreline hydraulic changes) are generally beneficial. The reviewed studies do not recommend specific habitat protection, conservation, mitigation, and management strategies. However, if the federal agencies express concern about the possible cumulative effects of marine substrate modifications on potentially covered species, it would be appropriate to track such effects in the course of overall HPA program monitoring. In this way, new data could be accumulated to help guide adaptive management of the program.

Substrate modification in freshwater environments generally consists of placing fill or culverts into aquatic habitat or adjacent riparian/floodplain habitat. Means of reducing the impact of such actions include:

- Minimizing fill placement by siting bridge abutments far enough apart to span the channel or using bottomless culverts that span the channel.
- Minimizing use of approach fills or including flood relief culverts in approach fills.
- Siting bridges or culverts, where possible, at locations where the channel is naturally confined.
- Oversizing culverts to ensure that they will pass LWD and large bedload particles.

11.5 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 existing watershed condition and account for point and nonpoint source pollution loads from watershed sources other than the project, as well as legacy impacts of the system.
- 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, composites, or 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).

- Consider the existing watershed condition and account for point and nonpoint source pollution loads from watershed sources other than the project and from legacy impacts of the system when evaluating cumulative impacts from PAHs and metals. Professional experience and information on urban stormwater pollutants presented by Menzie et al. (2002) and numerous others support this measure as reasonable.
- As an indicator of pre-construction conditions, assess the PAH and metals contamination levels of the water body and sediment prior to construction.
- 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 many cases eliminate, the risk of incidental take due to water quality impairments.

11.6 Eelgrass and Macroalgae

Mitigation of impacts to eelgrass and macroalgae is best achieved through avoidance. If water crossings such as bridges are designed and located so that they do not reduce available light below approximately 325 $\mu M/m^2/sec$ over areas of natural eelgrass presence, 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). Post-disturbance monitoring of eelgrass beds in Puget Sound 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 & Stokes 2005).

In Washington, eelgrass transplantation has been used successfully 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 water crossing 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 of bridges over eelgrass and macroalgae by using the lowest possible number of pilings.
- Space pilings to minimize shade to areas suitable for eelgrass.
- Minimize dimensions of bridges to reduce shade.
- Incorporate design elements into bridges to reduce shade where feasible.
- Whenever possible, orient bridges 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 bridge deck as high above the water as practical to reduce shade.
- Avoid vessel impacts to eelgrass during water crossing construction by maximizing the vertical and horizontal distance between vessel propellers and eelgrass to the extent practicable.

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.

The reviewed literature did not identify minimization or mitigation techniques to address impacts to macroalgae.

11.7 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 1996b; 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 targeted on benefits to salmonids; 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) 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.

11.8 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 (in line with general conditions agreed to 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 years after project completion. The monitoring reports should include information on the percentage of plants replaced, by species. Monitoring reports should also state the cause of plant failure (in line with general conditions agreed to by the Corps, NMFS, and USFWS for Corps ESA Section 7 programmatic consultation).

- Save vegetation (specifically large trees and root wads) removed for the project for later use in restoration efforts (a condition of individual and programmatic Section 7 consultations that has been well received by the federal agencies). 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.
- Enforce revegetation requirements
- Require a revegetation performance bond for projects disturbing large areas (e.g., >500 square feet) of shoreline.

11.9 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 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 assume there will be a 15 dB_{peak} and RMS reduction in sound levels when using a bubble curtain (WSDOT 2006a).

Fabric barriers and cofferdams are also used to attenuate sound levels from pile driving by creating another interface through which sound travels, similar to the theory 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. 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).

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

11.10 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. For bridges, artificial lighting may not be avoidable; therefore, compensatory mitigation may be required to fully account for potential adverse impacts associated with artificial lighting.

11.11 Shading

Nightingale and Simenstad (2001b) and Carrasquero (2001) provide impact minimization measures for the design, construction, and revetment of a variety of overwater structures.

Many of these measures appear to be applicable to water crossings, especially bridges. The guidance provided by these authors includes:

- Increasing the height of overwater structures (in this case, bridges) to allow light transmission under the structures
- Decreasing structure width to decrease the shade footprint
- Using the smallest number of pilings possible, allowing more light to penetrate beneath the structure

It may also be helpful to construct bridges with a grated deck that allows some light transmission.

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.

11.12 Vessel Activities

The most significant issues related to vessel activities (including barges) during the construction of water crossings are vessel grounding in sensitive habitats, such as eelgrass, and the effects of propeller wash. WDFW's standard HPA provisions already prohibit such activities ("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.

12 REFERENCES

Abbe, T.B. and D.R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. *Regulated Rivers: Research & Management* 12: 201-221.

Able, K.W., J.P. Manderson, and A.I. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: the effects of man-made structures in the Lower Hudson River. *Estuaries* 21: 731-44.

Adams, P.B., C.B. Grimes, J.E. Hightower, S.T. Lindley, and M.L. Moser. 2002. Status Review for North American Green Sturgeon, *Acipenser mediorstris*. National Marine Fisheries Service, Southwest Fisheries Science Center. June 2002.

Adams, P.B. and J.E. Hardwick. 1992. Lingcod. Pages 161-164 in: W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.), *California's Living Marine Resources and Their Utilization*. California Sea Grant College Program. Davis, California. UCSGEP-92-12.

Alaska Natural Heritage Program. 2006. Longfin smelt. Compiled by Tracey Gotthardt, ANHP. Anchorage, AK.

Albers, W.D., and P.J. Anderson. 1985. Diet of Pacific cod, *Gadus macrocephalus*, and predation on the northern pink shrimp, *Pandalus borealis*, in Pavlof Bay, Alaska. *Fish. Bull.* 83: 601-10.

Ali, M.A. 1959. The ocular structure, retinomotor and photobehavioral responses of juvenile Pacific salmon. Ph.D. Dissertation, Univ. British Columbia.

Ali, M.A. 1962. Influence of light intensity on retinal adaptation in Atlantic salmon (*Salmo salar*) yearlings. *Can. J. Zool*. 40: 561-70.

Ali, M.A. 1975. Retinomotor Responses. *Vision in Fishes*. New York, NY: Plenum Press.

Anthony, J.L. and J.A. Downing. 2003. Physical impacts of wind and boat traffic on Clear Lake, Iowa, USA. *Lake and Reservoir Management* 19(1): 1-14.

Astrup, J., and B. Mohl. 1998. Discrimination between high and low repetition rates of ultrasonic pulses by cod. *J. Fish. Biol.* 52: 205-208.

Backman, T.W. and D.C. Barilotti. 1976. Irradiance reduction: effects on standing crops of the eelgrass *Zostera marina* in a coastal lagoon. *Marine Biology* 34: 33-40.

Bailey, K.M. 1982. The early life history of the Pacific hake, *Merluccius productus*. *Fish. Bull.* 80: 589-598.

Bailey, K.M., T.J. Quinn, P. Bentzen, and W.S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theragra chalcogramma*. *Adv. Mar. Biol.* 37: 179- 255.

Baker. P. 1995. Review of ecology and fishery of the Olympia oyster, *Ostrea lurida* with annotated bibliography. *Journal of Shellfish Research* 14(2): 501-518.

Baldwin, D.H., J.F. Sandahl, J.S. Labenia, and N.L. Scholz. 2003. Sublethal effects of copper on coho salmon: Impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. *Environ. Toxicol. and Chem.* 22: 2266-2274.

Banner, A. and M. Hyatt. 1973. Effects of noise on eggs and larvae of two estuarine fishes. *Transactions of the American Fisheries Society* 102: 134-136.

Bargmann, G.C. 1980. Studies on Pacific cod in Agate Pass, Washington. Wash. Dept. of Fish. Prog. Rpt. No. 123.

Bargmann, G.C. 1998. Forage fish management plan. A plan for managing the forage fish resources and fisheries of Washington. Adopted by the Washington Fish and Wildlife Commission on January 24, 1998. Olympia, Washington: Washington Department of Fish and Wildlife. September 1998.

Barks, C.S. and Funkhouser, J.E. 2002. Effects of a simulated change in land cover on surface-water velocity distribution at a bridge in southeastern Arkansas. In *Proceedings of the Second Federal Interagency Hydrologic Modeling Conference*, Las Vegas, NV, July 29 -

August 1, 2002. Subcommittee on Hydrology of the Interagency Advisory Committee on Water Information.

Bash, J., C. Berman, and S. Bolton. 2001. *Effects of turbidity and suspended solids on salmonids*. Prepared for the Washington State Transportation Commission.

Bates, Ken. 2003. Design of road culverts for fish passage. Olympia: Washington Department of Fish and Wildlife. http://wdfw.wa.gov/hab/engineer/cm/, accessed 2006.10.04.

Bauer, B.O., M.S. Lorang, and D.J. Sherman. 2002. Estimating boat-wake-induced levee erosion using sediment suspension measurements. *Journal of Waterway, Port, Coastal, and Ocean Engineering* 128(4): 152-162.

Beatty, D.D. 1965. A study of the succession of visual pigments in Pacific Salmon (*Oncorhynchus*). *Canadian Journal of Zoology* 44: 429-55.

Benda, L.E. and T.W. Cundy. 1990. Predicting deposition of debris flows in mountain channels. *Canadian Geotechnical Journal* 27(4) : 409-417.

Bennett, S.J., T. Pirim, and B.D. Barkdoll. 2002. Using simulated emergent vegetation to alter stream flow direction within a straight experimental channel. *Geomorphology* 44: 115-126.

Bilby, R.E. 1984. Post-logging removal of woody debris affects stream channel stability. *Journal of Forestry* 82: 609-613.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pp. 83-138 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. Bethesda, Maryland: American Fisheries Society Special Publication 19.

Black, J.A. and W.J. Birge. 1980. An avoidance response bioassay for aquatic pollutants. Res. Report No. 123, U.S. NTIS PB80-180490. Water Resources Research Institute, University of Kentucky, Lexington.

Blackmon, D., T. Wyllie-Echeverria, and D.J. Shafer. 2006. The role of seagrasses and kelps in marine fish support. U.S. Army Corps of Engineers Wetlands Regulatory Assistance Program ERDC TN-WRAP-06-1.

Blaxter, J.H.S., J.A.B. Gray, and E.J. Denton. 1981. Sound and startle responses in herring shoals. *J. Mar. Biol. Ass. U.K.* 6: 851-69.

Blinn, D.W., J.P. Shannon, L.E. Stevens, and J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. *Journal of the North American Benthological Society* 14:233-248.

Boehlert, G.W. 1980. Size composition, age composition, and growth of canary rockfish, *Sebastes pinniger*, and splitnose rockfish, *S. diploproa*, from the 1977 rockfish survey. *Mar. Fish. Rev.* 42: 57-63.

Boehlert, G.W. and M.M. Yoklavich. 1983. Effects of temperature, ration, and fish size on growth of juvenile black rockfish, *Sebastes melanops*. *Environ. Biol. Fish.* 8: 17-28.

Boehlert, G.W. and R.F. Kappenman. 1980. Variation of growth with latitude in two species of rockfish (*Sebastes pinniger* and *S. diploproa*) from the northeast Pacific Ocean. *Mar. Ecol. Prog.* Ser. 3: 1-10.

Boehlert, G.W., M.M. Yoklavich, and D.B. Chelton. 1989. Time series of growth in the genus *Sebastes* from the northeast Pacific Ocean. *Fish. Bull.* 87: 791-806.

Bolton, S. and J. Shelberg. 2001. *Ecological issues in floodplains and riparian corridors*. Submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Transportation. http://www.wsdot.wa.gov/research/reports/fullreports/524.1.pdf, accessed 2006.10.04.

Booth, D.B., D. Hartley, and R. Jackson. 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association* 38: 835-845.

Boussard, A. 1981. The reactions of roach (*Rutilus rutilus*) and rudd (*Scardinius erythrophthalmus*) to noises produced by high speed boating. Pp. 188-200 in *Proceedings of 2nd British Freshwater Fisheries Conference*.

Box, J.B. and J. Mossa. 1999. Sediment, land use and freshwater mussels: prospects and problems. *J. N. Am. Benthol. Soc.* 18(1): 99-117.

Box, J.B., D. Wolf, J. Howard, C. O'Brien, D. Nez, and D. Close. 2003. *The distribution and status of freshwater mussels in the Umalilla River system*. Prepared for Bonneville Power Administration. Project No. 2002-037-00. Portland, OR. 74 pp.

Brett, J.R. and C. Groot. 1963. Some aspects of olfactory and visual responses in Pacific salmon. *Journal of the Fish. Res. Board Canada* 20: 548-59.

Brett, J.R. and M.A Ali. 1958. Some observations on the structure and photomechanical responses of the Pacific salmon retina. *Journal of the Fish. Res. Board Canada* 15: 815-29.

Brim-Box, Jayne, David Wolf, Jeanette Howard, Christine O'Brien, Donna Nez, and David Close. 2004. Distribution and Status of Freshwater Mussels in the Umatilla River System, 2002-2003 Annual Report, Project No. 200203700, 74 electronic pages (BPA Report DOE/BP-00011402-1). http://www.efw.bpa.gov/publications/I00011402-1.pdf, accessed 2006.10.04.

Britt, Lyle L. 2001. Aspects of the vision and feeding ecology of larval lingcod (*Ophiodone longatus*) and kelp greenling (*Hexagrammos decagrammus*). M.S. Thesis, University of Washington.

Brookes, A. 1988. *Channelized rivers: perspectives for environmental management*. Chichester, UK: John Wiley and Sons.

Brooks, K.M. 1997. Literature review, computer model and assessment of the potential environmental risks associated with creosote treated wood products used in aquatic environments. Prepared for Western Wood Preservers Institute. April 25, 1995; Revised June 1, 1997. Cited in Brooks 2004.

Brooks, K.M. 2004. Environmental response to ACZA treated wood structures in a Pacific Northwest marine environment. Technical report prepared for J.H. Baxter and Company, San Mateo, CA. 30pp.

Burdick, D.M. and F.T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. *Environmental Management* 23(2): 231-240.

Busby, P.J, T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996. *Status review of West Coast steelhead from Washington, Idaho, Oregon, and California*. NOAA Technical Memo NMFS-NWFSC-27. Long Beach, California: NOAA Southwest Region, Protected Species Management Division. http://www.nwfsc.noaa.gov/publications/techmemos/tm27/tm27.htm, accessed 2006.10.06.

Cake, E.W., Jr. 1983. Habitat suitability index models: Gulf of Mexico American oyster. FWS/OBS/-82/10.57. US Dept. of Interior, Fish and Wildlife Service, Washington, D.C.

California Coastal Commission. 2000. W12b. Appeal No. A-1-MEN-00-043.

Canning, D.J., and H. Shipman. 1994. Coastal Erosion Management Studies in Puget Sound, Washington: Executive Summary. Coastal Erosion Management Studies Volume I. Water and Shorelands Resources Program. Report 94-74. Washington Department of Ecology. Olympia, WA.

Cardwell, R.D. and K.L. Fresh. 1979. *Predation upon juvenile salmon*. State of Wash. Dept. Fish Progr. Rep. Draft No. 8.

Carrasquero, J. 2001. *Over-Water Structures: Freshwater Issues. White Paper*. Herrera Environmental Consultants. Prepared for: Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. April 12.

Chambers, P.A., R.E. DeWreede, E.A. Irlandi, and H. Vandermeule. 1999. Management issues in aquatic macrophyte ecology: A Canadian perspective. *Canadian Journal of Botany* 77(4):471.

Clemens, W.A. and G.V. Wilby. 1961. Fishes of the Pacific coast of Canada. *Bull. Fish. Res. Board Can.* No. 68. 443pp.

Coho, C. and S.J. Burges. 1994. *Dam-break floods in low order mountain channels of the Pacific Northwest*. Water Resources Series Technical Report No. 138. Olympia, WA: Timber, Fish & Wildlife. http://www.ce.washington.edu/pub/WRS/WRS138, accessed 2006.10.04.

Colley, R.H. and J.E. Burch. 1961. A small-block screening test for accelerated evaluation of wood preservative for marine use. *Proceedings of the American Wood Preservers Association* 57: 1-11.

Collins, B.D., D.R. Montgomery, and A.D. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 66-76.

Cooper, P.A. 1991. *Leaching of wood preservatives from treated wood in service*. Prepared for Public Works Canada, Ottawa, Ontario.

Coops, H., N. Geilen, H.J. Verheij, R. Boeters, and G. van der Velde. 1996. Interactions between waves, bank erosion and emergent vegetation: an experimental study in a wave tank. *Aquatic Botany* 53(3): 187-198.

Copeland, R.R., D.N. McComas, C.R. Thorne, P.J. Soar, M.M. Jonas, and J.B. Fripp. 2001. *Hydraulic design of stream restoration projects*. U.S. Army Corps of Engineers Engineer Research and Development Center: Coastal and Hydraulics Laboratory ERDC/CHL TR-01-28.

Copeland, R.R., D.S. Biedenharn, and J.C. Fischenich. 2000. *Channel-forming discharge*. U.S. Army Corps of Engineers ERDC/CHL CHETN-VIII-5. 10pp.

Cowx, I.G. and R.L. Welcomme (eds.). 1998. *Rehabilitation of Rivers for Fish*. Oxford: Fishing News Books. 160p.

Cox, J., K. Mcdonald, and T. Rigert. 1994. *Engineering and Geotechnical techniques for shoreline erosion management in Puget Sound*. Coastal Erosion Management Studies, Volume 4. Olympia, WA : Shorelands and Coastal Zone Management Program, Washington Department of Ecology.

Cramer, M., K. Bates, D. Miller, K. Boyd, L. Fotherby, P. Skidmore, and T. Hoitsma. 2003. Integrated Streambank Protection Guidelines. Co-published by the Washington departments of Fish & Wildlife, Ecology, and Transportation. Olympia, Washington. 435 pp. http://www.wdfw.wa.gov/hab/ahg/strmbank.htm

Croft, A.R., and J.A. Adams. 1950. *Landslides and sedimentation on the North Fork of Ogden River*. USDA For. Serv. Intermt. For. & Range Exp. Stn. Res. Pap. INT-21, 4 p., illus.

Cuffey, K.M. 2002. *Freshwater mussels in a California North Coast Range river: occurrence, distribution, and controls*. University of California Water Resources Center Technical Completion Reports. http://repositories.cdlib.org/wrc/tcr/cuffey, accessed 2006.10.04.

deVries, P. 1997. Riverine salmonid egg burial depths: Review of published data and implications for scour studies. *Can. J. Fish. Aquat. Sci.* 54:1685-1698.

Dietrich, W.E. and T. Dunne. 1993. The channel head. Pp. 175-219 *in* K. Beven and M.J. Kirkby (eds.), *Channel Network Hydrology*, J. Wiley and Sons.

Dollar, E.S.J. 2000. Fluvial geomorphology. *Progress in Physical Geography* 24(3): 385-406.

Dowty, P., B. Reeves, H. Berry, S. Wyllie-Echeverria, T. Mumford, A. Sewell, P. Milos, and R. Wright. 2005. *Puget Sound submerged vegetation monitoring project 2003-2004 monitoring* *report*. Washington State Department of Natural Resources. Puget Sound Ambient Monitoring Program. Olympia, WA.

Duchrow, R.M., and W.H. Everhart. 1971. Turbidity measurement. *Transactions of the American Fisheries Society* 4: 682-690.

Duffy-Anderson, J.T., and K.W. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River Estuary: a study across a pier edge. *Marine Biology* 133(3): 409-418.

Dunn, J.R. and A.C. Matarese. 1987. A review of early life history of northeast Pacific gadoid fishes. *Fish. Res.* 5:163-184.

Dunne, T., and L.B. Leopold. 1978. *Water in Environmental Planning*. San Francisco: WH Freeman Co., pp. 590-594 and 693-695.

Ecology (Washington State Department of Ecology). 1999. Working in the Water. Pub.#99-06. http://www.ecy.wa.gov/biblio/9906.html, accessed 2006.10.04.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. *Ecology* 17:29–42.

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: Species life history summaries. NOAA/NOS Strategic Environmental Assessments Division. Rockville, Maryland. ELMR Rept. No. 8. 329pp.

Environment Canada. 1992. Interim Criteria for Quality Assessment of St. Lawrence River Sediment. St. Lawrence Action Plan.

Eschmeyer, W.N., E.S. Herald, and H. Hammon. 1983. *A field guide to Pacific Coast fishes of North America*. Boston: Houghton Mifflin. 336pp.

Everest, F.H., R.L. Beschta, J.C. Schrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Chapter 4. Fine sediment and salmonid production: A paradox. P. 98-142 *in* E.O. Salo and T.W. Cundy (eds), *Streamside Management: Forestry and Fishery Interactions*. University of Washington, Institute of Forest Resources. Contribution No. 57.

Fay, R.R. and A.N. Popper (eds.). 1999. *Comparative hearing: fish and amphibians*. New York: Springer-Verlag.

Fayram, A.H. 1996. Impacts of largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) predation on populations of juvenile salmonids in Lake Washington. M.S. thesis,. University of Washington, School of Fisheries, Seattle.

Fayram, A.H. and T.H. Sibley. 2000. Impact of predation by smallmouth bass on sockeye salmon in Lake Washington. *North American Journal of Fisheries Management* 20: 81–89.

Feist, B.E. 1991. Potential impacts of pile driving on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon behavior and distribution. M.S. Thesis, University of Washington School of Fisheries.

Feist, B.E., J. Anderson, and R. Miyamoto. 1992. Potential impacts of pile driving on juvenile pink (*Onchorhynchus gorbuscha*) and chum (*O. keta*) salmon behavior and distribution. Pound Sounds Final Report. University of Washington, Seattle, WA.

FERC (Federal Energy Regulatory Commission). 2005. Final Environmental Impact Statement Volume I Capacity Replacement Project. Docket Nos. CP05-32-000, -001 FERC/EIS – 0178. Chapter 4 only. http://www.ecy.wa.gov/programs/sea/nw_capacity_replacement/, accessed 2006.10.04.

Fields, P.E. 1966. Final report on migrant salmon light guiding studies (Contract No. D.A.-45-108 CIVENG-63-29) at Columbia River Dams. University of Washington. College of Fisheries. Report for the Fisheries Engineering Research Program. U.S. Army Engineer Division, North Pacific Corps of Engineers, Portland, OR.

Fisheries and Oceans Canada. 2006. High-pressure directional drilling. http://www.dfo-mpo.gc.ca/regions/central/habitat/os-eo/prov-terr/sk/index_e.htm, accessed 2006.12.06.

Folmar, L. C., and W. W. Dickhoff. 1981. Evaluation of some physiological parameters as predictive indices of smoltification. *Aquaculture* 23: 309-24.

Fresh, K. 1998. Taking stock: anadromous salmonids and their habitats in the Puget Sound basin. In: Salmon in the City: Can Habitat in the Path of Development be Saved? Proceedings of a conference by American Public Works Association, Stormwater Managers Committee in Mount Vernon, Washington. Washington State University. http://depts.washington.edu/cwws/Research/Reports/salmoninthecity.pdf, accessed 2006.10.04.

Fresh, K., B.W. Williams, S. Wyllie-Echeverria, and T. Wyllie-Echeverria. 2000. Mitigating impacts of overwater floats on eelgrass *Zostera marina* in Puget Sound, Washington using light permeable deck grating. Prepublication, draft.

Fresh, K.L., B. Williams, and D. Penttila. 1995. Overwater structures and impacts on eelgrass in Puget Sound, WA. Puget Sound Research '95 Proceedings. Seattle, WA: Puget Sound Water Quality Authority.

Fresh, Kurt. November 2000. Personal communication (review comments forwarded by the state salmon recovery program steering committee to José Carrasquero, Herrera Environmental Consultants, regarding the draft white paper on over-water structures [freshwaters]). Washington Department of Fish and Wildlife, Olympia.

Frest, T.J. and E.J. Johannes. 1995. Interior Columbia Basin Mollusk Species of Special Concern. Final report to the Interior Columbia Basin Ecosystem Management Project. Walla Walla, Washington. Cited in WDNR (2006b).

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road Construction and Maintenance. Pp. 297-324 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland Management on Salmonid*

Fishes and Their Habitats. Bethesda, Maryland: American Fisheries Society Special Publication 19.

Gardner, F. (ed.). 1981. Washington Coastal Areas of Major Biological Significance. Baseline Studies Program. Olympia, Washington: Washington State Department of Ecology.

Garrad, P.N., and R.D. Hey. 1988. River management to reduce turbidity in navigable broadland rivers. *Journal of Environmental Management* 27(3): 273-288.

Garrison, K.J., and B.S. Miller. 1982. Review of the early life history of Puget Sound fishes. University of Washington Fisheries Research Institute, UW-8216. Seattle, Washington. 729pp.

Geist, D.R. 2000a. Hyporheic discharge of river water into fall chinook salmon (*Oncorhynchus tshawytscha*) spawning areas in the Hanford Reach, Columbia River. *Can. J. Fish. Aquat. Sci.* 57: 1647–1656.

Geist, D.R. 2000b. The interaction of ground water and surface water within fall Chinook salmon spawning areas in the Hanford Reach of the Columbia River. Pp. 95-98 *in* Proceedings of the Ground-Water/Surface-Water Interactions Workshop, EPA/542/R-00/007.

Ginetz, R.M., and P.A. Larkin. 1976. Factors affecting rainbow trout (*Salmo gairdneri)* predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). *Journal of the Fisheries Research Board of Canada* 33: 19–24.

Giorgi, A.E. 1981. The environmental biology of the embryos, egg masses and nesting sites of the lingcod, *Ophiodon elongatus*. NMFS, NWAFC Proc. Rept. No. 81- 06. Seattle, Washington. 107pp.

Gjovik, L.R. 1977. Pretreatment molding of southern pine: Its effect on the permanence and performance of preservatives exposed in sea water. *Proceedings of the American Wood Preservers' Association* 73: 142-153.

Godin, J.-G.J. 1982. Migrations of salmonid fishes during early life history phases: daily and annual timing. Pp. 22-50 *in* E.L. Brannon and E.O. Salo (eds.), *Proceedings of the First Intl. Salmon Trout Migratory Behavior Symp.* UW.

Goetz, F.A., E. Jeanes, E. Beamer, G. Hart, C. Morello, M., Camby, C. Ebel, E. Conner, and H. Berge. 2004. Bull Trout in the nearshore (preliminary draft). June 2004.

Gottesfeld, A.S., M.A. Hassan, J.F. Tunnicliffe, and R.W. Poirier. 2004. Sediment dispersion in salmon spawning streams: the influence of floods and salmon redd construction. *Journal of the American Water Resources Association* 40(4): 1071-1086.

Grant, J., and B. Thorpe. 1991. Effects of suspended-sediment on growth, respiration, and excretion of the soft-shelled clam (*Mya arenaria*). *Can. Journ. Fish. Aquat. Sci.* 48: 1285-92.

Gray, G.A., G.M. Sonnevil, H.C. Hansel, C.W. Huntington, and D.E. Palmer. 1984. Feeding activity, rate of consumption, daily ration and prey selection of major predators in the John Day pool. U.S. Fish and Wildlife Service, Annual report (Contract DI-AI79-82BP34796). Cook, Washington. Cited in Carrasquero 2001.

Gray, Gerard A. and Dennis W. Rondorf. 1986. Predation on juvenile salmonids in Columbia basin reservoirs. Pp. 178–185 *in* G.E. Hall and M.J. Van Den Avyle (eds.), *Reservoir Fisheries Management: Strategies for the 80's*. Bethesda, Maryland: American Fisheries Society. Cited in Carrasquero 2001.

Greig, S.M., D.A. Sear, and P.A. Carling. 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny: Implications for sediment management. *Science of The Total Environment* 344(1-3): 241-258.

Groot, C. and L. Margolis (eds.). 1991. *Pacific Salmon Life Histories*. Vancouver, British Columbia: University of British Columbia Press.

Haas, M.E., C.A. Simenstad, J.R. Cordell, D.A. Beauchamp, and B.S. Miller. 2002. *Effects of large overwater structures on epibenthic juvenile salmon prey assemblages in Puget Sound, WA*. http://www.wsdot.wa.gov/Research/Reports/500/550.1.htm, accessed 2006.10.23.

Haldorson, L., and L.J. Richards. 1986. Post-larval copper rockfish in the Strait of Georgia: Habitat use, feeding, and growth in the first year. Pages 129-141 in *Proceedings International Rockfish Symposium*. Alaska Sea Grant College Program. Anchorage, Alaska.

Hallock, M. and P.E. Mongillo. 1998. *Washington state status report for the pygmy whitefish*. Olympia, Washington: Washington Department of Fish and Wildlife. http://wdfw.wa.gov/wlm/diversty/soc/status/whitfish/dftpwfsh.pdf, accessed 2006.10.23.

Hansen, J.A., J.D. Rose, R.A. Jenkins, K.G. Gerow, and H.L. Bergman. 1999. Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper: neurophysiological and histological effects on the olfactory system. *Environ. Toxicol. and Chem.* 18:1979-1991.

Hansen, J.A., P.G. Welsh, J. Lipton, D. Cacela, and A.D. Dailey. 2002. Relative sensitivity of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) to acute exposures of cadmium and zinc. *Environ. Toxicol. Chem.* 21:67-75.

Hard, J.J., R.G. Kope, W.S. Grant, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1996. *Status review of pink salmon from Washington, Oregon, California*. U.S. Department of Commerce., NOAA Technical Memorandum NMFS-NWFSC-25. Seattle, Washington: Northwest Fisheries Science Center. http://www.nwfsc.noaa.gov/publications/techmemos/tm25/tm25.html, accessed 2006.10.04.

Harris, C. 1974. The Geographical Distribution and Habitat of the Olympic Mudminnow, (N*ovumbra hubbsi*). Masters Thesis. University of Washington. Seattle, Washington.

Hart, J.L. 1973. Pacific Fishes of Canada. *Fish. Res. Board Can. Bull.* 180. 730pp.

Hastings, M.C. 1995. Physical effects of noise of fishes. Proceedings of INTER-NOISE 95, The 1995 International Congress on Noise Control Engineering, vol. II, pp. 979-984.

Hastings, M.C. and A. N. Popper. 2005. Effects of sound of fish. Prepared for Jones and Stokes and the California Department of Transportation. Sacramento, California.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: The life support system. Pp. 315-341 in: V.S. Kennedy (ed.), *Estuarine Comparisons*. New York, New York: Academic Press.

Heard, W.R. 1991. Life History of Pink Salmon (*Oncorhynchus gorbuscha*). Pp. 120-230 in C. Groot and L. Margolis (eds.), *Pacific Salmon Life Histories*. . Vancouver, British Columbia: University of British Columbia Press.

Heathershaw, A.D., P.D. Ward, and A.M. David. 2001. The Environmental Impact of Underwater Sound. Pro. I.O.A. Vol. 23(4):1-13. Cited in WSDOT 2006a.

Heck, K. I. Jr. and R.J. Orth. 1980. Structural components of eelgrass (*Zostera marina*) meadows in the lower Chesapeake Bay--Decapod crustacea. *Estuaries* 3: 289-95.

Heck, K.I. Jr. and T.A. Thoman. 1984. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. *Estuaries* 7(1): 70-92.

Heiser, D.W. and E.L. Finn. 1970. Observations of juvenile chum and pink salmon in marina and bulkheaded areas. Suppl. Progress Report. WDF, Olympia, WA.

Helfman, Gene S. 1979. Fish attraction to floating objects in lakes. Pp. 49–57 in D.L. Johnson and R.A. Stein (eds.), *Response of Fish to Habitat Structure in Standing Water*. Bethesda, Maryland: American Fisheries Society.

Hicks, B.J., J.D. Hall, P.A. Bisson and J.R. Sedell. 1991. Responses of Salmonids to Habitat Change. Pp. 483-518 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. Bethesda, Maryland: American Fisheries Society Special Publication 19. E.

Hill, D.F., and M.M. Beachler. 2002. ADV Measurements of Planing Boat Prop Wash in the Extreme Near Field. Proceedings of the 2002 Conference on Hydraulic Measurements and Experimental Methods.

Hoar, W. S. 1951. The behavior of chum, pink, and coho salmon in relation to their seaward migration. *J. Fish Res. Board Can.* 8: 241-63.

Hoar, W. S., M.H.A. Keenleyside, and R.G. Goodall. 1957. Reactions of juvenile Pacific salmon to light. *J. Fish. Res. Board Can.* 14: 815-30.

Holing, Dwight. 1994. The sound and the fury: Debate gets louder over ocean noise pollution and marine mammals. *The Amicus Journal* 16(3):19-25.

Howell, M.D., M.D. Romano, and T.A. Rien. 2001. Draft outmigration timing and distribution of larval eucachon, *Thaleichthys pacificus*, in the lower Columbia River, Spring 2001. Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife.

Hruby, T, T. Granger, K. Brunner, S. Cooke, K. Dublanica, R. Gersib, L. Reinelt, K. Richter, D. Sheldon, E. Teachout, A. Wald, and F. Weinmann. 1999. Methods for Assessing Wetland Functions Volume I: Riverine and Depressional Wetlands in the Lowlands of Western Washington. Publication #99-115. July. Washington Department Ecology, Olympia.

Hueckel, G.J. and R.L. Slayton. 1982. Fish foraging on an artificial reef in Puget Sound, Washington. *Mar. Fish. Rev.* 44:38-44.

Incardona, J. and N. Scholz. 2006. Cardiovascular defects in fish embryos exposed to polycyclic aromatic hydrocarbons. http://www.nwfsc.noaa.gov/research/divisions/ec/ecotox/fishneurobiology/cardio.cfm, accessed 2006.10.23.

Incardona, J.P., T.K. Collier and N.L. Scholz. 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicol Appl Pharmacol.* 196(2):191-205.

Ingersoll, C.G., P.S. Haverland, E.L. Brunson, T.J. Canfield, F.J. Dwyer, C.E. Henke, N.E. Kemble, D.R. Mount, and R.G. Fox. 1996. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. *J. Great Lakes Res.* 22(3): 602-623.

Jackson, G.A. 1984. Internal wave attenuation by coastal kelp stands. Journal of Physical Oceanography 14: 1300-1306.

JASCO. 2005. British Columbia Transmission Corporation, Vancouver Island Transmission Reinforcement Project, Atmospheric and underwater acoustics assessment report. Victoria, B.C.

Johnson, L.L., T.K. Collier, and J.E. Stein. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12: 517-538.

Johnson, O.W., M.H. Ruckelshaus, W.S. Grant, F.W. Waknitz, A.M. Garrett, G.J. Bryant, K. Neely, and J.J. Hard. 1999. *Status review of coastal cutthroat trout from Washington, Oregon, and California*. NOAA Technical Memorandum NMFS-NWFSC- 37. Seattle, Washington: Northwest Fisheries Science Center. http://www.nwfsc.noaa.gov/publications/techmemos/tm37/tm37.html, accessed 2006.10.04.

Jones & Stokes. 2002. San Juan Islands Cable Replacement Project. Nearshore Habitat Disturbance Year 1 Post-Construction Monitoring Report. November 21. (J&S 0P001.00.005) Bellevue, WA. Prepared for Bonneville Power Administration. Vancouver, WA.

Jones & Stokes. 2005. San Juan Islands Cable Replacement Project. Nearshore Habitat Recovery 2005 Post-Construction Monitoring Report. December. (J&S 0P011.03.002) Bellevue, WA. Prepared for Bonneville Power Administration. Vancouver, WA.

Jones & Stokes. 2006. Biological Assessment. Vancouver Island Transmission Reinforcement Project. May. (J&S 05197.05) Bellevue, WA. Prepared for British Columbia Transmission Corporation (BCTC).

Kahler, T., M. Grassley, and D. Beauchamp. 2000. A summary of the effects of bulkheads, piers, and other artificial structures and shorezone development on ESA-listed salmonids in lakes. Prepared for the City of Bellevue. Bellevue, WA.

Kang, S.-M., J.J. Morrell, J. Simonsen, and S.T. Lebow. 2003. *Creosote movement from treated wood immersed in fresh water: Initial PAH migration*. IRG/WP/03-5. International Research Group on Wood Preservation. Prepared for the 34th Annual Meeting, Brisbane, Australia, 18-25 May.

Kapoor, B.G., and B. Khanna, eds. 2004. *Ichthyology Handbook*. Berlin: Springer-Verlag. 1080 pp.

Karrow, N.A., H.J. Boermans, D.G. Dixon, A. Hontella, K.R. Solomon, J.J. Whyte, and N.C. Bols. 1999. Characterizing the immunotoxicity of creosote to rainbow trout (*Oncorhynchus mykiss*): A microcosm study. *Aquatic Toxicology* 45(4):223-239.

Kendall, A.W. and W.H. Lenarz. 1986. Status of early life history studies of northeast Pacific rockfishes. Pages 99-128 in: *Proceedings International Rockfish Symposium*. Anchorage, Alaska: Alaska Sea Grant College Program.

King County. 2000. Selected ongoing and recent research on chinook salmon in the greater Lake Washington watershed. Conference held on November 8–9, 2000 in Seattle Washington by King County Department of Natural Resources, Wastewater Treatment Division.

Knutson, K.L. and V.L. Naef. 1997. *Management Recommendations for Washington's Priority Habitats: Riparian*. Olympia, WA: Washington Department of Fish and Wildlife. 181 p.

Kogan, I., C.K. Paull, L. Kuhnz, E.J. Burton, S. Von Thun, H.G. Greene, and J.P. Barry. 2003. Environmental impact of the ATOC/Pioneer Seamount submarine cable. www.montereybay.noaa.gov/research/techreports/cablesurveynov2003.pdf, accessed 2006.10.04).

Kondolf, M.G., M.J. Sale, and M.G. Wolman. 1993. Modification of fluvial gravel size by spawning salmonids. *Water Resources Research* 29(7):2265-2274.

Kosheleva, V. 1992. The impact of air guns used in marine seismic explorations on organisms living in the Barents Sea. Fisheries and Offshore Petroleum Exploitation 2nd International Conference, Bergen, Norway, 6-8 April 1992.

Kozloff, E. 1983. *Seashore life of the northern Pacific coast*. Seattle, WA: University of Washington Press.

Krumholz, L.A. 1943. A comparative study of the weberian ossicles in North American Ostariophysine fishes. *Copeia* 1943(1): 33-40.

Kynard, B., E. Parker, and T. Parker. 2005. Behavior of early life intervals of Klamath River green sturgeon, *Acipenser medirostris* with a note on body color. *Environmental Biology of Fishes* 72(1): 85-97. http://www.springerlink.com/content/v55401j240453410/, accessed 2006.10.06.

Lagler, K.F., A.S. Hazzard, W.E. Hazen, and W.A. Tompkins. 1950. Outboard motors in relation to fish behavior, fish production and angling success. Pp. 280–303 in *Transactions of the 15th Annual North American Wildlife Conference*.

Langer, O.E., B.G. Shepherd, and P.R.Vroom. 1977. Biology of the Nass River eulachon (*Thaleichthys pacificus*). Department of Fisheries and Environment Canada, Fisheries and Marine Service, Technical Report Series No. PAC, T-77-10. 56 p.

Laroche, W.A. and S.L. Richardson. 1981. Development of larvae and juveniles of the rockfishes *Sebastes entomelas* and *S. zacentrus* (Family Scorpaenidae) and occurrence off Oregon, with notes on head spines of *S. mystinus*, *S. flavidus*, and *S. melanops*. *Fish. Bull.* 79: 231-256.

Larsen, E.M., E. Rodrick, and R. Milner. 1995. *Management recommendations for Washington's priority species, Volume 1: Invertebrates*. Olympia, WA: Washington Department of Fish and Wildlife.

Latterell J.J., J.S. Bechtold, T.C. O'Keefe, R. Van Pelt, and R.J. Naiman. 2006. Dynamic patch mosaics and channel movement in an unconfined river valley of the Olympic Mountains. *Freshwater Biology* 51: 523-544.

Laughlin, J. 2006. *Underwater sound levels associated with pile driving at the Cape Disappointment boat launch facility, wave barrier project*. Washington State Parks Cape Disappointment Wave Barrier Project. Seattle, Washington: Washington Department of Transportation.

Leary, R.F., and F.W. Allendorf. 1997. Genetic confirmation of sypatric bull trout and Dolly Varden in western Washington. *Trans. Am. Fish. Soc*. 126:715-20.

Lebow, S, D. Foster and P. Lebow. 2004. Rate of CCA leaching from commercially treated decking. *Forest Products Journal* 54(2): 81-88.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. *Atlas of North American Freshwater Fishes*. North Carolina State Museum of Natural History. 867 pp.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. *Fluvial Processes in Geomorphology*. San Francisco: W. H. Freeman and Company, pp. 156-160.

Lewis, A.F.J., M.D. McGurk, and M.G. Galesloot. 2002. Alcan's Kemano River eulachon (*Thaleichthys pacificus*) monitoring program 1988-1998. Consultant's report prepared by Ecofish Research Ltd. for Alcan Primary Metal Ltd., Kitimat, B.C. 136 p.

Liknes, G.A. and P.J. Graham. 1988. Westslope cutthroat trout in Montana: life history, status and management. Pp. 53–60 in R.E. Gresswell (ed.), *Status and management of cutthroat trout*. Bethesda, Maryland: American Fisheries Society.

Linbo, T.L., C.M. Stehr, J.P. Incardona, and N.L. Scholz. 2006. Dissolved copper triggers cell death in the peripheral mechanosensory system of larval fish. *Environmental Toxicology and Chemistry* 25(2): 597-603.

Livingston, P.A. 1991. Food habitats and population level consumption of groundfish. Pages 9-88 *in* P.A. Livingston (ed.), *Groundfish food habitats and predation on commercially important prey species in the Eastern Bering Sea from 1984 to 1986*. NOAA Tech. Memo. NMFS F/NWC-207. Seattle, Washington: Northwest Fisheries Science Center.

Long, E.R., and L.G. Morgan. 1991. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends program. NOAA Technical Memorandum NOS OMA 52. Seattle, WA: National Oceanic and Atmospheric Administration. (Appendix L; as cited in MacDonald et al. 2000b.).

Love, M.S. 1991. *Probably more than you want to know about the fishes of the Pacific coast*. Really Big Press, Santa Barbara, California. 215p.

Love, M.S., and A. York. 2005. A comparison of the fish assemblages associated with an oil/gas pipeline and adjacent seafloor in the Santa Barbara Channel, southern California bight. *Bulletin of Marine Science* 77(1): 101-117.

Love, M.S., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the southern California bight. NMFS Tech. Rept. No. 87. 38pp.

Ludwig, M., D. Rusanowsky, and C. Johnson-Hughes. 1997. The impact of installation and use of a pier and dock assembly on eelgrass (*Zostera marina*) at Star Island, Montauk NY: Kalikow Dock Study., NMFS. USFWS.

Luning, K. 1981. Light. Pp. 326-355 *in* C.S. Lobban and M.J. Wynne (eds.), *The Biology of Seaweeds*. Oxford: Blackwell Sci. Publ.

Lussier, S.M., J.H. Gentile, and J. Walker. 1985. Acute and chronic effects of heavy metals and cyanide on *Mysidopsis bahia* (Crustacea:Mysidacea). *Aquat. Toxicol*. 7(1-2): 25-35.

MacDonald, D.D. 1994. Approach to the assessment of sediment quality in Florida coastal waters. Volume I: Development and evaluation of sediment quality assessment guidelines. Prepared for Florida Department of Environmental Protection. November.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000a. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch. Environ. Contam. Toxicol.* 39: 20-31.

MacDonald, D.D., T. Berger, K. Wood, J. Brown, T. Johnsen, M.L. Haines, K. Brydges, M.J. MacDonald, S.L. Smith, and D.P. Shaw. 2000b. A compendium of environmental quality benchmarks. GBE/EC-99-001. Prepared for Environment Canada.

Mace, P.M. 1983. Predatory-prey functional responses and predation by staghorn sculpins, *Leptocottus armatus* on chum salmon, *Oncorhynchus keta*. Ph.D. dissertation, University of British Columbia, Vancouver.

Matishov, G.G. 1992. The reaction of bottom-fish larvae to airgun pulses in the context of the vulnerable Barents Sea ecosystem. Fisheries and Offshore Petroleum Exploitation 2nd International Conference, Bergen, Norway, 6-8 April 1992.

Matthews, K.R. 1990a. A comparative study of habitat use by young-of-the-year, and adult rockfishes on four habitat types in central Puget Sound. *Fish. Bull.* 88:223-239.

Matthews, K.R. 1990b. An experimental study of the habitat preferences and movement patterns of copper, quillback, and brown rockfishes (*Sebastes* spp.). *Environ. Biol. Fish.* 29:161-178.

Maudlin, M., T. Coe, N. Currence and J. Hansen. 2002. *South Fork Nooksack River Acme-Saxon reach restoration planning: Analysis of existing information and preliminary recommendations*. Deming, WA: Lummi Natural Resources.

MBC Applied Environmental Sciences. 1987. *Ecology of important fisheries species offshore California*. Minerals Management Service, MMS 86-0093, Pacific Outer Continental Shelf Region. Washington, D.C. 252 pp.

McAnally, W.H., J.F. Haydel, and G. Savant. 2004. *Port sedimentation solutions for the Tennessee-Tombigbee Waterway in Mississippi*. Ports and Waterways Division Mississippi Department of Transportation. http://www.gomdot.com/research/pdf/SS117.pdf, accessed 2006.12.06.

McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. *J. Fish. Res. Board of Can.* 17: 665-76.

McFarland, W. N. and F.W. Munz. 1975. Part II: The photic environment of clear tropical seas during the day and Part III: the evolution of photopic visual pigments in fishes. *Vision Res.* 15: 1063-80.

McFarlane, G.A. and R.J. Beamish. 1986. Biology and fishery of Pacific hake *Merluccius productus* in the Strait of Georgia. *Int. N. Pac. Fish. Comm. Bull.* 50:365-392.

McKinnell, S., J.J. Pella, and M.L. Dahlberg. 1997. Populations-specific aggregations of steelhead trout (*Oncorhynchus mykiss*) in the North Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 2368-2376.

Meehan, W.R. (ed.). 1991. *Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats*. Special Publication 19. Bethesda, Maryland: American Fisheries Society.

Menzie, C.A., S.S. Hoeppner, J.J. Cura, J.S. Freshman, and E.N. LaFrey. 2002. Urban and suburban storm water runoff as a source of polycyclic aromatic hydrocarbons (PAHs) to Massachusetts estuarine and coastal environments. *Estuaries* 25(2): 165-176.

Miller, B.S., C.A. Simenstad, and L.R. Moulton. 1976. Puget Sound Baseline Program: nearshore fish survey, Annual Report July 1974-September 1975. Seattle, Washington: University of Washington Fisheries Research Institute.. 196pp.

Miller, D.E., P.B. Skidmore, and D.J. White. 2001. *Channel design*. Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

Miller, D.J. 1977. Loss of creosote from Douglas-fir marine piles. *Forest Products Journal* 27(11): 28-33.

MOEE (Ontario Ministry of the Environment and Energy). 1995. *Guidelines for Evaluating Construction Activities Impacting on Water Resources*. Guideline B-6. Toronto, Ontario, Canada.

Mongillo, P.E. and M. Hallock. 1999. *Washington State Status Report for the Olympic Mudminnow*. Olympia, WA: Washington Department of Fish and Wildlife. 36 pp. http://wdfw.wa.gov/wlm/diversty/soc/status/mudmin/omudmin.pdf, accessed 2006.10.04.

Mongillo, P.E. and M. Hallock. 1998. Washington State Status Report for the Margined Sculpin. Washington Department of Fish and Wildlife. September 1998.

Montgomery, D.R. and J.M. Buffington. 1993. *Channel classification, prediction of channel response, and assessment of channel condition*. Timber, Fish & Wildlife TFW-SH10-93-002. http://www.stage.dnr.wa.gov/forestpractices/adaptivemanagement/cmer/publications/TFW_SH10_93_002.pdf, accessed 2006.10.04.

Montgomery, D.R. and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. *GSA Bulletin* 109(5): 596–611.

Montgomery, D.R., E.M. Beamer, G.R. Pess, and T.P. Quinn. 1999. Channel type and salmonid spawning distribution and abundance. *Can. J. Fish. Aquat. Sci.* 56: 377–387.

Mork, O. I. and J. Gulbrandsen. 1994. Vertical activity of four salmonid species in response to changes between darkness and two intensities of light. *Aquaculture* 127: 317-28.

Moulton, L.L. 1977. *Ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound*. Ph.D. Dissertation. University of Washington.

Moyle, P., and J. Cech. 2004. *Fishes: An Introduction to Ichthyology*. Fifth ed. Upper Saddle River, NJ: Prentice-Hall, Inc.

Mullholland, R. 1984. *Habitat suitability index models: Hard clam*. FWS/OBS/-82/10.77. US Dept. of Interior, Fish and Wildlife.

Murphy, M.L. and W.R. Meehan. 1991. Stream ecosystems. Pp. 17-46 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. Bethesda, Maryland: American Fisheries Society Special Publication 19.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grand, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. *Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California*. U.S. Department of Commerce, NOAA-NMFS Technical Memo NMFS-NWFSC-35. Northwest Fisheries Science Center. Seattle, Washington. http://www.nwfsc.noaa.gov/publications/techmemos/tm35/, accessed 2006.10.06.

Nagel, K.-O. 1987. Untersuchungen an einer Najadenpopulation (Bilvalvia: Unionidae) in einem Baggersee bei Kassel (Nordhessen). *Philippia* 5:383-395.

Naiman, R.J., E.V. Balian, K.K. Bartz, R.E. Bilby, and J.J. Latterell. 2002. *Dead wood dynamics in stream ecosystems*. USDA Forest Service General Technical Report PSW-GTR-181.

Nakamoto, R.J. and T.T. Kisanuki. 1995. Age and growth of Klamath River green sturgeon (*Acipenser medirostris*). U.S. Fish and Wildlife Service Project #93-FP-13.

Neck, R.W. and R.G. Howells. 1994. Status survey of Texas heelsplitter, *Potamilus amphichaenus* (Frierson, 1898). Unpublished report, Texas Parks and Wildlife Department, Resource Protection Division and Inland Fisheries Division, Austin.

Nedeau, E., A.K. Smith, and J. Stone. 2005. Freshwater mussels of the Pacific Northwest. U.S. Fish and Wildlife Service. Vancouver, WA.

Neitzel, D.A. and T.J. Frest. 1989. Survey of Columbia River Basin streams for ashy pebblesnail *Fluminicola columbiana* and Great Columbia River limpet *Fisherola nuttali*. PNL-7103. Pacific National Laboratory, Richland, Washington.

Neitzel, D.A., and T.J. Frest. 1990. Survey of Columbia River basin streams for Columbia pebblesnail and shortface lanx. *Fisheries* 15(2) 2-3.

Nemeth, R. S. 1989. *The photobehavioral responses of juvenile chinook and coho salmon to strobe and mercury lights*. M.S. Thesis. University of Washington.

Nightingale, B. and C. Simenstad. 2001a. *Dredging Activities: Marine Issues*. University of Washington. Prepared for the Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

Nightingale, B. and C. Simenstad. 2001b. *Marine Overwater Structures: Marine Issues*. University of Washington . Seattle, WA. Prepared for Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

NMFS (NOAA's National Marine Fisheries Service). 1990. West coast of North America coastal and ocean zones strategic assessment: Data atlas. U.S. Dept. Commerce. NOAA. OMA/NOS, Ocean Assessments Division, Strategic Assessment Branch. Invertebrate and Fish Volume. Washington, D.C.

NMFS (NOAA's National Marine Fisheries Service). 1996a. Juvenile fish screen criteria. http://swr.nmfs.noaa.gov/hcd/pumpcrit.htm, accessed 2006.11.30.

NMFS (NOAA's National Marine Fisheries Service). 1996b. Making Endangered Species Act determinations of effect for individual or grouped actions at the watershed scale. Environmental and Technical Services Division, Habitat Conservation Branch. Lacey, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2003a. Biological Opinion for the Continued Maintenance of Weir Ponds and Proposed Fish Passage Improvement at Monitoring Facilities located on North Fork Caspar Creek and South Fork Caspar Creek, Jackson Demonstration Forest, Mendocino County, California. File No. 151422SWR02SR6251.

NMFS (NOAA's National Marine Fisheries Service). 2003b. Biological Opinion – Benicia-Martinez New Bridge Project 151422SWR02SR6292. NMFS, Southwest Region, Santa Rosa, CA.

NMFS (NOAA's National Marine Fisheries Service). 2004. Endangered Species Act – Section 7 Consultation Biological Opinion & Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Sucker Creek Bank Stabilization Project, Josephine County, Oregon (Corps No. 200300599).

NMFS (NOAA's National Marine Fisheries Service). 2005a. Biological and Conference Opinion Pursuant to Section 7 of the Endangered Species Act (ESA) on the Effects of Northwest Pipeline Corporation (Northwest) Capacity Replacement Project. NMFS Tracking No.: 2005-00271.

NMFS (NOAA's National Marine Fisheries Service). 2005b. Biological Opinion - La Conner Wharf and Float Project, La Conner, WA (HUC 171100070202, COE Ref. No. 200401163). NMFS Tracking No. 2004/01826. Seattle, WA.

NMFS (NOAA's National Marine Fisheries Service). 2006a. Endangered Species Act Section 7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Lafayette Highway Bridge Replacement, Yamhill River (HUC 170900080702), City of Lafayette, Yamhill County, Oregon (Corps No.: 200600248). NMFS Reference No.: 2006/02305.

NMFS (NOAA's National Marine Fisheries Service). 2006b. Endangered Species Act Section 7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Installation of Puget Sound Energy Natural Gas Pipeline from Thorp to Cle Elum, Kittitas County, WA, Upper Middle Yakima River Subbasin, 170300010204 Lanigan Springs, 1703000010310 Dry Creek, 170300010309 Robinson Creek (COE No. 200401162). NMFS Reference No.: 2005/02668.

NMFS (NOAA's National Marine Fisheries Service). 2006c. Biological Opinion - Cascade Marina Expansion Project in the Columbia River, Franklin County, WA (Sixth Field Hydrologic Unit Code: Zintel Canyon 170200160603). NMFS Tracking No. 2005/06498. Seattle, WA.

NMFS (NOAA's National Marine Fisheries Service). 2006d. Biological Opinion - Bridge Creek Culvert Removal Project, Bridge Creek, a tributary to the Upper Middle Fork of the John Day River, Sixth field HUC 170702030105, Grant County, OR. ODOT Key No. 12661. NMFS Tracking No. 2005/03011. Seattle, WA.

NMFS (NOAA's National Marine Fisheries Service). 2006e. Endangered Species Act Section7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Tidewater Cove Marina, Columbia River, Sixth Field HUC 170800010901- Salmon Creek, Clark County, Washington. (COE No. 200401353) NMFS Tracking No: 2005/00228.

NMFS (NOAA's National Marine Fisheries Service). 2006f. Biological Opinion - Biological Assessment for the National Marine Fisheries Service Entiat River Bridge-to-Bridge Restoration Project Fifth Field (HUC 1702001001), Chelan County, WA. NMFS Tracking No. 2006/01232. Seattle, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2006g. Endangered Species Act-Section 7 Formal Consultation Biological and Conference Opinion and Magnuson-Stevens Fishery

Management Conservation and Management Act Essential Fish Habitat Consultation Stream Crossing Structure Replacement and Removal Activities, Snake and Clearwater River Basins, 170601 & 170603, Idaho. NMFS Reference No.: 2005/06396, 2005/07365 and 2005/07366. E.

NMFS (NOAA's National Marine Fisheries Service). 2006h. Biological Opinion - Moore Road Bridge Replacement, North Yamhill River (HUC 170900080604), Yamhill County, OR. Corps No.: 200500794. NMFS Tracking No.: 2006/01047. Seattle, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2006i. Biological Opinion - Northwest Pipeline Corporation Capacity Replacement Project, Docket Nos. CP05-32-000, -001. NMFS Tracking No. 2006/02900. Seattle, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2006j. Biological Opinion - Scholls Ferry Road Bridge Replacement, Tualatin River (HUC 170900100501), Washington County, OR. COE No. 200500709. NMFS Tracking No. 2006/00161. Seattle, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2006k. Biological Opinion - Slate Creek Bridge Replacement located over the upper Salmon River within the Slate Creek Watershed (HUC 1706020108), Custer County, ID. NMFS Tracking No. 2005/006344. Seattle, WA. E.

NMFS (NOAA's National Marine Fisheries Service). 2006m. Biological Opinion - Sucker Creek Bridge Replacement and Bank Stabilization Project, Sucker Creek, Lower Sucker Creek Sixth field (HUC 171003110304), Josephine County, OR. Corps No. 200300599. NMFS Tracking No. 2005/05756. Seattle, WA. E.)

NMFS (NOAA's National Marine Fisheries Service). 2006n. Biological Opinion - City of Sweet Home Water Line, Wiley Creek (HUC 170900060101), Linn County, OR. Corps No. 200500500. NMFS Tracking No. 2005/04541. Seattle, WA E.

NRC (Natural Resources Consultants, Inc.). 2001. Final species memorandum and habitat assessment in the King County HCP planning area. Volume 2: Marine Fish. Prepared for King County Wastewater Treatment Division.

O'Connell, V.M., and D.W. Carlile. 1993. Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the eastern Gulf of Alaska. *Fish. Bull.* 91: 304-309.

Orth, R.J. and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. *Science* 22: 51-52.

Pacific Biodiversity Institute. 2006. Database search for "*Anodonta californiensis*" (California floater). http://www.pacificbio.org/ESIN/OtherInvertebrates/CaliforniaFloater/CaliforniaFloater_pg.html , accessed 2006.12.19.

Padma, T.V., R.C. Hale, M.H. Roberts, and R.N. Lipsius. 1999. Toxicity of creosote water-soluble fractions generated from contaminated sediments to the bay mysid. *Ecotoxicology and Environmental Safety* 42: 171-176.

Papanicolaou, A., and A. Maxwell. 2000. *Equilibrium geomorphologic conditions for high gradient bed streams*. Washington State Department of Transportation.

Parametrix and Battelle Marine Sciences Laboratory. 1996. *Anacortes Ferry Terminal eelgrass, macroalgae, and macrofauna habitat survey report*. Report for Sverdrup Civil, Inc. and WSDOT.

Parsley, M.J., L.G. Beckman and G.T. McCabe. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. *Transactions of the American Fisheries Society* 122: 217-227.

Patten, B.G. 1971. Increased predation by the torrent sculpin, *Cottus rhotheus*, on coho salmon fry, *Oncorhynchus kisutch*, during moonlight nights. *Journal Fisheries Research Board of Canada* 28(9): 1352–1354.

Pauley, G.B., D.A. Armstrong, R. Van Citter, and G.L. Thomas. 1989. *Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—Dungeness crab*. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.121). U.S. Army Corps of Engineers, TR EL-82-4. 20pp. http://www.nwrc.usgs.gov/wdb/pub/0172.pdf, accessed 2006.10.02.

Pauley, G.B., K.L. Oshima, and G.L. Thomas. 1988. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)-- Sea-run Cutthroat trout*. U.S. Fish and Wildlife Service Biological Report 82(11.86).

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). *Can. J. Fish. Aquatic. Sci.* 49: 1343-1356.

Pentec Environmental. 1997. *Movement of juvenile salmon through industrialized areas of Everett Harbor*. Edmonds, WA: Pentec Environmental.

Penttila, D. and D. Doty. 1990. Progress Report. Results of 1989 Eelgrass Shading Studies in Puget Sound. Washington Department of Fisheries, Marine Fish Habitat Investigations Division. Summary. http://depts.washington.edu/newwsdot/pentdot.html, accessed 2006.09.29.

Penttila, D., and M. Aquero. 1978. Fish usage of Birch Bay Village Marina, Whatcom County WA in 1976, Wash. Dept. Fish Prog. Rep. No. 39. WDF.

Penttila, D.E. 2000. Forage fishes of the Puget Sound region. NWSC/PSAMP Data Conference, LaConner, WA. Washington Department of Fish and Wildlife. http://www.wa.gov/wdfw/fish/forage/forage.htm, accessed 2006.10.06.

Persaud, D., R. Jaagumagi, and A. Hayton. 1991. The Provincial Sediment Quality Guidelines (Draft). Water Resources Branch, Ontario Ministry of the Environment, Toronto, Canada.

Petr, T. 2000. *Interactions between fish and aquatic macrophytes in inland waters: A review*. FAO Fisheries Technical Paper No. 396. Rome, FAO. 2000. 185p. http://www.fao.org/docrep/006/X7580E/X7580E00.htm#TOC, accessed 2006.10.03.

Pflug, D.E. and G.P. Pauley. 1984. Biology of smallmouth bass (*Micropterus dolomieui*) in Lake Sammamish, Washington. *Northwest Science* 58(2): 118–130.

Phillips, R.C. 1984. *Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile*. Seattle Pacific University, Seattle, WA. Prepared for U.S. Fish and Wildlife Service. NTIS Publication Number PB86-110376.

Poe, T.P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120(4): 405–420.

Poole, G.C and C.H. Berman. 2001. Pathways of human influence on water temperature dynamics in stream channels. *Environmental Management* 27: 787-802.

Popper, A.N. 2005. *A review of hearing by sturgeon and lamprey*. Environmental BioAcoustics, LLC. Rockville, Maryland. Submitted to the U.S. Army Corps of Engineers, Portland District.

Popper, A.N. and T.J. Carlson. 1998. Application of sound and other stimuli to control fish behavior. *Transactions of the American Fisheries Society* 127(5): 673–707.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. *J. Acoust. Soc. Am.* 117(6): 3958–3971.

Popper, A.N., T.J. Carlson, A.D. Hawkins, B.L. Southall, and R.L. Gentry. 2006. Interim criteria for injury of fish exposed to pile driving operations: a white paper.

Poston, T. 2001. *Treated Wood Issues Associated with Overwater Structures in Marine and Freshwater Environments*. Prepared for the Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

Poston, T.M., K.M. Krupka, and M.C. Richmond. 1996. *Estimation of Treated Piling Emplacement and Piling Leachate Concentrations in the Columbia River*. Working Draft. Pacific Northwest National Laboratory, Richland, WA. May 16.

Prinslow, T.E., E.O. Salo, and B.P. Snyder. 1979. *Studies of behavioral effects of a lighted and an unlighted wharf on outmigrating salmonids March-April 1978, Final Report*. Seattle, WA: University of Washington Fisheries Research Institute.

Protasov, V.R. 1970. *Vision and near orientation of fish*. Israel Program for Scientific Translations, Jerusalem.

PSAT (Puget Sound Water Quality Action Team). 2001. Eelgrass (*Zostera marina*). http://www.psat.wa.gov/Publications/Fact_sheets/eelgrass.pdf, accessed 2006.10.26.

PSNERP (Puget Sound Nearshore Project). 2003. Guidance for protection and restoration of nearshore ecosystems of Puget Sound. http://www.cev.washington.edu/lc/PSNERP/guidance.pdf, accessed 2006.10.26.

Puckett, K.J., and J.J. Anderson. 1988. Behavioral responses of juvenile salmonids to strobe and mercury lights. Final report to Stone and Webster Engineering Corp. Seattle, WA: University of Washington Fisheries Research Institute.

Quinn, T.P. 2005. *The behavior and ecology of Pacific salmon and trout*. Seattle, WA: University of Washington Press.

Quirollo, L.F. 1992. Pacific hake. Pages 109-112 in W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.), *California's Living Marine Resources and Their Utilization*. California Sea Grant College Program. Davis, California. UCSGEP-92-12. 129pp.

Radle, A.L. (undated). The effect of noise on wildlife: A literature review. http://interact.uoregon.edu/medialit/wfae/readings/radle.html#11, accessed 2006.10.12.

Radomski, P., and T.J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. *North American Journal of Fisheries Management* 21: 46-61.

Raleigh, R.F., W.J. Miller, and P.C. Nelson. 1986. *Habitat suitability index models and instream flow suitability curves: chinook salmon*. U.S. Fish and Wildlife Service Biological Report 82(10.122).

Rao, M.V., and V. Kuppusamy. 1992. Leachability of creosote : Fuel oil (1:1) wood preservative in marine environment. *Journal of the Timber Development Association of India* 38(3): 42-45.

Ratte, L.D. 1985. Under-pier ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in Commencement Bay, Washington. University of Washington.

Reid, S.M., and P.G. Anderson. 1998. Effects of sediment released during open-cut pipeline water crossings. http://aplwww.alliance-pipeline.com/contentfiles/45____EffectsofSediment.pdf, accessed 2006.12.06.

Reid, S.M., F. Ade, and S. Metikosh. 2004. Sediment entrainment during pipeline water crossing construction: predictive models and crossing method comparison. *Journal of Environmental Engineering and Science* 3: 81-88.

Reilly, C.A., T.W. Wyllie-Echeverria, and S. Ralston. 1992. Interannual variation and overlap in the diets of pelagic juvenile rockfish (Genus: *Sebastes*) off central California. *Fish. Bull.* 90: 505-515.

Reyff, J., P. Donavan, and C.R. Greene Jr. 2003. Underwater sound levels associated with seismic retrofit construction of the Richmond-San Rafael Bridge. Produced by Illingworth and Rodkin, Inc.

Richardson,W.J., C.R. Green Jr., C.I. Malme, and D.H. Thomson. 1995. *Marine Mammals and Noise*. Academic Press. San Diego, CA.

Riggs, C.D., and G.R. Webb. 1956. The mussel population of an area of loamy-sand bottom of Lake Texoma. *American Midland Naturalist* 56: 197-203.

Rosenthal, R.J., V. Moran-O'Connell, and M.C. Murphy. 1988. Feeding ecology of ten species of rockfishes (Scorpaenidae) from the Gulf of Alaska. *Calif. Dept. Fish and Game* 74:16-36.

Saldi-Caromile, K., K. Bates, P. Skidmore, J. Barenti, and D. Pineo. 2004. *Stream habitat restoration guidelines: Final draft*. Co-published by the Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington. http://wdfw.wa.gov/hab/ahg/shrg/index.htm, accessed 2006.11.28.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pp. 231-310 *in* C. Groot and L. Margolis (eds.), *Pacific Salmon Life Histories*. Vancouver, BC: University of British Columbia Press.

Salo, E.O., N.J. Bax, T.E. Prinslow, C.J. Whitmus, B.P. Snyder, and C.A. Simenstad. 1980. *The effects of construction of naval facilities on the outmigration of juvenile salmonids from Hood Canal, Washington*. Final Report FRI-UW-8006. Seattle, WA: University of Washington Fisheries Research Institute.

Salo, E.O., T.E. Prinslow, R.A. Campbell, D.W. Smith, and B.P. Snyder. 1979. Trident dredging study: the effects of dredging at the U.S. Naval Submarine Base at Bangor on outmigrating juvenile chum salmon, *Oncorhynchus keta*, in Hood Canal, Washington: final report, February to July 1977. Seattle, WA: University of Washington Fisheries Research Institute.

Sampson, D.B. 1996. Stock Status of Canary Rockfish off Oregon and Washington in 1996. Appendix C in Pacific Fishery Management Council. Status of the Pacific Coast Groundfish Fishery through 1996 and Recommended Acceptable Biological Catches for

1997: Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council. Portland, Oregon.

Sandahl, J.F., D.H. Baldwin, J.J. Jenkins, and N.L. Scholz. 2004. Odor-evoked filed potentials as indicators of sublethal neurotoxicity in juvenile coho salmon (*Oncorhynchus kisutch*) exposed to copper, chlorpyrifos, or esfenvalerate. *Can. J. Fish. Aquat. Sci.* 61: 404-413.

Scholik, A.R., and H.Y. Yan. 2001a. Effects of underwater noise on auditory physiology of fishes. *Proceedings of Institute of Acoustics, United Kingdom* 23(2): 27-36.

Scholik, A.R., and H.Y. Yan. 2001b. Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research* 152: 17-24.

Scholik, A.R., and H.Y. Yan. 2002. The effects of noise on the auditory sensitivity of the bluegill sunfish, *Lepomis macrochirus*. *Comparative Biochemistry and Physiology* A133: 43-52.

Schwarz, A.L. and G.L.Greer. 1984. Responses of Pacific herring, *Clupea harengus pallasi*, to some underwater sounds. *Can. J. Fish Aquat Sci.* 41: 1183-1192.

Scruggs, G.D. 1960. *Status of fresh-water mussel stocks in the Tennessee River*. U.S. Fish and Wildlife Service Special Science Report on Fish 370:1–41.

Sedell, J.R., and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U.S.A. fromits floodplain by snagging and streamside forest removal. *Verh. Internat. Verein. Limnol.* 22: 1828-1834.

Sedell, J.R., and K.J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. Pages 210–223 in N. B. Armantrout (ed.), *Acquisition and utilization of aquatic habitat inventory information*. Bethesda, Maryland: American Fisheries Society.

Sedell, J.R., F.J. Swanson, and S.V. Gregory. 1985. Evaluating fish response to woody debris. Pp. 222-245 in T.J. Hassler (ed.), *Proceedings of the Pacific Northwest stream habitat* *workshop*. Arcata, CA: California Cooperative Fishery Research Unit, Humboldt State University.

Sedell, J.R., J.E. Yuska and R.W. Speaker. 1986. Habitats and salmonid distribution in pristine, sediment-rich river valley systems: S. Fork Hoh and Queets River, Olympic National Park. Pages 33-46 in W.R. Meehan, T.R. Merrell, Jr., and T.A. Hanley (eds.), *Fish and wildlife relationships in old-growth forests.* American Institute of Fishery Research Biologists.

Shepard, B.B., K.L. Pratt, and P.J. Graham. 1984. *Life histories of westslope cutthroat trout and bull trout in the upper Flathead River Basin, Montana*. Montana Department of Fish, Wildlife and Parks, Helena, Montana.

Shively, R.S., R.A. Tabor, R.D. Nelle, D.B. Jepsen, J.H. Petersen, S.T. Sauter, and T.P. Poe. 1991. *System-wide significance of predation on juvenile salmonids in the Columbia and Snake river systems*. U.S. Fish and Wildlife Service, Annual Report. Project 90-078 (Contract DE-AI79-90BP07096). Cook, Washington.

Shreffler, D. K. and R. Moursund. 1999. *Impacts of ferry terminals on migrating juvenile salmon along Puget Sound shorelines: Phase II field studies at Port Townsend Ferry Terminal*. Contract GCA-1723. Washington State Dept. of Transportation.

Shteinman, B. and Y. Kamenir. 1999. Study of long shore sediment transport in the vicinity of hydrotechnical constructions. In C.A. Brebbia and P. Anagnostopoulos (eds.), *Coastal Engineering and Marina Developments*. . Southampton, Boston: WIT Press.

Sibley, P.K., M.L. Harris, K.T. Bestari, T.A. Steele, R.D. Robinson, R.W. Gensemer, K.E. Day, and K.R. Solomon. 2004. Response of zooplankton and phytoplankton communities to creosote-impregnated Douglas fir pilings in freshwater microcosms. *Archives of Environmental Contamination and Toxicology* 47: 56-66.

Sibley, P.K., M.L. Harris, K.T.J. Bestari, T.A. Steele, R.D. Robinson, R.W. Gensemer, K.E. Day, and K.R. Solomon. 2001. Response of zooplankton communities to liquid creosote in freshwater microcosms. *Environmental Toxicology and Chemistry* 20(2): 394-405.

Sigler, John W. 1988. Effects of chronic turbidity on anadromous salmonids: Recent studies and assessment techniques perspective. In C.A. Simenstad (ed.), *Effects of dredging on anadromous Pacific coast fishes*. Seattle, WA: Washington Sea Grant Program, University of Washington.

Simenstad, C.A., B. Nightingale, R.M. Thom, and D. K. Shreffler. 1999. *Impacts of ferry terminals on juvenile salmon migrating along Puget Sound shorelines: Phase I synthesis of state of knowledge*. Research Project T9903 Task A2. Washington State Transportation Center.

Simenstad, C.A., B.S. Miller, C.F. Nyblade, K. Thornburgh, and L.J. Bledsoe. 1979. *Food web relationship of northern Puget Sound and the Strait of Juan de Fuca*. EPA Interagency Agreement No. D6-E693-EN. Office of Environmental Engineering and Technology, US EPA.

Smith, S.L., D.D. MacDonald, K.A. Keenleyside, C.G. Ingersoll, and L.J. Field. 1996. A preliminary evaluation of sediment quality assessment values for freshwater ecosystems. *J. Great Lakes Res.* 22(3): 624-638.

Snyder, D.E. 2003. *Electrofishing and its harmful effects on fish*. Information and Technology Report USGS/BRD/ITR-2003-0002. U.S. Government Printing Office, Denver, CO, 149 p.

Soar, P.J., and C.R. Thorne. 2001. *Channel restoration design for meandering rivers*. U.S. Army Corp of Engineers. Report ERDC/CHL.

Southard, S.L., R.M. Thom, G.D. Williams, J.D. Toft, C.W. May, G.A. McMichael, J.A. Vucelick, J.T, Newell, and J.A. Southard. 2006. *Impacts of ferry terminals on juvenile salmon movement along Puget Sound shorelines*. Prepared for the Washington State Department of Transportation, Project Number 46820.

Sprague, J.B. 1964. Avoidance of copper-zinc solutions by young salmon in the laboratory. *J. Water Pollut. Control Fed.* 36: 990-1004.

Sprague, J.B. 1968. Avoidance reactions of rainbow trout to zinc sulfate solutions. *Water Res.* 2: 367-372.

Starr, R.M., D.S. Fox, M.A. Hixon, B.N. Tissot, G.E. Johnson, and W.H. Barss. 1996. Comparison of submersible-survey and hydroacoustic survey estimates of fish density on a rocky bank. *Fish. Bull.* 94: 113-123.

Stasse, H.L. and H.S. Rogers. 1965. 1958 cooperative creosote project. II Marine tests. Analysis of marine panels after exposure for one to four years. Pp. 81-85 in *Proceedings of the Annual Meeting of the American Wood-Preservers' Association*.

Stein, D. and T.J. Hassler. 1989. *Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific southwest): Brown rockfish, copper rockfish, and black rockfish*. U.S. Fish Wildlife Ser., Biol. Rept. No. 82 (11.113): 15pp.

Stein, J.N. 1970. *A study of the largemouth bass population in Lake Washington*. M.S. thesis. University of Washington College of Fisheries.

Stocker, M. 2002. *Fish mollusks and other sea animals, and the impact of anthropogenic noise in the marine acoustical environment*. Prepared for Earth Island Institute by Michael Stoker Associates.

Stratus (Stratus Consulting Inc., Duke University). 2005a. *Creosote-treated wood in aquatic environments: technical review and use recommendations*. Prepared for the National Oceanic and Atmospheric Administration's National Marine Fisheries Service.

Stratus (Stratus Consulting). 2005b. *Treated wood in aquatic environments: technical review and use recommendations*. Prepared for: Joe Dillon, NOAA NMFS.

Sturm, T.W. 2004. *Enhanced abutment scour studies for compound channels*. Report No. FHWA-RD-99-156, Office of Infrastructure Research and Development, Federal Highway Administration, McLean, VA.

Sumida, B.Y. and H.G. Moser. 1984. Food and feeding of Bocaccio and comparison with Pacific hake larvae in the California current. *Calif. Coop. Oceanic Fish. Invest. Rept.* 25:112-118.

Suttle, K.B., M.E. Power, J.M. Levine, and C. McNeelya. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. *Ecological Applications* 14(4): 969–974.

Swanston, D.N. 1991. Natural processes. Pp. 83-138 *in* W.R. Meehan (ed.), *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. Bethesda, Maryland: American Fisheries Society Special Publication 19.

Swartz, R.C., P.F. Kemp, D.W. Schults, G.R. Ditsworth, and R.J. Ozretich. 1989. Acute toxicity of sediment from Eagle Harbor, Washington, to the infaunal amphipod *Rhepoxynius abronius*. *Environmental Toxicology and Chemistry* 8:215-222.

Tabor, R. U.S. Fish and Wildlife Service. Personal communication, telephone conversation with Tom Kahler (The Watershed Company), 9 June 2000, and 11 July 2000.

Tabor, R., F. Mejia, and D. Low. 2000. *Predation of juvenile salmon by littoral fishes in the Lake Washington–Lake Union ship canal, preliminary results*. Prepared for presentation at the American Fisheries Society, North Pacific International Chapter. 2000 conference, April 10–12, 2000, Mount Vernon, Washington.

Tabor, R.A., G. Brown, and V.T. Luiting. 1998. *The effect of light intensity on predation of sockeye salmon fry by prickly sculpin and torrent sculpin*. Lacey, Washington: U.S. Fish and Wildlife Service Western Washington Office, Aquatic Resources Division.

Tabor, R.A., H.A. Gearns, C.M. McCoy III, and S.Camacho. 2006. *Nearshore habitat use by juvenile chinook salmon in lentic systems*. 2003 and 2004 report. Lacey, WA: United States Fish and Wildlife Service.

Tabor, R.A., R.S. Shively, and T.P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. *North American Journal of Fisheries Management* 13: 831–838.

Taylor, W. S. and W.S. Wiley. 1997. Port of Seattle fish mitigation study: Pier 64/65 short-stay moorage facility: qualitative fish and avian predator observations. Seattle, WA.

Thayer, G. W., W.J. Kenworthy, and M.S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic Coast: A community profile. FWS/OBSO-84/02. Washington, D.C.: U.S. Fish and Wildlife Service.

Thom, R.M., A.B. Borde, P.J. Farley, M.C. Horn and A. Ogston. 1996. Passenger-only ferry propeller wash study: threshold velocity determinations and field study, Vashon Terminal. Battelle Marine Sciences Laboratory Report to WSDOT. PNWD-2376/UC- 000. 15+pp.

Thom, R.M., and D.K. Shreffler. 1996. *Eelgrass meadows near ferry terminals in Puget Sound. Characterization of assemblages and mitigation impacts*. Battelle Pacific Northwest Laboratories, Sequim, WA.

Thom, R.M., Bourne, A.B. Borde, G.D. Williams, J.A. Southard, S.L. Blanto, D.L. Woodruff. 2001. Effects of Environmental Stressors on Eelgrass Restoration Projects. Puget Sound Research. '01. Conference Proceedings. http://www.psat.wa.gov/Publications/01_proceedings/sessions/oral/7b_thom.pdf, accessed 2006.10 02).

Thom, R.M., D.K. Shreffler, and K. Macdonald. 1994. *Shoreline Armoring Effects on Coastal Ecology and Biological Resources in Puget Sound, Washington*. Report 94-80. Shorelands and Environmental Assistance Program, Washington Department of Ecology.

Thom, R.M., L.D. Antrim, A.B. Borde, W.W. Gardiner, D.K. Shreffler, P.G. Farley, J.G. Norris, S. Wyllie-Echeverria, and T.P. McKenzie. 1998. *1997 Puget Sound's eelgrass meadows: factors contributing to depth distribution and spatial patchiness*. Puget Sound Research '98, Conference Proceedings. http://www.psat.wa.gov/Publications/98_proceedings/pdfs/2c_thom.pdf, accessed 2006.09.29.

Toft, J., C. Simenstad, J. Cordell, and L. Stamatiou. 2004. *Fish distribution, abundance, and behavior at nearshore habitats along City of Seattle marine shorelines, with an emphasis on juvenile salmonids*. SAFS-UW-0401. Wetland Ecosystem Team, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA. Prepared for Seattle Public Utilities, City of Seattle, WA.

Tonina, D. and J.M. Buffington. 2003. Effects of discharge on hyporheic flow in a pool-riffle channel: implications for aquatic habitat. *Eos Trans. AGU* 84(46), Fall Meet Suppl., Abstract H52A-1154.

Tonina, D. and J.M. Buffington. 2005. Biogeomorphology: Effects of salmon redds on river hydraulics and hyporheic flow in gravel-bed rivers. *Eos Trans. AGU* 86(52), Fall Meet Suppl., Abstract H53D-0493.

Tribble, S.C. 2000. Sensory and feeding ecology of larval and juvenile Pacific sand lance, *Ammodytes hexapterus*. M.S. Thesis, University of Washington.

Tucker, J. and C. Theiling. 1998. Freshwater mussels. Chapter 11 in USGS: *Ecological Status and Trends of the Upper Mississippi River System*. http://www.umesc.usgs.gov/reports_publications/status_and_trends.html, accessed 2006.10.04.

Turnpenny, A. W. H., Thatcher, K. P., and Nedwell, J. R. 1994. *The effects on fish and other marine animals of high-level underwater sound*. Report FRR 127/94, Fawley Aquatic Research.

USEPA (U.S. Environmental Protection Agency). 1996. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. Assessment and Remediation of Contaminated Sediments (ARCS) Program. EPA 905-R96-008. U.S. Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 1999. EPA Guidance Manual Turbidity Provisions. http://www.epa.gov/safewater/mdpd/pdf/turbidity/chap_o7.pdf, accessed 2006.10.04.

USEPA (U.S. Environmental Protection Agency). 2002. National recommended water quality criteria: 2002. EPA 822-R-02-047. U.S. Environmental Protection Agency, Washington, DC. November.

USEPA (U.S. Environmental Protection Agency). 2003. *EPA Region 10 guidance for Pacific Northwest state and tribal temperature water quality standards*. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA. E.

USFWS (U.S. Fish and Wildlife Service). 1986. *Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) steelhead trout*. Biological Report 82 (11.82). TR EL-82-4.

USFWS (U.S. Fish and Wildlife Service). 1998. *A framework to assist in making Endangered Species Act determinations of effect for individual or grouped actions at the bull trout subpopulation watershed scale*. DRAFT.

Vagle, S. 2003. On the impact of underwater pile driving noise on marine life. Canada DFO, Institute of Ocean Sciences, Ocean Science and Productivity Division.

Valovirta, I. 1990. Conservation of *Margaritifera margaritifera* in Finland. Council of Europe Environmental Encounters Series 10: 59-63.

Vines, C.A., T. Robbins, F.J. Griffin, and G.N. Cherr. 2000. The effects of diffusible creosote-derived compounds on development in Pacific herring (*Clupea pallasi*). *Aquatic Toxicology* 51: 225-239.

Warner, K. 1972. Further studies of fish predation of salmon stocked in Maine lakes. *Progressive Fish-Culturist* 34:217–221.

Washington Forest Practices Board. 1995. *Board manual: Standard methodology for conducting watershed analysis. Appendix E. Stream Channel*. Olympia: Washington Forest Practices Board. http://www.dnr.wa.gov/forestpractices/watershedanalysis/manual/index.html, accessed 2006.10.04.

Waters, G.T. 1999. *Freshwater mussels and water quality: A review of the effects of hydrologic and instream habitat alterations*. Ohio Biological Survey and Aquatic Ecology Laboratory. Ohio State University. Proceedings of the first Freshwater Mollusk Conservation Symposium.

Waters, T.F. 1995. *Sediment in streams: sources, biological effects and control*. Bethesda, MD: American Fisheries Society. 251 p.

Watson, C.C., D.S. Biedenharn, and S.H. Scott. 1999. *Channel rehabilitation: Processes, design, and implementation*. Vicksburg, MS: U.S. Army Corps of Engineers Research and Development Center.

WDFW (Washington Department of Fish and Wildlife). 1997a. Washington State Forage fish fact sheet: Puget Sound herring fact sheet. WDFW, Forage Fish Management Unit. Olympia, WA. http://www.wdfw.wa.gov/fish/forage/herring.htm, accessed 2006.11.03.

WDFW (Washington Department of Fish and Wildlife). 1997b. Washington State Forage fish fact sheet: Washington State sand lance fact sheet. WDFW, Forage Fish Management Unit. Olympia, WA. http://www.wdfw.wa.gov/fish/forage/lance.htm, accessed 2006.11.03.

WDFW (Washington Department of Fish and Wildlife). 1997c. Washington State Forage fish fact sheet: Washington State surf smelt fact sheet. WDFW, Forage Fish Management Unit. Olympia, WA. http://www.wdfw.wa.gov/fish/forage/smelt.htm, accessed 2006.11.03.

WDFW (Washington Department of Fish and Wildlife). 1998. Habitat engineering fish streams information: screening requirements for water diversions. http://wdfw.wa.gov/hab/engineer/fishscrn.htm, accessed 2006.11.30.

WDFW and ODFW (Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife). 2001. Washington and Oregon eulachon management plan. Olympia, WA: Washington Department of Fish and Wildlife. 32 p.

WDNR (Washington Department of Natural Resources). 2004. Maury Island Aquatic Reserve. Final Management Plan. October 29, 2004. Aquatic Resources Division. Olympia, WA. http://www.dnr.wa.gov/htdocs/aqr/reserves/pdf/mgmtplan10_29_04.pdf, accessed 2006.10.04.

WDNR (Washington Department of Natural Resources). 2006a. Draft fish covered species paper. Olympia, WA.

WDNR (Washington Department of Natural Resources). 2006b. Draft invertebrate covered species paper. Olympia, WA.

Weis, J.S. and P. Weis. 1994. Effects of contaminants from chromated copper arsenate-treated lumber on benthos. *Arch. Environ. Contam. Toxicol.* 26: 103-109.

Weis, J.S. and P. Weis. 1996. The effects of using wood treated with chromated copper arsenate in shallow-water environments: A review. *Estuaries* 19(2A): 306-310.

Weis, J.S., P. Weis, and T. Proctor. 1998. The extent of benthic impacts of CCA-treated wood structures in Atlantic Coast estuaries. *Arch. Environ. Contam. Toxicol.* 34: 313-322.

Weis, P, J.S. Weis, A. Greenberg, and T.J. Nosker. 1992. Toxicity of construction materials in the marine environment: A comparison of chromated-copper-arsenate-treated wood and recycled plastic. *Arch. Environ. Contam. Toxicol.* 22: 99-106.

Weis, P., J.S. Weis, and J. Couch. 1993. Histopathology and bioaccumulation in *Crassostrea virginica* living on wood preserved with chromated copper arsenate. *Diseases Aquat. Org.* 17: 41-46.

Weitkamp, D.E. 1981. *Shilshole Bay Fisheries Resources*. No. 81-0712-018 F. Parametrix Inc., Seattle, WA.

Weitkamp, D.E. 1982. *Juvenile chum and chinook salmon behavior at Terminal 91*. Report to Port of Seattle. Parametrix Inc.

West, J.E. 1997. *Protection and restoration of marine life in the inland waters of Washington state*. Puget Sound/Georgia Basin Environmental Report Series: Number 6. Puget Sound/Georgia Basin International Task Force. Puget Sound Action Team. Olympia, WA.

Wildish, D.J., and J. Power. 1985. Avoidance of suspended sediments by smelt as determined by a new ''single fish'' behavioral bioassay. *Bulletin of Environmental Contamination and Toxicology* 34: 770–774.

Williams, G.D., and R.M. Thom. 2001. *Marine and estuarine shoreline modification issues*. Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

Willson, M.F., R.H. Armstrong, M.C. Hermans, and K. Koski. 2006. *Eulachon: a review of biology and an annotated bibliography*. Alaska Fisheries Science Center and NOAA Fisheries. 243 pp.

WNWCB (Washington Noxious Weed Control Board). 2005. *Myriophyllum spicatum*. http://www.nwcb.wa.gov/weed_info/Written_findings/Myriophyllum_spicatum.html, updated 2005.09.29, accessed 2006.10.10.

WNWCB (Washington Noxious Weed Control Board). 2006. Noxious Weed Control Board Home Page. http://www.nwcb.wa.gov/index.htm, accessed 2006.10.02.

Wones, A. and C. Cziesla. 2004. A comparison of three cable installation methods. Jones and Stokes. Bellevue, WA. Poster presented at: Restore Americas Estuaries Conference. Seattle, WA. E.

WSDOT (Washington State Department of Transportation). 2006a. Biological assessment preparation for transportation projects, advanced training manual. Olympia, WA.

WSDOT (Washington State Department of Transportation). 2006b. Fish exclusion protocols and standards. Olympia, WA. 8 pgs.

Wydoski and. Whitney. 1979. *Inland Fishes of Washington*. Seattle: University of Washington Press.

Wydoski, R. S. and R. R. Whitney. 2003. *Inland Fishes of Washington*, Second Editon. American Fisheries Society and University of Washington Press. 322 pp.

Wyllie-Echeverria, S., and R.C. Phillips. 1994. Seagrasses of the northwest Pacific. In S. Wyllie-Echeverria, A.M. Olson, and M.J. Hershman (eds.), *Seagrass Science and Policy in the Pacific Northwest: Proceedings of a Seminar Series*. Prepared for: U.S. Environmental Protection Agency. (SMA 94-1). EPA 910/R-94-004.

Xiao, Y., J. Simonsen, and J.J. Morrell. 2002. *Effect of water flow rate and temperature on leaching from creosote-treated wood*. Research Note FPL-RN-0286. Madison, WI: U.S. Forest Service Forest Products Laboratory .

Yager, E., M. Schmeeckle, W.E. Dietrich, and J.W. Kirchner. 2004. The effect of large roughness elements on local flow and bedload transport. *Eos Trans. AGU* 85(47), Fall Meet Suppl., Abstract H41G-05.

Yelverton, J.T., D.R. Richmond, W.Hicks, K. Saunders, and E.R. Fletcher. 1975. *The relationship between fish size and their response to underwater blast*. Report DNA 3677T, Director, Defense Nuclear Agency. Washington D.C.

APPENDIX A

STANDARD HPA PROVISIONS

Chapter 220-110 WAC

Hydraulic code rules

Last Update: 6/22/05

Chapter Listing

WAC Sections

220-110-070 Water crossing structures.

220-110-100 Conduit crossing.

220-110-310 Utility lines.

220-110-070
Water crossing structures.

In fish bearing waters, bridges are preferred as water crossing structures by the department in order to ensure free and unimpeded fish passage for adult and juvenile fishes and preserve spawning and rearing habitat. Pier placement waterward of the ordinary high water line shall be avoided, where practicable. Other structures which may be approved, in descending order of preference, include: Temporary culverts, bottomless arch culverts, arch culverts, and round culverts. Corrugated metal culverts are generally preferred over smooth surfaced culverts. Culvert baffles and downstream control weirs are discouraged except to correct fish passage problems at existing structures.

An HPA is required for construction or structural work associated with any bridge structure waterward of or across the ordinary high water line of state waters. An HPA is also required for bridge painting and other maintenance where there is potential for wastage of paint, sandblasting material, sediments, or bridge parts into the water, or where the work, including equipment operation, occurs waterward of the ordinary high water line. Exemptions/5-year permits will be considered if an applicant submits a plan to adhere to practices that meet or exceed the provisions otherwise required by the department.

Water crossing structure 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 water crossing structures:

(1) Bridge construction.

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

(b) The bridge structure or stringers shall be placed in a manner to minimize damage to the bed.

(c) Alteration or disturbance of bank or bank vegetation shall be limited to that necessary to construct the project. All disturbed areas shall be protected from erosion, within seven calendar 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.

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

(e) The bridge shall be constructed, according to the approved design, to pass the 100-year peak flow with consideration of debris likely to be encountered. Exception shall be granted if applicant provides hydrologic or other information that supports alternative design criteria.

(f) Wastewater from project activities and water removed from within the work area shall be routed to an area landward of the ordinary high water line to allow removal of fine sediment and other contaminants prior to being discharged to state waters.

(g) Structures containing concrete shall be sufficiently cured prior to contact with water to avoid leaching.

(h) Abutments, piers, piling, sills, approach fills, etc., shall not constrict the flow so as to cause any appreciable increase (not to exceed .2 feet) in backwater elevation (calculated at the 100-year flood) or channel wide scour and shall be aligned to cause the least effect on the hydraulics of the watercourse.

(i) Riprap materials used for structure protection shall be angular rock and the placement shall be installed according to an approved design to withstand the 100-year peak flow.

(2) Temporary culvert installation.

The allowable placement of temporary culverts and time limitations shall be determined by the department, based on the specific fish resources of concern at the proposed location of the culvert.

(a) Where fish passage is a concern, temporary culverts shall be installed according to an approved design to provide adequate fish passage. In these cases, the temporary culvert installation shall meet the fish passage design criteria in Table 1 in subsection (3) of this section.

(b) Where culverts are left in place during the period of September 30 to June 15, the culvert shall be designed to maintain structural integrity to the 100-year peak flow with consideration of the debris loading likely to be encountered.

(c) Where culverts are left in place during the period June 16 to September 30, the culvert shall be designed to maintain structural integrity at a peak flow expected to occur once in 100 years during the season of installation.

(d) Disturbance of the bed and banks shall be limited to that necessary to place the culvert and any required channel modification associated with it. Affected bed and bank areas outside the culvert shall be restored to preproject condition following installation of the culvert.

(e) The culvert shall be installed in the dry, or in isolation from stream flow by the installation of a bypass flume or culvert, or by pumping the stream flow around the work area. Exception may be granted if siltation or turbidity is reduced by installing the culvert in the flowing stream. The bypass reach shall be limited to the minimum distance necessary to complete the project. Fish stranded in the bypass reach shall be safely removed to the flowing stream.

(f) Wastewater, from project activities and dewatering, shall be routed to an area outside the ordinary high water line to allow removal of fine sediment and other contaminants prior to being discharged to state waters.

(g) Imported fill which will remain in the stream after culvert removal shall consist of clean rounded gravel ranging in size from one-quarter to three inches in diameter. The use of angular rock may be approved from June 16 to September 30, where rounded rock is unavailable. Angular rock shall be removed from the watercourse and the site restored to preproject conditions upon removal of the temporary culvert.

(h) The culvert and fill shall be removed, and the disturbed bed and bank areas shall be reshaped to preproject configuration. 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 need to be considered.

(i) The temporary culvert shall be removed and the approaches shall be blocked to vehicular traffic prior to the expiration of the HPA.

(j) Temporary culverts may not be left in place for more than two years from the date of issuance of the HPA.

(3) Permanent culvert installation.

(a) In fish bearing waters or waters upstream of a fish passage barrier (which can reasonably be expected to be corrected, and if corrected, fish presence would be reestablished), culverts shall be designed and installed so as not to impede fish passage. Culverts shall only be approved for installation in spawning areas where full replacement of impacted habitat is provided by the applicant.

(b) To facilitate fish passage, culverts shall be designed to the following standards:

(i) Culverts may be approved for placement in small streams if placed on a flat gradient with the bottom of the culvert placed below the level of the streambed a minimum of twenty percent of the culvert diameter for round culverts, or twenty percent of the vertical rise for elliptical culverts (this depth consideration does not apply within bottomless culverts). Footings of bottomless culverts shall be buried sufficiently deep so they will not become exposed by scour within the culvert. The twenty percent placement below the streambed shall be measured at the culvert outlet. The culvert width at the bed, or footing width, shall be equal to or greater than the average width of the bed of the stream.

(ii) Where culvert placement is not feasible as described in (b)(i) of this subsection, the culvert design shall include the elements in (b)(ii)(A) through (E) of this subsection:

(A) Water depth at any location within culverts as installed and without a natural bed shall not be less than that identified in Table 1. The low flow design, to be used to determine the minimum depth of flow in the culvert, is the two-year seven-day low flow discharge for the subject basin or ninety-five percent exceedance flow for migration months of the fish species of concern. Where flow information is unavailable for the drainage in which the project will be conducted, calibrated flows from comparable gauged drainages may be used, or the depth may be determined using the installed no-flow condition.

(B) The high flow design discharge, used to determine maximum velocity in the culvert (see Table 1), is the flow that is not exceeded more than ten percent of the time during the months of adult fish migration. The two-year peak flood flow may be used where stream flow data are unavailable.

(C) The hydraulic drop is the abrupt drop in water surface measured at any point within or at the outlet of a culvert. The maximum hydraulic drop criteria must be satisfied at all flows between the low and high flow design criteria.

(D) The bottom of the culvert shall be placed below the natural channel grade a minimum of twenty percent of the culvert diameter for round culverts, or twenty percent of the vertical rise for elliptical culverts (this depth consideration does not apply within bottomless culverts). The downstream bed elevation, used for hydraulic calculations and culvert placement in relation to bed elevation, shall be taken at a point downstream at least four times the average width of the stream (this point need not exceed twenty-five feet from the downstream end of the culvert). The culvert capacity for flood design flow shall be determined by using the remaining capacity of the culvert.

Table 1

Fish Passage Design Criteria for Culvert Installation

Criteria	Adult Trout >6 in. (150mm)	Adult Pink, Chum Salmon	Adult Chinook, Coho, Sockeye, Steelhead
1. Velocity, Maximum (fps)			
Culvert Length (ft)			
a. 10 - 60	4.0	5.0	6.0
b. 60 - 100	4.0	4.0	5.0
c. 100 - 200	3.0	3.0	4.0
d. > 200	2.0	2.0	3.0
2. Flow Depth Min (ft)	0.8	0.8	1.0
3. Hydr. Drop Max (ft)	0.8	0.8	1.0

(E) Appropriate statistical or hydraulic methods must be applied for the determination of flows in (b)(ii)(A) and (B) of this subsection. These design flow criteria may be modified for specific proposals as necessary to address unusual fish passage requirements, where other approved methods of empirical analysis are provided, or where the fish passage provisions of other special facilities are approved by the department.

(F) Culvert design shall include consideration of flood capacity for current conditions and future changes likely to be encountered within the stream channel, and debris and bedload passage.

(c) Culverts shall be installed according to an approved design to maintain structural integrity to the 100-year peak flow with consideration of the debris loading likely to be encountered. Exception may be granted if the applicant provides justification for a different level or a design that routes that flow past the culvert without jeopardizing the culvert or associated fill.

(d) Disturbance of the bed and banks shall be limited to that necessary to place the culvert and any required channel modification associated with it. Affected bed and bank areas outside the culvert and associated fill shall be restored to preproject configuration following installation of the culvert, and 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.

(e) Fill associated with the culvert installation shall be protected from erosion to the 100-year peak flow.

(f) Culverts shall be designed and installed to avoid inlet scouring and shall be designed in a manner to prevent erosion of streambanks downstream of the project.

(g) Where fish passage criteria are required, the culvert facility shall be maintained by the owner(s), such that fish passage design criteria in Table 1 are not exceeded. If the structure becomes a hindrance to fish passage, the owner shall be responsible for obtaining a HPA and providing prompt repair.

(h) The culvert shall be installed in the dry or in isolation from the stream flow by the installation of a bypass flume or culvert, or by pumping the stream flow around the work area. Exception may be granted if siltation or turbidity is reduced by installing the culvert in the flowing stream. The bypass reach shall be limited to the minimum distance necessary to complete the project. Fish stranded in the bypass reach shall be safely removed to the flowing stream.

(i) Wastewater, from project activities and dewatering, shall be routed to an area outside the ordinary high water line to allow removal of fine sediment and other contaminants prior to being discharged to state waters.

[Statutory Authority: RCW 75.08.080. 94-23-058 (Order 94-160), § 220-110-070, filed 11/14/94, effective 12/15/94. Statutory Authority: RCW 75.20.100 and 75.08.080. 83-09-019 (Order 83-25), § 220-110-070, filed 4/13/83.]

220-110-100
Conduit crossing.

Conduit crossing projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. An HPA is not required for conduit crossings attached to bridge structures. The following technical provisions shall apply to conduit crossing projects:

(1) Conduit alignment shall be as nearly perpendicular to the watercourse as possible.

(2) The conduit shall be installed at sufficient depth so that subsequent disturbance of the bed of the watercourse is avoided.

(3) If the method used is boring or jacking:

(a) Pits shall be isolated from surface water flow;

(b) Wastewater, from project activities and dewatering, shall be routed to an area outside the ordinary high water line to allow removal of fine sediment and other contaminants prior to being discharged to state waters.

(4) If the method used is trench excavation:

(a) Trenches shall be excavated in the dry or shall be isolated from the flowing watercourse by the installation of a cofferdam, culvert, flume, or other approved method;

(b) Plowing, placement, and covering shall occur in a single pass of the equipment;

(c) Disturbance of the bed as a result of the plowing operation shall be limited to the amount necessary to complete the project.

(5) Trenches shall be backfilled with approved materials and the bed shall be returned to preproject condition.

(6) Excess spoils shall be disposed of so as not to reenter the watercourse.

(7) The conduit approach trench shall be isolated from the watercourse until laying of the conduit across the watercourse takes place.

(8) Alteration or disturbance of the banks 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.

[Statutory Authority: RCW 75.08.080. 94-23-058 (Order 94-160), § 220-110-100, filed 11/14/94, effective 12/15/94; 87-15-086 (Order 87-48), § 220-110-100, filed 7/20/87. Statutory Authority: RCW 75.20.100 and 75.08.080. 83-09-019 (Order 83-25), § 220-110-100, filed 4/13/83.]

220-110-310
Utility lines.

Utility line 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 utility line projects. In addition, these projects shall comply with technical provisions and timing restrictions in WAC 220-110-240 through 220-110-271.

(1) Timing restrictions for digging trenches in the beach area for the installation of cables, sewer lines, and other utilities may be further restricted to protect other important fish life.

(2) Excavation of trenches within the beach area shall not occur when the project area is inundated by tidal waters.

(3) Trenches excavated for placement of utilities may remain open for limited times during construction, but fish shall be prevented from entering open trenches.

(4) If a fish kill occurs, or fish are observed in distress, excavation activities shall immediately cease and the department shall be notified immediately.

(5) Excavation for and installation of cables, sewer lines, and other utilities shall be conducted with equipment and techniques that minimize adverse impacts to fish and shellfish and their habitats.

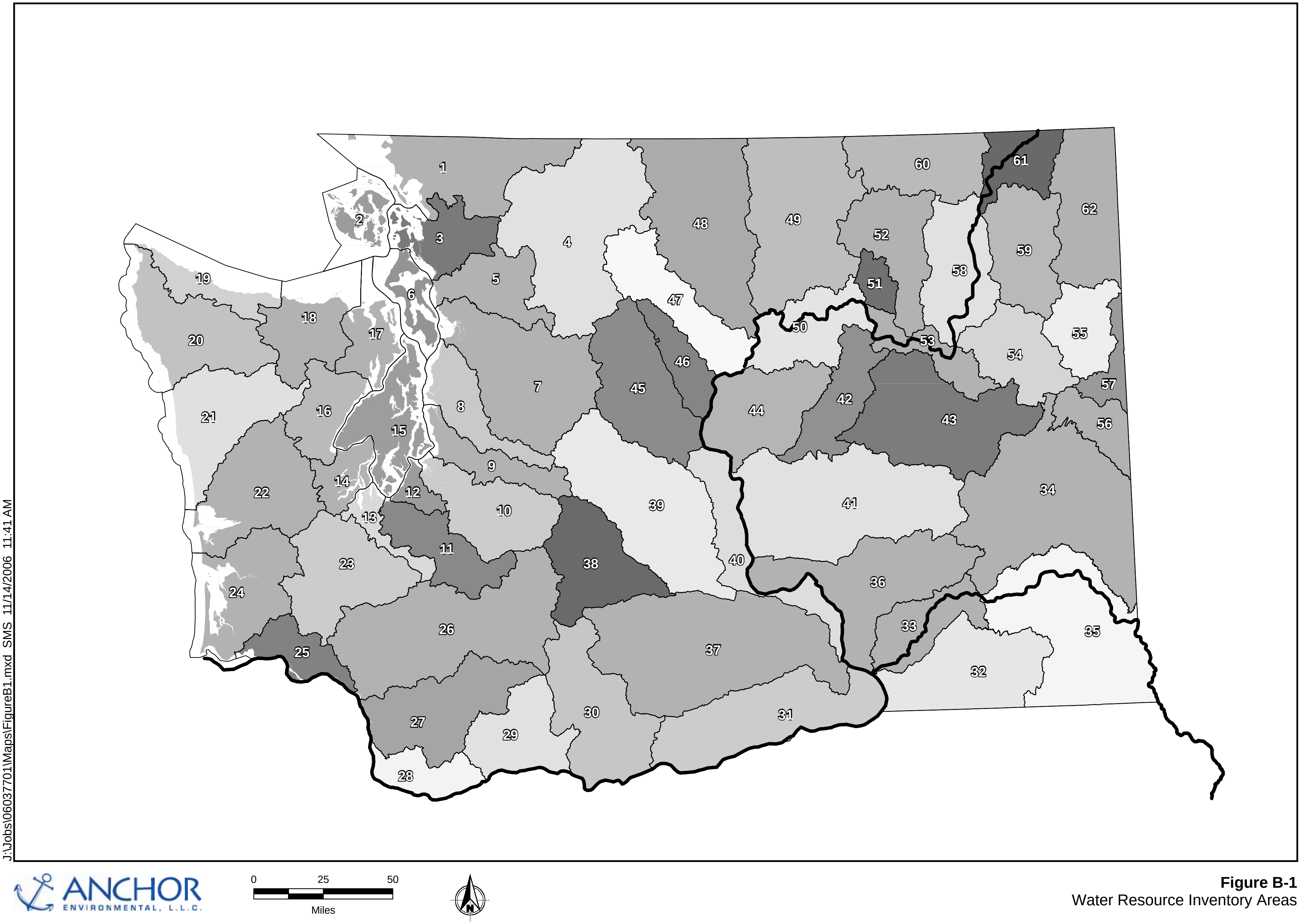
(6) Utility lines shall be located to avoid Pacific herring spawning beds, rockfish and lingcod settlement and nursery areas and eelgrass (Zostera spp).

(7) Kelp (Order laminariales) and intertidal wetland vascular plants (except noxious weeds) adversely impacted due to excavation or installation activities shall be replaced using proven methodology.

[Statutory Authority: RCW 75.08.080. 94-23-058 (Order 94-160), § 220-110-310, filed 11/14/94, effective 12/15/94. Statutory Authority: RCW 75.20.100 and 75.08.080. 83-09-019 (Order 83-25), § 220-110-310, filed 4/13/83.]

APPENDIX B

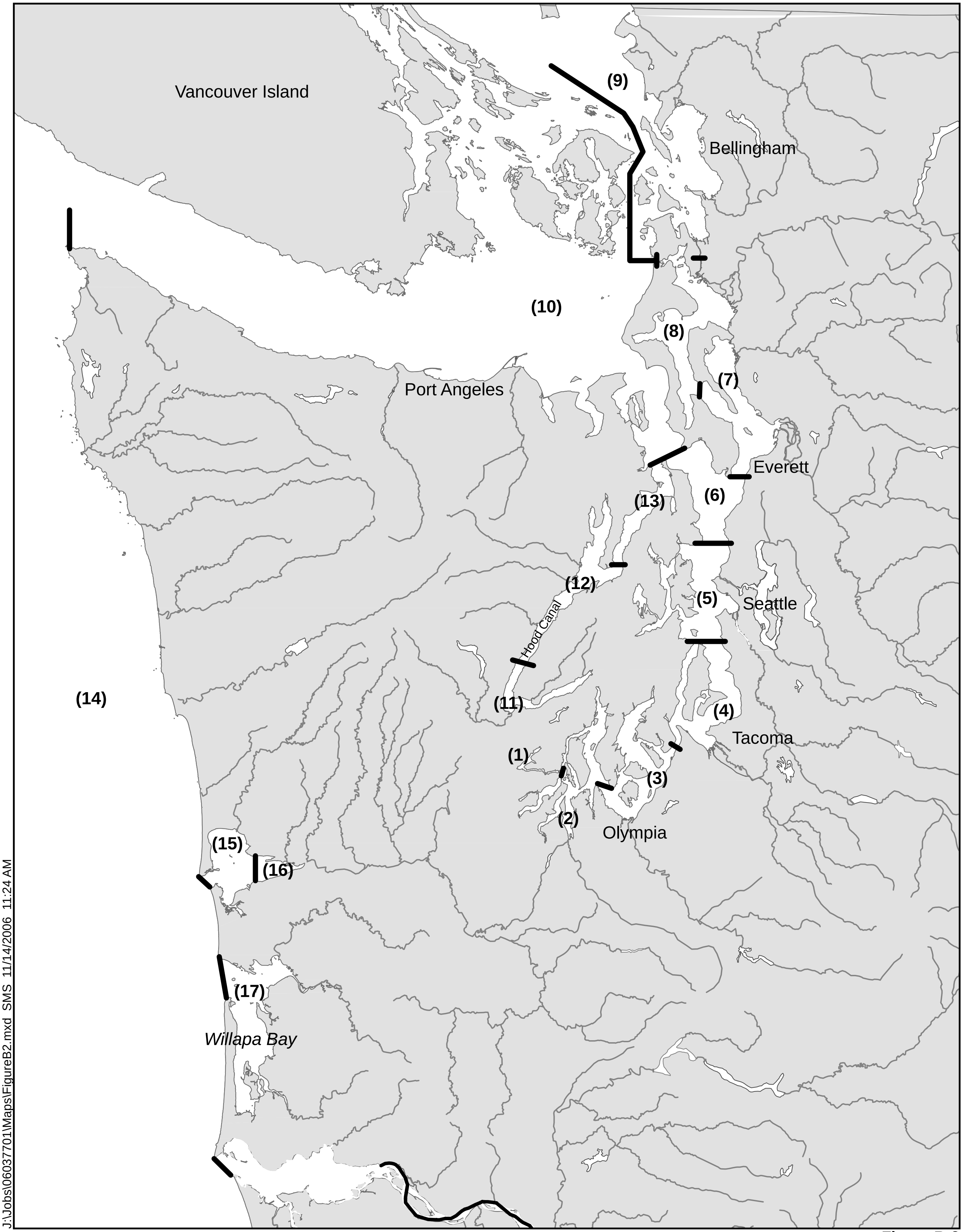
MAPS: TRAs AND WRIAs



J:\Jobs\060377\01\Maps\FigureB1.mxd SMS 11/14/2006 11:41 AM

ANCHOR ENVIRONMENTAL, L.L.C.

Figure B-1
Water Resource Inventory Areas



J:\Jobs\060377\01\Maps\FigureB2.mxd SMS 11/14/2006 11:24 AM

0 7.5 15

Miles

ANCHOR ENVIRONMENTAL, L.L.C.

Figure B-2

Tidal Reference Areas