WHITE PAPER

Habitat Modifications

Prepared for

Washington Department of Fish and Wildlife

December 2007 Working Draft

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Prepared for
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December 28, 2007 Working Draft

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Executive Summary

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

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

This white paper is one of a suite of white papers prepared to establish the scientific basis for the HCP and assist WDFW decision-making on what specific HPA activities should be covered by the HCP. This particular white paper compiles and synthesizes existing scientific information on habitat modifications. This broad activity type includes the following subactivity types:

- Beaver Dam Removal/Modifications
- Large Woody Debris Addition/Removal
- Spawning Substrate Augmentation
- In-Channel/Off-Channel Habitat Modifications
- Riparian and Estuarine Planting/Restoration
- Wetland Creation/Restoration/Enhancement
- Beach Nourishment/Contouring
- Reef Creation
- Eelgrass and other Aquatic Vegetation Enhancement.

In reviewing the best available scientific information regarding these activities it is the intent of this white paper to:

- Compile and synthesize the best available scientific information related to the potential human impacts on HCP species, their habitats, and associated ecological processes resulting from the construction and presence of the aforementioned habitat modification project types.

- Use this scientific information to estimate the circumstances, mechanisms, and risks of incidental take potentially or likely to result from the construction and presence of habitat modification projects.

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

The literature review conducted for this white paper identified six impact mechanisms that could potentially affect those aquatic species considered for coverage under the HCP (referred to as "HCP species"). These mechanisms of impact are both direct and indirect and can have temporary, short-term effects or permanent, long-term effects. The impact mechanisms analyzed in this white paper are:

- Construction activities
- Hydraulic and geomorphic modifications
- Ecosystem fragmentation
- Aquatic vegetation modifications
- Riparian vegetation modifications
- Water quality modifications.

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

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

- Identify the risk of "take" associated with impact mechanisms based on the distribution information.

- Identify cumulative impacts.

- Identify data gaps.
- Identify habitat protection, conservation, and mitigation strategies.

1.0 Introduction

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

The HCP will identify the impacts on HCP species, the potential for take, and mitigation measures for hydraulic projects that require HPAs. This white paper is part of the effort to compile the best available scientific information to protect these species which are exposed to hydraulic projects both during and after the construction phase. To accomplish this, WDFW is analyzing the adequacy of existing rules (Washington Administrative Code [WAC] 220-110), as well as possible management directives and mitigation measures, to avoid and/or minimize potential take to the maximum extent practicable. As the Hydraulic Project Approval authority covers all waters of the state, this white paper considers hydraulic project impacts in both freshwater and marine environments. This white paper is one of a suite of white papers prepared to establish the scientific basis for the HCP and assist WDFW decision-making on what specific HPA activities should be covered by the HCP and what minimization and mitigation measures can be taken to address the potential effects of hydraulic projects. This white paper covers impacts and mitigation/minimization measures to be taken associated with the construction and presence of habitat modification projects. Species considered for coverage under the HCP (referred to in the white paper as "HCP species") are listed in Table 1-1. For the purpose of this white paper, some of the HCP species have been grouped when applicable (each group is separated by a grey horizontal line in Table 1-1).

Table 1-1. HCP species addressed in this white paper.

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

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

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

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

[a] Status:

FE=Federal Endangered
FP=Federal Proposed
FT = Federal Threatened
FC = Federal Candidate

FSC = Federal Species of Concern
SC = State Candidate
SS = State Sensitive
SPHS = State Priority Habitat Species

2.0 Objectives

The objectives of this white paper are to:

- Compile and synthesize the best available scientific information related to the impacts on HCP species, their habitats, and associated ecological processes resulting from the construction and presence of large woody debris structures, beach nourishment and contouring features, spawning substrate replacement, eelgrass and other vegetation restoration, reef creation, in-channel and off-channel habitat, riparian and estuarine wetland creation/restoration/enhancement, and beaver dam removal.
- Use the scientific information regarding the above activities to estimate the circumstances, mechanisms, and risk of incidental take.
- Identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), for avoiding and/or minimizing the risk of incidental take of HCP species.

3.0 Methods

Information presented in this white paper is primarily based on the compilation and synthesis of the best available scientific information related to human impacts on HCP species, their habitats, and associated ecological processes. The methodology entailed the acquisition of existing literature, followed by an analysis of impacts based on a review of the literature. The conceptual framework for assessing potential impacts is described in detail in Section 6 (*Conceptual Framework of Assessing Impacts*). Below is a discussion of the literature acquisition and scientific review process.

To acquire the appropriate literature, an extensive search of the available literature was conducted using the Thomson Scientific Web of Science database, which has reference to more than 8,500 scientific journals encompassing all fields of environmental science. This yielded several hundred relevant publications, most published within the last 10 years. In addition, literature cited in previous white papers and conference proceedings from the last four Puget Sound – Georgia Basin Research Conferences were reviewed to identify relevant "grey literature" sources. The University of Washington School of Aquatic and Fisheries Sciences, Fisheries Research Institute Reports (UW-FRI) database that includes more than 500 reports pertaining to research conducted by the Fisheries Research Institute personnel from its inception to the present, was also searched. A thorough search of theses and dissertations in the Cascade system of libraries was performed to locate relevant student work. Finally, because this white paper was prepared by a collection of scientists from a diverse range of backgrounds, many other primary resources (e.g., consultant reports, textbooks) were found in the personal collections of staff at Herrera Environmental Consultants, Inc. (the consulting firm working with WDFW to prepare this white paper).

To identify knowledge gaps and evaluate the state of scientific knowledge applicable to the potential impacts of habitat modification measures on the HCP species and their habitats, the acquired literature was examined to assess the broader issue of how these species use aquatic habitats and how habitat modifications and their construction alter habitat functions.

Existing literature reviews, peer-reviewed journal articles, books, theses/dissertations, and technical reports were reviewed for information specific to aquatic species and their interaction with their physical environment. Through this process, a collection of information was assembled on the life history, habitat uses, and the potential impacts (both positive and negative) habitat modification measures pose to HCP species.

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

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

4.0 Hydraulic Project Description

This section provides a regulatory and descriptive background for each of the habitat modification project subactivity types. The background information includes the historical and current application of each project subactivity type, the general motivation for conducting specific habitat modifications, and a description of what the subactivity type entails. Additionally, the rules that are applicable to each subactivity type are presented in Section 4.2 (*Statues and Rules Regulating Habitat Modifications*).

4.1 Characteristics, Applications, and Descriptions of Habitat Modification Subactivity Types

The habitat modification activity type is primarily reserved for those projects which are designed to improve habitat for fish and invertebrates. The exception to this rule is beaver dam and large woody debris removal which, although classified with other habitat modification activities that improve habitat, have been shown to degrade habitat through numerous impact mechanisms (see Section 7 [*Direct and Indirect Impacts*]). Although many of the subactivity types described below may provide a net benefit to aquatic habitat and HCP-listed organisms, most are associated with negative impacts during the construction phase. This section provides an application background for each subactivity type which will lay the framework for the subsequent discussion of activity-related impacts in Section 7 (*Direct and Indirect Impacts*) of this white paper.

4.1.1 Beaver Dam Removal/Modifications

Beaver are ecosystem engineers that can drastically alter fluvial environments through the conversion of lotic habitat to lentic habitat (Naiman et al. 1986). The mosaic of connected aquatic habitat patches created by beaver are utilized by numerous aquatic species (Pollock et al. 2003) and beaver dam presence is widely believed to be a net benefit to aquatic organisms (Clifford et al. 1993; Ray et al. 2004; Sigourney et al. 2006). However, until relatively recently it was thought that beaver dams acted as barriers to fish migration and that beaver dam removal would benefit migratory species (Naiman et al. 1988). This, combined with concerns of flooding caused by beaver activity has lead to the modern day removal and modification of beaver dams.

Today beaver dam modification and removal is a fairly common activity in Washington State. Beaver dam removal is conducted using various methods. Most common is the removal of the dam with hand held tools. This removal method will have the least impact on aquatic habitat because it generally is a more gradual process than the other methods. Other methods include using explosives and heavy machinery to remove dams. These methods are usually reserved for large dams and are associated with greater impacts on the aquatic ecosystem. To reduce impacts associated with dam removal but still control beaver-induced flooding, beaver dam modification has become a popular alternative to removal. The use of “beaver deceivers” can stabilize the pool volume and water level while conserving the ecological function of the dam and associated impoundment. The impacts associated with both removal and modification are addressed in Section 7 (*Direct and Indirect Impacts*) of this white paper.

4.1.2 Large Woody Debris Placement/Movement/Removal

The removal of large woody debris (LWD) from river channels began in earnest in 1829 with the launching of the first snagboats on the Ohio and Mississippi Rivers (Wohl 2004). Snags, or submerged large wood, were a menace to ferrying boats and as commerce along these riverine corridors grew so did the need for clear passage. The practice of “snagging” (also called de-snagging) a river did not however stop at lowland rivers. With clear passage up the mainstems of rivers loggers could more easily access heavily wooded tributaries. These smaller channels were also snagged and what wood was not removed by hand was later scoured out by log drives. Studies of paired streams, some with a history of log drives and some undisturbed, have shown that channels which have had a history of log drives contained 10 to 100 times fewer logs and significantly fewer pools (Wohl 2001; Napolitano 1998).

With the realization that the habitat created by instream wood is vital for resident aquatic organisms, people began in earnest to put wood back into streams. Today large woody debris placement, movement, and removal are the most common habitat modification activities in the state of Washington. Almost all LWD additions involve the use of natural materials, primarily woody debris taken from on-site riparian zones and off-site areas as well. The wood is often secured to the bank or bed of the channel using rebar, cable, or chains. Many wood additions involve burying the bole or root wad of the tree in the bank or bed, driving timber or steel piles, and layering rack member and key members through the structure. LWD additions range in scale from single logs to massive engineered logjams. The impacts associated with both wood additions and removals are discussed in Section 7 (*Direct and Indirect Impacts*).

4.1.3 Spawning Substrate Augmentation

Spawning gravel augmentation is a popular fluvial restoration technique that is widely applied but seldom studied. Gravel augmentation for the purpose of spawning habitat improvement has been promoted episodically by various government agencies since the 1960s (Bunte 2004). The two most common methods of spawning substrate augmentation are direct gravel placement and passive gravel placement. Direct placement involves shaping the channel (by adding or removing gravel) to ensure that the 1.5-year recurrence interval flow fills the channel to its morphological bankfull stage. One form of this method involves providing bed material that is partially mobilized at bankfull flow and long-term gravel additions to match the post-restoration transport capacity. Another form of this method involves using a gravel size which will be minimally mobilized at bankfull discharges; this reduces the need for future augmentations but increases the probability that the gravels will become clogged with silt and organic material. Passive gravel placement involves supplying gravel to the channel at a logistically convenient location. The gravel is placed en-mass and mobilized during high-discharge events. As the gravel is entrained and deposited downstream, spawning habitat is created. This method is either conducted independently or in concert with direct gravel placement augmentations.

4.1.4 In-Channel/Off-Channel Habitat Creation/Modifications

In-channel and off-channel habitat modification is a broad subactivity type which includes the placement of nonwood structures within the channel, bank protection measures, channel realignment, side channel creation/connection, and the creation or enhancement of backwater sloughs and pools. The activities covered under this subactivity type are all popular restoration tools in fluvial environments and have been widely applied in the state of Washington over the past twenty years. The majority of these restoration measures are designed to create refugia within the river-floodplain system so that organisms can survive during extreme low flow and high flow conditions. In-channel habitat modification has been widely practiced but some research has indicated that these projects have a relatively high failure rate (Frissell and Nawa 1992; Roni et al. 2002) and practitioners and researchers have begun to recommend focusing on off-channel habitat creation and modification (Roni et al. 2002). Section 7 (*Direct and Indirect Impacts*) of this white paper addresses the impact mechanisms associated with both in-channel and off-channel habitat creation/modification.

4.1.5 Riparian Planting/Restoration/Enhancement

In practice this subactivity type involves a combination of invasive species removal and native species planting. These two activities will have different impacts on the adjacent aquatic environments as invasive species removal temporarily removes cover and destabilizes banks, while planting will increase cover and bank stability once plants have become established and grown. This subactivity type is a popular restoration method because it generally does not involve potentially damaging work within the aquatic habitat. Consequently, it is widely practiced in the state of Washington.

4.1.6 Wetland Creation/Restoration/Enhancement

Wetland creation, restoration, and enhancement are conducted primarily by adjusting the hydroperiod of a parcel of land. This is done by either altering geomorphology in such a way as to increase or decrease the duration of wet or dry periods, or by adjusting the system hydrology. Initial construction phase activities will typically be associated with negative impacts on fish and invertebrates but, in time, the ecosystem functions provided by the wetland habitat will render the activity a net ecosystem benefit. To control hydroperiod and create optimal habitat, wetland creation, restoration, and enhancement activities may in certain instances require partial wetland filling. Wetland filling will be associated with localized habitat degradation, but if the project is properly designed a net ecosystem improvement will result. Wetland creation, restoration, and enhancement activities are commonly practiced in the state of Washington.

4.1.7 Beach Nourishment/Contouring

Beach nourishment is a common activity within Washington State. In contrast to other locales where this activity is practiced in sandy, exposed environments (e.g., on the Atlantic and Gulf coasts), it primarily occurs in Washington State in sheltered, coarse-grained (i.e., gravel and cobble) settings (Shipman 2001). These activities are sufficiently different that they require a separate description.

In sandy settings, often in exposed environments (e.g., the outer coast), a variety of mechanisms of nourishment have been used. One common method is to pump sandy material excavated from offshore the project site. This is most common where erosion problems are caused by the transport of sand offshore due to suspension from large waves (Dean and Dalrymple 2002). It is also common to use dredge spoils to nourish beaches. Jetty Island in Everett is an example of this type of nourished beach (Everett 2006). It is also conceivable that in Washington, where quarried sand is readily available, nourishment materials could originate from onshore, but past nourishment activities have primarily relied on dredged material as a nourishment material source (USACE 1983).

In coarse-grained environments, the most popular method is to use upland quarried alluvium. Delivery to the site is most often by truck, not barge (Shipman 2001). The material added can be from a range of sizes from pebble (0.1 inch in diameter) to cobble (several inches in diameter).

4.1.8 Reef Creation

Reef creation is probably the most well-studied fish habitat enhancement activity in the world (Baine 2001). Reefs have been created for habitat and recreational purposes for over seventy years in Washington State (NSC 2007). Early reefs were often harbor or coastal structures slated for demolition (NSC 2007). Wastes that would ordinarily be landfilled or incinerated (e.g., used tires) have also been used to create reefs (Hartwell et al. 1998). Derelict vessels have been used, though they are often stripped of potentially toxic or leachable materials before they are submerged at the project site (Baine 2001). Reef creation is a relatively uncommon practice in Washington State.

4.1.9 Eelgrass and other Aquatic Vegetation Creation, Restoration, and Enhancement

Eelgrass planting is a relatively new habitat enhancement activity. Although planting plans have been implemented for 25 years (Thom 1990), successful programs where eelgrass has been reintroduced to areas where it occurred prior to development, have only occurred recently (Thom et al. 2005). Successful programs must have an adaptive management plan, including the potential planting in successive years to ensure a viable stand (Thom et al. 2005). A number of mechanisms have been proposed to introduce new eelgrass. The most common is to manually plant shoots previously grown in a greenhouse (Fonseca et al. 1998). However, more recently broadcast seeding has been demonstrated to be successful when performed under certain conditions (Pickerell et al. 2005).

4.2 Statutes and Rules Regulating Habitat Modifications

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.” Habitat modification activities in and adjacent to aquatic habitat will alter local hydrology and geomorphology and thus are defined as hydraulic projects. Habitat modification is a broad activity type and consequently many parts of the Washington Administrative Code (WAC) are applicable to the subactivity types which are defined as Habitat Modifications.

The mechanisms of impact on HCP species associated with these projects include the long duration impacts associated with structure placement or activity and impacts from construction activities that could result in modifications to aquatic system processes and morphology. This includes modifications to hydraulic and geomorphic characteristics, aquatic and riparian vegetation, and changes in water quality that could result in direct and indirect effects on HCP species. It also includes the effects of fish handling, relocation, and exclusion associated with such activities.

The following WACs listed in Table 4-1 are applicable to the listed subactivity types: (note* indicates that the activity may be related to the project subactivity type, but is not an implicit component of the activity).

Table 4-1. WAC sections potentially applicable to the Habitat Modifications white paper.

	Freshwater	Saltwater
Subactivity Type	Applicable WACs	Applicable WACs
Beaver Dam Removal/Modifications	220-110-080 (channel change)	220-110-250 (habitats of concern)
	220-110-120 (temporary bypass)	220-110-270 (common)
	220-110-150 (LWD)	220-110-271 (prohibited work window)
	220-110-050* (freshwater banks)	220-110-280* (non-SFRM bank)
	220-110-130* (dredging)	220-110-130* (dredging)
	220-110-160* (logging)	
	220-110-223* (lake bank)	
Large Woody Debris	220-110-150 (LWD)	220-110-250 (habitats of concern)
	220-110-050* (freshwater banks)	220-110-270 (common)
	220-110-080* (channel change)	220-110-271 (prohibited work window)
	220-110-120* (temporary bypass)	220-110-280* (non-SFRM bank)
	220-110-160* (logging)	220-110-285* (SFRM bank)
	220-110-223* (lake bank)	220-110-130* (dredging)
Spawning Substrate Augmentation	220-110-080 (channel change)	220-110-250 (habitats of concern)
	220-110-120 (temporary bypass)	220-110-270 (common)
		220-110-271 (prohibited work window)
In-Channel, Off-Channel Habitat Creation	220-110-080 (channel change)	220-110-250 (habitats of concern)
	220-110-120 (temporary bypass)	220-110-270 (common)
	220-110-150 (LWD)	220-110-271 (prohibited work window)
	220-110-050* (freshwater banks)	220-110-280* (non-SFRM bank)
	220-110-130* (dredging)	220-110-285* (SFRM bank)
	220-110-140* (gravel removal)	220-110-130* (dredging)
	220-110-160* (logging)	
	220-110-223* (lake bank)	
Riparian Planting/Restoration	220-110-050 (freshwater banks)	220-110-250 (habitats of concern)
	220-110-150 (LWD)	220-110-270 (common)
	220-110-160 (logging)	220-110-271 (prohibited work window)
	220-110-223 (lake bank)	220-110-280 (non-SFRM bank)
	220-110-120* (temporary bypass)	220-110-285 (SFRM bank)
Wetland Creation/Restoration/Enhancement	220-110-080 (channel change)	220-110-250 (habitats of concern)
	220-110-150 (LWD)	220-110-270 (common)
	220-110-160 (ponds)	220-110-271 (prohibited work window)
	220-110-050* (freshwater banks)	220-110-280* (non-SFRM bank)
	220-110-120* (temporary bypass)	220-110-285* (SFRM bank)
	220-110-130* (dredging)	220-110-130* (dredging)
	220-110-140* (gravel removal)	
	220-110-223* (lake bank)	
Beach Nourishment/Contouring	220-110-130 (dredging)	220-110-250 (habitats of concern)
	220-110-140 (gravel removal)	220-110-270 (common)
	220-110-080* (channel change)	220-110-271 (prohibited work window)
	220-110-120* (temporary bypass)	220-110-130 (dredging)
Reef Creation	220-110-080 (channel change)	220-110-250 (habitats of concern)
	220-110-120 (temporary bypass)	220-110-270 (common)
	220-110-130* (dredging)	220-110-271 (prohibited work window)
	220-110-331-338* (aquatic vegetation)	220-110-130* (dredging)

Table 4-1 (continued). WAC sections potentially applicable to the Habitat Modifications white paper.

Subactivity Type	Freshwater	Saltwater
	Applicable WACs	Applicable WACs
Eelgrass and other Aquatic Vegetation Enhancement	220-110-331-338 (aquatic vegetation)	220-110-250 (habitats of concern)
	220-110-050 (FW banks)	220-110-270 (common)
	220-110-080 (channel change)	220-110-271 (prohibited work window)
	220-110-120 (temporary bypass)	220-110-331-338 (aquatic vegetation)
	220-110-130* (dredging)	220-110-250 (habitats of concern)
	220-110-140* (gravel removal)	220-110-270 (common)
	220-110-150 (LWD)	220-110-271 (prohibited work windows)
	220-110-170 (outfalls)	220-110-280 (nonSFRM bank)
	220-110-223 (lake banks)	220-110-285 (SFRM bank)
		220-110-320* (dredging)

Note: * indicates that the activity may be related to the topics covered in this white paper, but it is not necessarily an implicit component of the activity as specified in the WAC. FW = fresh water; SFRM = single-family residential marine; LWD = large woody debris.

5.0 Potentially Covered Species and Habitat Use

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Source: Modified from Jones & Stokes 2006.

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

[b] Tidal Reference Areas as follows (from WAC 220-110-240): 1 = Shelton, 2 = Olympia, 3 = South Puget Sound, 4 = Tacoma, 5 = Seattle, 6 = Edmonds, 7 = Everett, 8 = Yokeko Point, 9 = Blaine, 10 = Port Townsend, 11 = Union, 12 = Seabeck, 13 = Bangor, 14 = Ocean Beaches, 15 = Westport, 16 = Aberdeen, 17 = Willapa Bay.

6.0 Conceptual Framework for Assessing Impacts

Habitat modification activities will alter hydrology, and habitat structure and connectivity. Each of the subactivity types discussed in this white paper will impact aquatic habitat to varying degrees. Many of these impacts will be positive and many will be negative. It is the intent of this white paper to review the extant literature that assesses the severity and duration of these impacts. For the purposes of this white paper, an **impact** is defined as an unnatural disturbance to habitat-controlling factors, such as light, wave energy, substrate, water quality characteristics, flow characteristics, or channel geomorphology. These controlling factors determine the habitat structure (e.g., sand or cobble substrates or disconnected or connected side channels). Habitat structure will in turn be characterized by habitat processes that can be defined as the dynamic biogeochemical, biologic, and physical processes which occur within a given aquatic habitat. For example, the habitat structure of a riparian floodplain will engender increased autotrophy (a habitat process). Subsequently, increased autotrophy serves the ecological function of providing more food resources for fish and invertebrates. Figure 6-1 illustrates the conceptual framework used in this white paper to define habitat modification impacts on HCP species and their habitats.

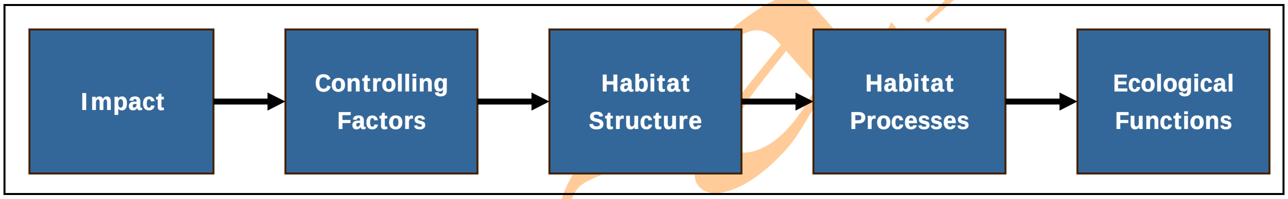


Figure 6-1. Conceptual framework for assessing impacts (Williams and Thom 2001).

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

The identification of impact mechanisms associated with HPA-authorized activities that affect habitat is based on a model described by Williams and Thom (2001). For analyzing take potential and refining the impact analysis as it pertains directly to listed species or species that will be addressed in the HCP, the “exposure-response” model developed by USFWS was used (National Conservation Training Center 2004). Each of these models is discussed in more detail below.

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

- Elucidate impacts associated with each HPA activity

- Determine how those impacts manifest themselves in impacts on habitat and habitat functions utilized by the species that will be addressed in the HCP

- Develop recommendations for impact avoidance, minimization, and mitigation measures that target the identified impacts.

Table 6-1. Impact mechanisms and submechanisms.

Impact Mechanism	Submechanisms
Construction Activities	■ Equipment Operation ■ Bank, Channel, Shoreline Disturbance ■ Temporary Exclusion/Dewatering
Hydraulic and Geomorphic Modifications	■ Altered Channel Geometry ■ Altered Bank and Shoreline Stability ■ Altered Substrate Composition ■ Altered Wave Energy ■ Altered Nearshore Circulation ■ Altered Sediment Supply
Ecosystem Fragmentation	■ Altered Longitudinal Connectivity ■ Altered Groundwater-Surface Water Interactions ■ Altered Terrestrial/Aquatic Connectivity ■ Altered Habitat Complexity
Aquatic Vegetation Modifications	■ Altered Autochthonous Production ■ Altered Habitat Complexity
Riparian Vegetation Modifications	■ Altered Shading and Solar Input ■ Altered Bank and Shoreline Stability ■ Altered Allochthonous Inputs ■ Altered Buffering Capability
Water Quality Modifications	■ Altered Temperature Regime ■ Altered Dissolved Oxygen ■ Altered Suspended Solids ■ Altered Pollutant Loading

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

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

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

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

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

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

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

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

Table 6-2. Definitions of terms used in the exposure-response analysis for this white paper.

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

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

Table 6-3. Definitions of the terminology used for risk of take determinations in this white paper.

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

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

7.0 Direct and Indirect Impacts

This section provides a review and synthesis of what is known about the effects of each of the aforementioned impact mechanisms on HCP species, using the methodology described in the *Conceptual Framework for Assessing Impacts* (Section 6). The impact mechanisms, submechanisms, and related ecological stressors associated with each of the nine subactivity types addressed in this white paper are described herein. Additionally, the biological and ecological effects of stressor exposure are characterized and expressed in terms of possible direct and indirect effects on HCP species. The information presented in this section is intended to provide a general overview of the possible direct and indirect effects, supported by detailed Exposure and Response Matrices for each individual species or relevant grouping of species considered in this white paper (Appendix A). This discussion also provides supporting information for the strategy recommendations presented in *Habitat Protection, Conservation, Mitigation, and Management Strategies* (Section 11).

This section presents the best available scientific information regarding the potential impacts of habitat modification subactivities (e.g. beaver dam removal, beach nourishment) on HCP species. Studies that have addressed subactivity impact on habitat and ecological processes are presented first. Subsequently, field-based studies that have directly measured subactivity impacts on fish and invertebrate populations are presented. Lastly, in Section 7.10 (*Discussion of Common Stressors*), studies that have directly measured fish response to stressors are presented. Many subactivity types will result in the same stress on affected organisms; instead of repeating these stressor study results for each subactivity type, these studies are presented together in Section 7.10.

7.1 Beaver Dam Removal/Modifications

Beaver dam modification is often requested in circumstances where these structures cause flooding of property and infrastructure. The approach to managing these structures is often physical removal, although other management methods such as “beaver deceivers” are also employed. Beaver deceivers are essentially culverts installed in beaver dams that drain the backwater area behind the structure, but leave the dam intact. Beaver dam removal is a source of considerable disturbance to the aquatic environment. The removal of large woody debris (LWD) associated with a beaver dam will inevitably have a negative impact on resident aquatic organisms. However, sometimes when beaver construct dams which – through the impoundment of waters and rerouting of flows – threaten adjacent property or structures, the removal of the wood associated with the dam becomes necessary. If left unchecked, beaver could rapidly repopulate stream reaches in areas where backwater flooding could cause property and infrastructure damage. For example, on the Kabetogama Peninsula, Minnesota, Naiman et al. (1988) noted an increase in dam number from 71 to 835 over a 46 year period. During this period, 12-15 percent of the upland area was altered by beaver activity. Although such alteration may be damaging to floodplain infrastructure, the literature overwhelmingly indicates that beaver impoundments are beneficial to fluvial ecosystems and that the removal of beaver dams will be associated with both direct and indirect impacts on many of the 52 HCP species that depend on freshwater environments, particularly in smaller stream and river systems.

7.1.1 Impact Mechanisms

This section summarizes the literature which has addressed the impact mechanisms associated with beaver dam removal. These mechanisms are categorized into six general impact pathways: Construction Activities, Geomorphic and Hydraulic Modifications, Ecosystem Fragmentation, Aquatic Vegetation Modifications, Riparian Vegetation Modifications, and Water Quality Modifications. Section 7.1.2 (*Summary of Impact on Aquatic Fauna*) addresses the associated impact on aquatic fauna.

7.1.1.1 Construction Activities

Most activities which are categorized under the habitat modification activity type in the HPA process are a net benefit to the affected aquatic ecosystem. However, each activity type includes construction activities which are the vehicle for a number of impact mechanisms. The effects of these impact mechanisms on HCP species including changes in animal behavior, growth, and mortality due to increased noise, suspended sediment, chemical contamination from heavy machinery, channel dewatering, and downstream sedimentation. Each of these impact mechanisms is discussed in this section. For the purpose of this assessment, the Construction Activities impact mechanism category includes all equipment use and activities related to the removal or modification of beaver dams.

7.1.1.1.1 Equipment Operation

Underwater noise produced by beaver dam removal or modification will be dependant upon the scale of the affected dam and the techniques and/or design used to remove or modify the structure. The majority of beaver dams are constructed of tree boles, branches, and sediment of varying particle size (Gurnell 1998). Removal may involve the use of chain saws and other hand tools for small dams and heavy machinery for larger dams. If heavy machinery is used, construction noise may reach nuisance levels but will likely not reach lethal levels. For more information on the impacts of noise on HCP species, see Section 7.10 (*Discussion of Common Stressors*).

Chemical contamination during construction activities can be primarily ascribed to fuel spills and other contamination from the operation of heavy machinery. Hydrocarbon contamination from machinery could impact fish and invertebrates in the case of an accidental spill, or when machinery is operating in open water. If best management practices are followed, the potential for these impacts can be greatly reduced. For a discussion of the impact of elevated hydrocarbons on aquatic species, see Section 7.10 (*Discussion of Common Stressors*).

7.1.1.1.2 Bank, Channel, and Shoreline Disturbance

Channel disturbance associated with dam removal is not as much a function of the mechanical removal itself but instead a function of the drastically altered hydraulics caused by the removal. Consequently, the impacts on the bank and channel associated with beaver dam removals is addressed in Section 7.1.1.2 (*Geomorphic and Hydraulic Modifications*) below.

7.1.1.2 Geomorphic and Hydraulic Modifications

Beaver dams alter channel form and flow. The impounding of waters leads to upstream sediment deposition and substrate fining and downstream sediment coarsening (Bednarek 2001). The removal of a beaver dam will have multiple geomorphic ramifications. Incision within the former impoundment will disturb the benthos and coarsen the substrate. Aggradation downstream of the former impoundment will promote channel complexity and potentially smoother downstream gravels until the sediment wave has passed through the system (Doyle et al. 2003). Depths and velocities within the former impoundment will change as the wetted perimeter decreases with drawdown. Finally, bank stability within the former impoundment will rapidly decrease until the channel adjusts and vegetation becomes established (Shafroth et al. 2002). This section addresses the geomorphic changes associated with beaver dam removal.

7.1.1.2.1 Altered Channel Geometry

Downstream channel geometry will only be temporarily impacted with the removal of most beaver impoundments. This is due to the fact that the impoundments are typically small (Pollock et al. 2004) and contain mostly fine sediment (Butler and Malanson 1995) which is readily entrained and exported after dam removal. This fine sediment will be deposited downstream in low energy environments (e.g., pools, channel margins) but will likely be entrained and exported in subsequent flooding events.

When a beaver dam is removed, the planform of the upstream reach responds by narrowing. This narrowing limits access to shallow water habitat (see next section) and decreases the surface area exposed to solar radiation. Some beaver impoundments have been shown to create warm water habitat patches along the watercourse (Margolis, Raesly et al. 2001). In thermally impacted reaches this warming may be detrimental to cold water fishes. In specific cases, removal of beaver dams could improve habitat conditions for cold water dependent species such as bull trout and Dolly Varden and other native salmonids. However, temperature conditions are strongly influenced by regional climate, watershed position, impoundment geometry, aspect, topography, groundwater influence, and riparian vegetation. Consequently, while some beaver ponds exhibit elevated temperatures (Margolis, Raesly et al. 2001) many others do not (Mcrae and Edwards 1994). In general, beaver dams should be considered a natural component of the landscape in which they occur, and it is expected that HCP species occurring in the same environments have evolved in concert with the conditions that they impose.

When a beaver dam is removed, the associated impoundment will dewater. Dewatering will have an immediate impact on stranded aquatic organism within the impoundment and a more long lasting impact manifest through the loss of habitat diversity and productivity. Non-motile organisms will not be able to evacuate the impoundment during dewatering and will suffer direct mortality. If dewatering is accompanied by electrofishing or other means of fish removal, there will also be adverse impacts associated with these actions.

One ramification of impoundment dewatering is that there is the potential for a spike in nutrient export with resulting water quality effects both within the former impoundment area and downstream. Beaver dam impoundments tend to accumulate phosphorus-associated sediments, and the resulting biological activity produces ammonium-rich porewater in the substrate (Margolis, Castro, et al. 2001). Scouring of the impoundment bed following dam removal mobilizes these sediments and liberates the trapped porewater, exporting it downstream in large pulses. In a study of a low-head dam removal in central California, Ahearn and Dahlgren (2005) found that annual ammonium export increased from 0 lb (0 kg) before removal to 141 lb (64 kg) in the year after removal, while phosphate export increased from -22–128 lb (-10–58 kg). Orr et al. (2006) also noted a spike in soluble reactive phosphorus immediately after removal of the Boulder Creek, Wisconsin dams. These nutrient releases could be beneficial for aquatic biota in oligotrophic headwater reaches, but detrimental in nutrient impacted lowland areas. For more information on the impacts of nutrient-enrichment in productive waters see Section 7.10 (*Discussion of Common Stressors*).

7.1.1.2.2 Altered Bank and Shoreline Stability

Beaver dams impound water and thus promote a depositional environment. Depending on sediment loading, size class, and stream velocities through the impoundment, beaver ponds may retain a significant amount of sediment. Additionally, because beaver dams inundate adjacent floodplains and generally are more productive than adjacent channels (Hammerson 1994), the accumulation of organic material within the impoundment will contribute to the volume of the sediment wedge behind the dam. A study by Naiman et al. (1986) estimated retention of 1.13×10^7 ft^3 (3.2×10^6 m^3) of sediment within beaver ponds on 2nd to 4th-order streams in Quebec. If impounded sediment were evenly distributed over the total area of stream bed in the study area, it would have reached a depth of 16.5 in (42 cm). When a beaver dam is removed, a portion of this sediment will be mobilized and exported as suspended sediment and bed load.

Although research has indicated widely varying results (Bash et al. 2001), the scientific consensus is that elevated suspended sediment concentrations can be detrimental to fish and invertebrates when the stressor exceeds the natural range of turbidity typical for the system, or when sensitive life-history stages are exposed during periods or for durations over which stressor exposure would not typically occur (Bash et al. 2001; Newcombe and Jensen 1996). Suspended solids may affect aquatic species by altering their physiology, behavior, or habitat. The direct and indirect impacts of suspended solids on fish and invertebrates are addressed in Section 7.10 (*Discussion of Common Stressors*).

The majority of the research on sediment export following beaver dam removal has focused on catastrophic failure of beaver dams from natural causes (Butler and Malanson 2005). The effects of an appropriately engineered removal will be less severe as dam removal and subsequent drawdown are gradual. Consequently, the flood wave associated with the removal will be relatively attenuated. Nevertheless, with sediment accumulation rates behind beaver dams ranging from 0.8–11 in/yr (2–28 cm/yr) (Butler and Malanson 1995), the sediment stored behind beaver dams can be substantial and sediment export and subsequent downstream deposition will, in many cases, be inevitable.

Erosional processes following beaver dam removal will be much the same as that following the removal of low-head man-made dams. Doyle et al. (2002) hypothesized that small dam removal channel evolution would follow the classic model of incision and widening which is induced by base-level lowering. This model purports that channel downcutting will destabilize banks and lead to bank failure. Bank failure will, in turn, induce channel widening and bed aggradation—processes that lead to an eventual dynamic equilibrium in the longitudinal profile of the channel (Schumm et al. 1984). Doyle et al. (2003) confirmed that dam removal erosional processes adhere to Schumm's model with the study of two low-head dam removals in 2003. Consequently, it is assumed that these processes would also apply to beaver dam removal. Immediately following removal a knickpoint forms at the relic dam site and through successive erosive storm events migrates upstream through the sediment wedge. The over-steepened banks within the sediment wedge then begin to fail and the channel widens. Through widening and sediment deposition the channel eventually reaches a quasi-equilibrium state (Schumm et al. 1984). This process adds sediment to the channel, sediment which may impact biota in downstream reaches.

7.1.1.2.3 Altered Substrate Composition

Beaver dam presence within a channel creates complex hydraulics with slackwater areas behind the dam impounding sediment and collecting particulate organic matter (POM), and a hydraulic jump at the dam face creating local scour. These dynamic hydraulic conditions produce a diverse array of substrate upon which different organisms thrive. The removal of a beaver impoundment will eliminate this diversity of substrate and create a channel system with less habitat diversity. Several of the 52 HCP species occur in environments where beaver dams are part of the landscape, and several of these species, including coho salmon, coastal and west slope cutthroat trout, and Olympic mudminnow rely on these habitats to greater or lesser degrees during some phase of their life history. Any action that results in a reduction or alteration of the habitat diversity associated with beaver dams would result in direct and indirect effects on species that utilize these habitats. For example, the Olympic mudminnow is restricted to slackwater habitats in slow moving streams, ponds, and wetlands with several centimeters of soft sediment substrate (Mongillo and Hallock 1999), conditions typical in beaver ponds. The organic-rich benthic layer within a beaver impoundment serves as the foundation for primary productivity within the beaver pond. Beaver dam removal disturbs this substrate and reverts the impounded reach to a less productive, coarse-grained channel reach (Naiman et al. 1988).

Bedload export after dam removal has been examined in only a few studies. Doyle et al. (2003) monitored downstream sediment deposition after the removal of two low-head dams in southern Wisconsin. They found that fine sediments were deposited on channel margins (especially point bars) immediately after removal but that, within 3 months, most of the fines had been exported further downstream. They also noted that, following the export of the fines, a slug of sand was exported from one of the former impoundments. The sand at one station was deposited on a point bar and redirected the stream thalweg into the opposite bank. As with the fines, the sand was eliminated from the system within 3 months with only remnant patches remaining on elevated portions of the point bars. Macroinvertebrate assemblages were only slightly impacted immediately after removal and within 1 year benthic communities had fully recovered (Doyle et al. 2003; Stanley et al. 2002). Another study of a dam removal in Boulder Creek, Wisconsin found that an insignificant amount of sediment was exported following removal of two, 6.5-ft (2-m) high dams (Orr et al. 2006). This was due to the fact that the impoundments were narrow and had relatively high thalweg velocities prior to removal. Consequently, there was limited sediment accumulation behind the dam. These findings point to the fact that sediment export following beaver dam removal will be ephemeral and in some cases nonexistent. Therefore, the impacts on HCP species associated with potential sediment deposition on spawning gravels and burrowing sites will likely only be short term (1–3 years).

7.1.1.3 Ecosystem Fragmentation

As ecosystem engineers, beaver alter their environments by modifying riparian vegetation and the channel base level. These alterations lead to an increase in aquatic habitat patches (Johnston and Naiman 1990). This section addresses the connectivity of these patches both before and after dam removal.

Much of the research concerning ecosystem fragmentation and impoundments has focused on the impacts of dam presence and not dam removal. The creation of a reservoir through damming turns the impounded section of the river into a slow-moving, lentic habitat and alters the species composition of the river (Grubbs and Taylor 2004). Lake-adapted species may begin to flourish and riverine biota may become more susceptible to displacement. For example, in the Snake River in Washington, the combination of a series of 4 large reservoirs has contributed to the increase of salmonid predator densities (Wik 1995). This same phenomenon has been noted in beaver ponds, where introduced predatory species have been shown to flourish (Pollock et al. 2003). Despite this, high salmonid abundance has been noted in beaver impoundments (Leidholtbruner et al. 1992; Pollock et al. 2003; Pollock et al. 2004; Ray et al. 2004; Sigourney et al. 2006). With the removal of a beaver dam, lentic habitat will be converted to lotic habitat and a corresponding shift in the community structure will ensue.

Beaver dams function as agents of ecosystem connection or fragmentation. Although beaver impoundments have been shown to be home to over 80 North American fish species (Pollock et al. 2003), studies have shown that beaver dams can function as seasonal barriers to fish movement (Murphy et al. 1989; Schlosser 1995). But while longitudinal connection may be limited by dam presence, lateral connectivity of the channel with its floodplain is increased upstream and downstream of beaver dams (Westbrook et al. 2006). Finally, it has recently been quantitatively shown that beaver dam presence can raise local groundwater tables and thereby promote hyporheic exchange with the channel (Westbrook et al. 2006).

In most cases, beaver dam removal will lead to habitat fragmentation and thus a "lost opportunity" for resource and organism transfer between adjacent habitat patches and for the evolution of these habitat patches through time. "Lost-opportunity impacts" result from projects that adversely alter natural fluvial processes important to the ongoing creation of fish and wildlife habitats (WDFW 2003).

7.1.1.3.1 Altered Longitudinal Connectivity

Early research suggested that beaver dams may serve as barriers that are detrimental to resident species (see Pollock et al. 2003). However, more recent research has indicated that longitudinal connectivity is only seasonally altered and that beaver activity is an overall net benefit to aquatic organisms (Pollock et al. 2003; Rolauffs et al. 2001; Sigourney et al. 2006). Although beaver dams do create a change in head at the dam face which could impede fish passage, dam structures are complex and relatively permeable under a range of flow conditions (Naiman et al. 1986). Consequently, beaver dams do not present a barrier to passage comparable to man-made dams.

Beaver dams are usually built within free-flowing reaches so the presence of the dam itself creates pool habitat which is utilized by many of the HCP species, notably juvenile coho salmon (Pollock et al. 2004). The juveniles are present in beaver impoundments in part because the low energy environment of the impoundment provides refuge and foraging habitat (Rolauffs et al. 2001). Beaver dam removal or modification may therefore result in increased longitudinal connectivity, but at the cost of reduced availability of suitable habitats for those species dependent on the impounded environment.

7.1.1.3.2 Altered Terrestrial/Aquatic Connectivity

Although there is some debate concerning beaver dam impact on longitudinal connectivity, there is unanimous agreement that beaver impoundments increase lateral terrestrial-aquatic connectivity. Beaver dams raise the water surface elevation within the channel and inundate adjacent floodplain habitat (Westbrook et al. 2006). Shallow flooded riparian areas are some of the most productive habitat within a watershed (Bunn et al. 2003; Junk et al. 1989; Schemel et al. 2004; Sommer et al. 2005; Sommer et al. 2001) and, consequently, beaver dam construction increases stream (Naiman et al. 1994) and riparian (Duke et al. 2007) productivity. Beaver impoundments flood adjacent riparian vegetation and create a hydraulic conduit for terrestrial organic matter to enter the channel. This additional carbon input combined with high retention caused by the structure of the dam and increased solar input from canopy loss, are the drivers of elevated productivity in beaver impoundments. With the removal of a beaver dam, the organic matter is exported and the terrestrial-aquatic linkage is weakened. This will lead to reduced food resources in the waterway and an associated impact on HCP species.

Floodplain connectivity also creates fish forage and refuge habitat. Due to abundant food resources and habitat which is protected from the high velocities associated with flooding events, the inundated perimeters of beaver ponds are ideal habitat for many of the HCP species (Pollock et al. 2003). Chinook which rear on floodplains have been shown to grow faster than those which rear in adjacent channels (Sommer et al. 2001). Additionally, in a 2004 study of the Sacramento Splittail (Ribeiro et al. 2004) it was shown that fishes which reared in floodplain habitat showed higher fitness and length increment. Beaver ponds create and also increase access to floodplain habitat. The removal of beaver impoundments will sever this connection and reduce the quality of habitat for many of the HCP species. (For a list of the fish species which most commonly inhabit beaver ponds, see Section 7.1.2 [*Summary of Impact on Aquatic Fauna*]).

7.1.1.3.3 Altered Groundwater-Surface Water Interactions

Numerous studies have shown that beaver impoundments increase lateral connectivity between the channel and terrestrial environment, but impoundments can also increase vertical connectivity within the waterway. Vertical connectivity, as defined by Ward (1989), is a measure of the exchange between groundwater and surface water through the bed and banks of the channel (i.e., hyporheic exchange). By creating a head differential across the structure of the dam, beaver activity directs water into the benthos. These waters either move through interflow or shallow groundwater routes to the floodplain and channel below the dam. In a study of small man-made dams in the black Prairie region of Texas it was found that the result of upstream impoundment was to increase riparian vegetation production by increasing hyporheic exchange through the riparian corridor (Duke et al. 2007). In a separate study in the Rocky Mountains, researchers showed that beaver dams and ponds increased water retention during flooding events and attenuated the wet season flows. Instead of efficient routing through the channel which was observed below the impoundments, in areas affected by beaver the flow routing was more complex and the local groundwater level was elevated during both low and high flows (Westbrook et al. 2006).

Increased hyporheic exchange can be beneficial to salmonids because the eggs of these species require well oxygenated gravels for proper egg development (Ecology 2002; Groot and Margolis 1991), and hyporheic exchange promotes increased oxygen levels in the benthos (Greig et al. 2007). Additionally, increased hyporheic exchange has been associated with nutrient uptake (Sheibley et al. 2003) and may attenuate the transport of dissolved and particulate metals (Gandy et al. 2007). Elevated metals and nutrients can both have negative ramifications for fish and invertebrate health (see Section 7.10 [*Discussion of Common Stressors]*). Consequently, any activity which impacts the functioning of the hyporheic zone are likely to result in direct and indirect effects on HCP species that occur in environments subject to this subactivity type during at least some phase of their life history.

7.1.1.4 Aquatic Vegetation Modifications

Macrophytes which populate many floodplain ponds are most abundant in the littoral zones (Ahearn et al. 2006). Consequently, when a beaver pond is dewatered much of the aquatic vegetation is left isolated in dry upland areas. The result is a substantial decrease in aquatic vegetation and the standing vegetation stock (Naiman et al. 1988). This, coupled with the loss of shallow water refugia, may represent the single greatest impact on fish and invertebrates associated with beaver extirpation and dam removal. This section addresses the impact mechanisms associated with aquatic vegetation removal.

7.1.1.4.1 Altered Habitat Complexity

Freshwater aquatic vegetation provides shelter and clinging substrate for a variety of prey of HCP species, including mollusks and many fishes (nonsalmonids) with a strong association with this vegetation (Petr 2000). Several of the HCP species which have been shown to commonly utilize vegetated habitat in beaver ponds include cutthroat trout, bull trout, Dolly Varden, Olympic mudminnow, sockeye and coho salmon, and dace species (Mongillo and Hallock 1999; Pollock et al. 2003). These and other species with similar requirements could be at relatively high risk from projects that remove or reduce this vegetation. In fluvial systems, slack water results in productive patches that provide habitat diversity in these systems which are otherwise dominated by high velocity less-productive habitat (Johnston and Naiman 1990). The loss of this habitat will decrease habitat diversity and impact HCP species.

7.1.1.4.2 Altered Autochthonous Production

Beaver dam removal will decrease the amount of shallow water habitat available for macrophyte and algal production. The decrease in autogenic production will cause a shift in the form of the food resources available to primary consumers. Shredders and scrappers may replace grazers, and the changing macroinvertebrate population may have an overall impact on higher trophic level species (Winkelmann et al. 2007). Altered food web complexity may, as a result, affect foraging opportunities for HCP species that feed on aquatic macroinvertebrates in beaver ponds and similar environments during some phase of their life history.

7.1.1.5 Riparian Vegetation Modifications

Beaver dam removal and impoundment dewatering results in the creation of a stream reach which initially has little riparian vegetation. However, nutrient-rich sediments from the benthos of the former impoundment (Ahearn and Dahlgren 2005) may be rapidly colonized with wetland vegetation and invasive species. The establishment of mature riparian stands may take years to decades (Auble et al. 2007), but dense stands of rapidly growing native and invasive plants such as *Typha* spp. (cattails) may provide channel shading in the short term. An initial lack of riparian vegetation will decrease allochthonous carbon supplementation which will have trophic ramifications. Additionally, bank stability will be degraded until the channel adjusts and vegetation begins to grow and stabilize the banks. Finally, riparian buffering capacity may increase as the former impoundment will serve as additional buffer area between the channel and upland pollution sources. This section addresses these issues by presenting applicable research related to each submechanism.

7.1.1.5.1 Altered Allochthonous Input

As indicated above, beaver dam removal will reduce aquatic vegetation biomass and thus autogenic production. The removal of beaver dams will also weaken the terrestrial-aquatic linkage and reduce allochthonous input from the riparian zone (Naiman et al. 1994). Until riparian vegetation becomes established after dewatering, there will be reduced vegetation adjacent to the channel and thus decreased direct delivery of organic material to the channel. It has also been shown that impoundments can increase riparian vegetation downstream of the dam by augmenting floodplain groundwater (Duke et al. 2007). Consequently, it can be assumed that the removal of beaver dams which impound a large cross section of the floodplain will impact downstream riparian vegetation by altering hyporheic flow and thus will also reduce downstream allochthonous inputs.

Beaver actively recruit wood from the adjacent floodplain to augment their dams and build lodges (Collen and Gibson 2001). Beaver extirpation would eliminate this pathway for wood recruitment. The wood imported to the channel by beaver activity can serve as shelter for fishes (Cederholm et al. 1997), substrate for algal growth (Atilla et al. 2003), and habitat for macroinvertebrates (Clifford et al. 1993; Rolauffs et al. 2001). Rolauffs et al. (2001) found that macroinvertebrate emergence was 3.2 and 5.5 times higher from a beaver dam than from the adjacent brook and pond areas, respectively. This indicates that not only are beaver ponds important for fluvial ecosystem functioning, but that the associated dam structures provide additional habitat benefits. Removal of beaver dams will, of course, eliminate those habitats created by both the pond and the dam.

7.1.1.5.2 Altered Shading and Solar Input

While some beaver ponds have been shown to raise stream temperatures (Margolis, Raesly et al. 2001; Mcrae and Edwards 1994), a literature review by Pollock et al. (2003) noted that other studies have indicated that beaver ponds do not significantly affect temperature. The discussion of the potential impacts of altered temperatures caused by beaver dam removal is provided in Section 7.10 (*Discussion of Common Stressors*).

7.1.1.5.3 Altered Bank and Shoreline Stability

Riparian vegetation plays a vital role in stream bank stability (Pollen 2007). The removal of a beaver dam will be followed by channel formation within the former impoundment (Doyle et al. 2002) and until vegetation becomes established the banks of this “new” channel will be unstable. This will lead to channel widening and increased sediment loading to the channel. The ramifications of this are discussed below in the Section 7.10 (*Discussion of Common Stressors*).

7.1.1.5.4 Altered Buffering Capability

Riparian and bank vegetation has been shown to act as a filter for polluted waters from upgradient sources moving through overland flow, interflow, and shallow groundwater pathways (Hickey and Doran 2004). The creation of a beaver dam impacts the riparian zone upstream of the dam. Inundation and clearing of vegetation by beaver results in the conversion of the terrestrial riparian zone into an aquatic system with minimal cover. In this way the riparian buffer upstream of the dam can be reduced by beaver activity and the removal of beaver will then increase the width of the buffer. This must be weighed against the fact that beaver ponds create riparian wetlands. Because these wetlands have rich organic soils, there is the potential for elevated nutrient removal to occur in the littoral areas of the pond (Cooper 1990). Finally, dams have been shown to increase riparian growth downstream of the impoundment (Duke et al. 2007). Consequently, the removal of beaver dams may be associated with reduced buffering capacity in downstream riparian zones. Reduced buffering capacity may lead to increased nutrient and pollutant loading to the channel. The ramifications of these changes in water quality are discussed below.

7.1.1.6 Water Quality Modifications

The primary water quality impacts associated with beaver dam removal are related to suspended solids and temperature. (Immediate effects associated with suspended solids export are addressed in Section 7.1.1.2 [*Geomorphic and Hydraulic Modifications*].) Elevated suspended solids concentrations may continue for years after dam removal (Ahearn and Dahlgren 2005) until the upstream channel has incised, widened, and stabilized (Stanley and Doyle 2002). A positive aspect of beaver dam removal is that there is the potential to decrease average stream temperatures through the altered reach, although this effect will be dependent on site specific conditions and should not be expected in all cases. While results from the literature are mixed with regards to the thermal impact of beaver impoundments, it can generally be assumed that warm water species will suffer most with the removal of beaver dams. Finally, beaver dams serve a vital function as areas of hydraulic retention where organic materials and sediments accumulate. The transient storage provided by beaver dams serves to impede flows, increase the contact time between solutes and sediment and organisms, and promote carbon, nutrient, and pollutant retention (Ensign and Doyle 2005; Gandy et al. 2007; Naiman et al. 1988).

7.1.1.6.1 Altered Temperature Regime

Beaver ponds are generally wider and shallower than the associated stream channel and consequently receive more solar radiation and are more susceptible to elevated temperatures. If a reach is already thermally impacted, then the presence of a beaver dam could promote the elevation of stream temperatures above the acceptable threshold of between 48 and 68°F (9 and 20°C) depending upon the species and life-history stage affected (WAC 173-201A 2006). Beaver dam removal may lead to decreased stream temperatures which could benefit cold water species such as bull trout and Dolly Varden. However, it should also be recognized that slightly elevated temperatures may be beneficial for even cold water species as it can enhance growth rates and thus survival (McCullough et al. 2001). This type of response would be expected where coldwater fish species have evolved in those systems influenced by beaver activity.

7.1.1.6.2 Altered Suspended Solids

Beaver impoundments reduce stream velocities and act as sediment sinks (Naiman et al. 1994). Aquatic vegetation in beaver impoundments also slows stream velocities and contributes to sediment retention (Chambers et al. 1999). Beaver pond removal will contribute to suspended solids concentrations immediately after removal and in the long-term. Elevated turbidity and increased suspended solids are known to increase the vulnerability of affected life-history stages. The potential for direct and indirect effects is related to the species and life-history stages exposed, their sensitivity to stressor exposure, and their ability to behaviorally avoid the stressor. The direct and indirect effects of stressor exposure include physiological, developmental, and behavioral impairments suffered by fishes and invertebrates exposed to increased suspended solids; increased competition and predation exposure caused by displacement from favorable habitats; and changes in foraging opportunities caused by altered food web complexity. The potential impacts of suspended solids on fish and invertebrate are discussed in more detail in Section 7.10 (*Discussion of Common Stressors*).

7.1.1.6.3 Altered Pollutant Loading

Human impact on stream channels is frequently manifested through geomorphic simplification and a decrease in transient storage of wood, sediment, nutrients, and other organic materials. Beaver dams serve to counteract geomorphic simplification and to provide this transient storage capacity as integral components of the natural landscape. The removal of beaver dams degrades transient storage capacity, potentially leading to degraded water quality in downstream aquatic ecosystems. Beaver impoundments have been shown to be effective sinks for nitrogen and phosphorus (Margolis, Castro et al. 2001; Naiman et al. 1994) and by increasing hyporheic exchange and transient storage they may also serve to sequester metals pollution from urban areas, particularly metals and other pollutants prone to sorption on fine sediments and organic material (Gandy et al. 2007). The potential impact on species caused by elevated levels of nutrients and other pollutants is discussed in Section 7.10 (*Discussion of Common Stressors*).

7.1.1.6.4 Altered Dissolved Oxygen

As noted above, increased nutrient loading can contribute to eutrophication. Eutrophication is characterized by elevated carbon fixation; this excess carbon in the aquatic system contributes to elevated levels of respiration. In waters with minimal physical mixing, oxygen consumed through respiration is not readily replaced with oxygen from the atmosphere. The result is a decrease in ambient dissolved oxygen levels which can lead to impairment in many of the HCP species. (See Section 7.10 [*Discussion of Common Stressors]* for a general discussion of the effect of low dissolved oxygen on fish and invertebrates.)

7.1.2 Summary of Impact on Aquatic Fauna

This section summarizes the current knowledge concerning the impact of beaver dam removal on the 52 HCP species. Beaver dams do not affect marine environments and thus marine species are not addressed in this section.

7.1.2.1 Impact on Fishes

There is little if any experimental research on the impact of beaver dam removal on aquatic species. Instead, the impact must be inferred from studies which have assessed the benefits of beaver impoundments and other studies that have addressed the ramifications of small man-made dam removals. The removal of beaver dams will impact the majority of the HCP species which utilize beaver pond habitat during at least some portion of their life history. Table 7-1 [adapted from (Pollock et al. 2003)] shows the relative abundance of several aquatic fish species that

1 **Table 7-1. Fish species known to utilize beaver pond habitat.**

Species	Common Name	Abundance
Aphredoderus sayanus	Pirate perch	C
Campostomus anomalum	Central stoneroller	C
Catostomus commersoni	White sucker	C
Centrarchus macropterus	Flier	C
Phoxinus eos	Northern redbelly dace	C
Culaea inconstans	Brook stickleback	C
Enneacanthus chaetodon	Blackbanded sunfish	C
Enneacanthus gloriosus	Bluespotted sunfish	C
Erimyzon oblongus	Creek chubsucker	C
Esox americanus	americanus Redfin pickerel	C
Esox niger	Chain pickerel	C
Etheostoma serrifer	Sawcheek darter	C
Fundulus diaphanus	Banded killifish	C
Fundulus lineolatus	Lined topminnow	C
Gambusia holbrooki	Eastern mosquitofish	C
Hybognathus hankinsoni	Brassy minnow	C
Ameirus melas	Black bullhead	C
Lepomis auritus	Redbreast sunfish	C
Lepomis cyanellus	Green sunfish	C
Lepomis gibbosus	Pumpkinseed sunfish	C
Lepomis gulosus	Warmouth	C
Lepomis marginatus	Dollar sunfish	C
Lepomis punctatus	Spotted sunfish	C
Notropis cummingsae	Dusky shiner	C
Notropis heterodon	Blackchin shiner	C
Notropis lutipinnis	Yellowfin shiner	C
Luxilus umbratilis	Redfin shiner	C
Oncorhynchus clarkii	**Cutthroat trout**	**C**
Oncorhynchus kisutch	**Coho salmon**	**C**
Oncorhynchus nerka	**Sockeye salmon**	**C**
Phoxinus neogaeus	Finescale dace	C
Phoxinus phoxinus	Minnow	C
Pimephales promelas	Fathead minnow	C
Pungitius pungitius	Ninespine stickleback	C
Salmo trutta	Brown trout	C
Salvelinus fontanilus	Brook trout	C
Salvelinus malma	**Dolly Varden char**	**C**
Semotilus atromaculatus	Creek chub	C
Semotilus coporalis	Fallfish	C
Cottus spp.	Sculpins	LC
Esox lucius	Northern pike	LC
Gasterosteus aculeatus	Threespine stickleback	LC
Micropterus salmoides	Largemouth bass	LC
Notemigonus crysoleucas	Golden shiner	LC
Luxilus cornutus	Common shiner	LC
Notropis heterolepis	Blacknose shiner	LC
Notropis topeka	Topeka shiner	LC
Perca flavescens	Yellow perch	LC

Table 7-1 (continued). Fish species known to utilize beaver pond habitat.

Species	Common Name	Abundance
Prosopium spp.	Whitefish	LC
Ameiurus natalis	Yellow bullhead	U
Ameiurus platycephalus	Flat bullhead	U
Acantharchus pomotis	Mud sunfish	U
Ictalurus nebulosus	Brown bullhead	U
Lepomis humilis	Orangespotted sunfish	U
Lota lota	Burbot	C
Cyprinella lutrensis	Red shiner	U
Noturus leptacanthus	Speckled madtom	U
Notropis petersoni	Coastal shiner	U
Oncorhynchus mykiss	**Steelhead**	**U**
Oncorhynchus mykiss	**Rainbow trout**	**U**
Oncorhynchus tshawytscha	**Chinook salmon**	**U**
Pimephales notatus	Bluntnose minnow	U
Prosopium williamsoni	Mountain whitefish	U
Margariscus margarita	Pearl dace	O
Amia calva	Bowfin	O
Anguilla rostrata	American eel	O
Elassoma zonatum	Banded pygmy sunfish	O
Etheostoma exile	Iowa darter	O
Etheostoma fricksium	Savannah darter	O
Etheostoma fusiforme	Swamp darter	O
Etheostoma nigrum	Johnny darter	O
Etheostoma olmstedi	Tessellated darter	O
Etheostoma spectabile	Orangethroat darter	O
Lepomis macrochirus	Bluegill	O
Minytrema melanops	Spotted sucker	O
Nocomis leptocephalus	Bluehead chub	O
Notropis dorsalis	Bigmouth shiner	O
Noturus gyrinus	Tadpole madtom	O
Oncorhynchus gorbuscha	**Chum salmon**	**O**
Percina caprodes	Logperch	O
Umbra limi	Central mudminnow	O
Umbra pygmaea	Eastern mudminnow	O

Source: Pollock et al. 2003.
C = common, LC = locally common, U = uncommon, O = occasional.
Bold text indicates HCP species.

occur in beaver impoundments. HCP species are noted in **boldface** type. As discussed above, the primary impact on fishes associated with beaver dam removal will be due to loss of foraging, refuge, and rearing habitat. Secondary impacts will result from elevated suspended sediments and related stressor conditions during and subsequent to dam removal. These ephemeral impacts are short-term to intermediate-term in duration, and the resulting effects on aquatic species (including HCP species) are predominantly due to changes in the availability of suitable habitat and foraging opportunities, and behavioral responses to stressor exposure (Thomson et al. 2005). Increased nutrient and pollutant export associated with a single beaver dam removal will most likely not affect fishes, but the cumulative impact of channel simplification from the pre-Columbian era until present day has had a profound effect on nutrient and pollutant spiraling in fluvial systems (Wohl 2004), and must be taken into account when assessing potential impacts associated with any channel simplification activity such as beaver dam removal.

In summary, for fish, the primary stressors associated with beaver dam removal are:

- Loss of shallow water habitat/cover
- Loss of aquatic vegetation
- Increased suspended solids
- Increased pollutant loading.

These stressors will lead to adverse impacts on HCP species but must be weighed against the potential benefits of beaver dam removal including:

- Decreased stream temperatures
- Removal of potential migration barrier.

The synthesis of these results is presented in Section 9 (*Potential Risk of Take*).

7.1.2.2 Impact on Invertebrates

No studies have addressed the impact of beaver dam removal on HCP invertebrate species. There have, however, been studies which have addressed macroinvertebrate response to the removal of man-made dams. Research has indicated that dam removal will result in a significant decrease in downstream macroinvertebrate density for at least 1 year following removal (Stanley et al. 2002; Thomson et al. 2005). Given the habitat preferences of the California floater, Western ridged mussel, and the Great Columbia River spire, these species may inhabit beaver impoundments and the reaches immediately downstream (WDNR 2006b). The removal of a beaver impoundment would strand upstream invertebrates and potentially bury downstream individuals. Thus the construction phase and the sediment export following removal would be the primary impact mechanisms for invertebrates.

For invertebrates, the primary stressors of beaver dam removal will be:

- Stranding
- Burial
- Increased suspended sediment.

The sections above provide a discussion of the impact mechanisms and stressors associated with beaver dam removal. For a more general discussion of the stressors that are the end result of these impact mechanisms, see Section 7.10 (*Discussion of Common Stressors*).

7.2 Large Woody Debris Placement/Movement/Removal

The placement of large woody debris (LWD) in channels with the goal of creating desirable habitat for target species is the most common channel restoration practice in Washington. LWD creates and alters channel structures, sediment transport, and hydraulic complexity (Montgomery et al. 1995), contributes to the formation of a variety of habitat types (Brooks et al. 2004) including riffles (Curran and Wohl 2003), and provides cover and organic substrate for fish and other aquatic biota (Flebbe 1999). In addition, the LWD presence also regulates the transport and retention of sediment (Gomi et al. 2001), organic matter (Diez et al. 2000), and nutrient concentrations (Ensign and Doyle 2005), and influences carbon cycling and sequestration (Chen et al. 2005; Guyette et al. 2002). There is no evidence that small scale additions of wood to channels and shorelines can have negative impacts on aquatic biota. However, construction-related impacts and logjam failures may induce a negative response from local fauna. Also, numerous studies have indicated that LWD removal can be detrimental to aquatic ecosystems.

This section addresses the impact mechanisms associated with large woody debris addition and removal. The impacts associated with LWD movement are identical to the impacts associated with removal in the short-term, but LWD movement projects will not have the same lasting effects as LWD removal. To simplify the discussion, the impacts associated with LWD placement and removal are discussed below, and LWD movement is only addressed if the associated impacts are expected to be notably different. For LWD placement and movement, the impact mechanisms associated with construction are weighed against the beneficial impact of LWD and an estimate of impact on fish and invertebrates is presented. For LWD removal, construction-related and long-term negative impacts are addressed. The vast majority of LWD additions, movements, and removals occur in fluvial environments, consequently, the majority of the research which has been conducted on LWD ecology and geomorphology has been in this setting. This discussion will focus on fluvial systems and reference lacustrine and marine environments where applicable.

7.2.1 Impact Mechanisms

This section addresses the impact mechanisms associated with large woody debris placement, repositioning, and removal. Section 7.2.2 (*Summary of Impact on Aquatic Fauna*) deals with the associated impact on aquatic fauna.

7.2.1.1 Construction Activities

Large woody debris additions and movements range in scale from small stream restorations involving the hand placement of small pieces of wood, to river projects involving engineered logjams, large key members, structural logs, piles, and the use of heavy machinery. Occasionally, anchoring mechanisms, including “ecology blocks,” are used to stabilize wood structures. If these anchoring mechanisms become mobilized, the result may be localized scour and bank erosion. However, with proper engineering, engineered logjams can be constructed without the need for large anchors. Due to the variable scale of wood-related projects, the impacts associated with construction activities will be highly variable. The potential impact mechanisms that could result in risk of take include equipment operation in and around the stream channel, bank and channel disturbance, and temporary dewatering requiring fish handling and removal.

In many cases, the construction phase associated with LWD removal will have a greater impact than LWD placement or movement. This is due to the fact that LWD members act as structural elements within in aquatic environments. Therefore, removal will have an immediate impact on channel form as sediments retained by the wood are released and the channel adjusts to new baselevel conditions. In addition, large-scale projects may have significant (but short-term) construction-related impacts. For example, the placement of large engineered logjams may require the temporary redirection of a stream or river system into a constructed bypass channel. The watering and dewatering of the existing and temporary channels may have similarly extensive short-term effects on channel form and sediment mobilization.

7.2.1.1.1 Equipment Operation

The placement of large wood in a channel or along a shoreline will commonly involve the use of heavy machinery. The use of such machinery (e.g. excavators) will generate noise and visual and physical disturbance, and increase the potential for fuel and/or oil spills. Although there are no studies which have addressed equipment noise associated with wood placement, there have been many studies which have addressed noise associated with pile driving [see Section 7.10 (*Discussion of Common Stressors*)]. The installation of some large engineered logjams entails pile driving and the associated noise may be associated with adverse impacts on HCP species. Smaller wood installations will be associated with less noise and the potential impacts will be proportionally less. Wood removal and movement will not entail pile driving; thus, noise associated with these activities is not expected to reach levels which are considered potentially lethal. A thorough discussion of the impact of elevated noise levels on fish and invertebrates in provided in Section 7.10 (*Discussion of Common Stressors*).

Whenever machinery is operated near open water there is the potential for chemical contamination from accidental spills or equipment wear. Hydrocarbon contamination from machinery could impact fish and invertebrates in the case of an accidental spill, or when machinery is operating in open water. If best management practices are followed, the potential for these impacts can be greatly reduced. For a discussion of the impact of elevated hydrocarbons on aquatic species see Section 7.10 (*Discussion of Common Stressors*).

7.2.1.1.2 Bank, Channel, and Shoreline Disturbance

Equipment operation within or around river channels and shorelines will disturb riparian vegetation, impact the substrate of the channel, and compact soils in the work area. If riparian vegetation must be removed to access the project site, there will be associated impacts on the stability of the bank or shoreline. By dissipating the erosive energy of flood waters, wind and rain, and by filtering sheet flows, riparian vegetation limits the amount of fine sediment entering river and stream systems (Brennan and Culverwell 2004; Knutson and Naef 1997; Levings and Jamieson 2001). If riparian vegetation is removed as part of an HPA-permitted activity, stream banks and shorelines will likely be exposed to the erosive effects of wind, rain, and current. The removal of riparian trees and understory can dramatically alter stream bank stability and the filtering of sediments from overland flow (Kondolf and Curry 1986; Shields 1991; Shields and Gray 1992; Simon 1994; Simon and Hupp 1992; Waters 1995), resulting in increased erosion and increased inputs of fine sediment (Bolton and Shellberg 2001). These sediments may clog spawning gravels and temporarily increase suspended sediment concentrations.

Compaction of riparian soils may lead to various forms of channel degradation, but this impact pathway has not been well studied. Soil compaction can lead to decreased plant growth and increased runoff (Greacen and Sands 1980). Decreased plant growth would impact the riparian vegetation and lead to decreased channel shading, while increased runoff could cause localized channel incision and increased pollutant/nutrient loading. Although this impact pathway may indeed exist, no studies have evaluated the severity or frequency of the impact in the context of floodplain work zones.

7.2.1.1.3 Temporary Exclusion/Dewatering

Temporary dewatering will not always be necessary during LWD-related projects; however, fish exclusion measures will be commonly practiced. For a discussion of impacts and stressors associated with dewatering and fish handling see Section 7.10 (*Discussion of Common Stressors*).

7.2.1.2 Geomorphic and Hydraulic Modifications

In the Pacific Northwest, channel form and the presence, orientation, quantity, and shape of large woody debris are inextricably linked (Abbe and Montgomery 1996). Due to high rainfall, the natural instability of shallow rooted conifers, and slow conifer decay rates, wood loading in Pacific Northwest channels is greater than anywhere else in the United States (Cordova et al. 2007; Richardson et al. 2005). The removal of this wood through historic land use and management efforts has lead to widespread channel degradation (Wohl 2004). In the past two decades, habitat restoration has focused increasingly on the placement of wood in channels and along shorelines to restore the historic hydraulic complexity and habitat forming processes which characterized the waterways and the shorelines of the Pacific Northwest (Palmer et al. 2005). Many of the HCP species addressed in this white paper are adapted to live in these complex systems and as a consequence, they will realize benefits from the improved habitat conditions provided by the addition of large woody debris. Conversely, the hydraulic and geomorphic modification caused by wood removal projects will impose stressors on aquatic species whose life histories have been historically dependant upon aquatic habitat with abundant wood.

This section addresses the hydraulic and geomorphic ramifications of LWD placement and removal in channels and along shorelines. The impact of LWD placement will usually be positive (exceptions noted below) and the hydraulic and geomorphic benefits of wood placement should be weighed against the negative impacts associated with construction when assessing potential impacts. Conversely, wood removal has been shown to negatively impact aquatic habitat, and this impact on habitat will be associated with indirect impacts on HCP species. The hydraulic and geomorphic impacts of LWD addition and removal can be categorized into altered channel geometry and altered bank and shoreline stability, as discussed below.

7.2.1.2.1 Altered Channel Geometry

The addition of large woody debris to a channel will locally divert flow and generate patches of scour and aggradation. For example, mid-channel logjams are associated with a crescent pool, an upstream arcuate bar, and a downstream central bar which frequently serves as a locus for forest patch development and channel bifurcation (Abbe and Montgomery 1996; Latterell et al. 2006). This process leads to heterogeneity in stream depths and substrate composition (Baillie and Davies 2002; Beechie and Sibley 1997; Brooks et al. 2004; Cordova et al. 2007; Kail 2003; Martin 2001; Thompson 2002; Webb and Erskine 2003). In the Williams River, Australia researchers added 436 logs (20 major logjams) to a 1.1 km reach of the channel; after 12 months they noted an increase in pool and rifle area, the addition of a pool-riffle sequence, and a substantial increase in the spatial complexity of bed material distribution (Brooks et al. 2004). Numerous other studies in the United States (Beechie and Sibley 1997; Cordova et al. 2007; Thompson 2002) and across the globe (Baillie and Davies 2002; Webb and Erskine 2003) have found similar results. The sediment storage provided by many small woody debris dams in confined channels can moderate sediment flux from small basins impacted by punctuated sediment inputs (Lancaster 2001; Massong and Montgomery 2000). Conversely, LWD removal is associated with channel simplification, incision, floodplain disconnection, and substrate coarsening (Diez et al. 2000; Faustini and Jones 2003). HCP species that occur in riverine environments prefer a wide range of stream depths and substrate types so that any activity which promotes an abundant and diverse array of habitat types will benefit these species, while activities which reduce habitat complexity will be associated with adverse impacts.

LWD addition on a larger reach scale will induce aggradation, which is desirable in many incised channel systems and will create more lateral and vertical connectivity (addressed below). Based on case studies of natural logjams throughout Washington, Brummer et al. (2006) found that logjams can increase channel migration rates by forcing vertical fluctuations in the channel bed and water surface elevations of more than 6.5 ft (2 m). In the same study of the Williams River discussed above, Brooks et al. (2004) noted a net gain of 52 yd^3 (40 m^3) of sediment storage per 10,764 ft^2 (1,000 m^2) of channel area in the treatment reach; during the same period, the control reach experienced a net loss of 529 ft^3/10,764 ft^2 (15 m^3/1,000 m^2). A parallel fish study in the same reaches indicated that fish abundance and diversity increased in the restored channel. Other studies have also shown that channels with LWD retain more bedload (Faustini and Jones

2003) and particulate organic matter (POM) (Cordova et al. 2007; Diez et al. 2000), than similar reaches without wood. In degraded and incised systems, channel aggradation will be beneficial to HCP species and must be taken into account when assessing potential impacts.

It should be noted that some studies have indicated that LWD additions in high gradient (Hilderbrand et al. 1997; Martin 2001) and low gradient (Beechie and Sibley 1997) systems do not affect channel geometry and sediment transport as much as wood in mid-order alluvial reaches. This is due to the fact that bed rock controls in high gradient reaches have the potential to dominate channel forming processes, while in low gradient reaches channel spanning jams are rare and thus wood influence on base-level (or the local gradient at which water will flow) is reduced. Consequently, to increase the likelihood of restoration success, LWD addition projects should focus on middle watershed reaches.

Wood removal will have the greatest impact when key members are extracted from the channel. Removal of these key members will be associated with the destabilization of alluvium impounded behind the extracted LWD and a subsequent increase in suspended sediment and bed load transport (Diez et al. 2000; Faustini and Jones 2003; Smith et al. 1993). This process will occur until the channel has reached a new dynamic equilibrium. Depending upon the presence and distribution of other geomorphic controls present within the reach (e.g., bedrock, glacial erratics, colluvium), the resultant channel form will likely be characterized by fewer pools, less habitat complexity, less cover, and a lowered base-level.

LWD presence can also create flow diversions which will add to channel complexity (Kail 2003) and help to reactivate abandoned side channels (Abbe and Montgomery 2003; Gurnell and Petts 2006). Side channel habitat provides low energy refugia for fishes and is largely viewed as a net benefit to stream organisms (Jungwirth et al. 1993). Side channels are generally narrower than mainstem channels and thus are closely linked with adjacent riparian environments. Increased bank area increases the opportunity for wood recruitment (Bragg and Kershner 2004). In this way, LWD additions which promote channel bifurcation will act as a catalyst for further wood recruitment. Conversely, LWD removal will result in increased channel velocities (Ensign and Doyle 2005) which will be associated with increased scour (Diez et al. 2000), and consequently the potential abandonment of side channels (Erskine and Webb 2003).

7.2.1.2.2 Altered Bank and Shoreline Stability

By redirecting water flow, LWD has both positive and negative impacts on channel bank stability (Keller and Swanson 1979). Bank stability and lateral channel migration can be influenced by LWD accumulations. Channel avulsion induced by LWD will result in localized bank instability as a new channel is cut around the logjam. These dynamics are however, on the whole, balanced by the stabilizing forces of LWD within the floodplain corridor (Naiman 1992). As discussed above, LWD increases channel roughness, slows stream velocities, raises local base-level, and contributes to channel aggradation. All these processes will lead to increased bank stability. Large woody debris is increasingly used in the construction of instream structures designed for purposes of enhancing aquatic habitat and protecting property and infrastructure from the threat of bank erosion. Stable instream structures perform these functions primarily through the addition of form roughness and the deflection of flow.

Large woody debris also provides structure for lake and marine shorelines but there is little research which has quantified the impact of LWD addition or removal to shoreline stability in these environments (Brennan and Culverwell 2004). Consequently, this stands as a data gap.

7.2.1.3 Ecosystem Fragmentation

The addition of wood to a channel will, depending upon the size, quantity, orientation, and channel dimensions, create a complex depositional environment. Studies by Stewart and Martin (2005) and Baillie and Davies (2002) have shown that LWD promotes in-channel sediment storage as the logs deflect flow and increase channel roughness. Large woody debris promotes heterogeneity in channel form by creating flow divergence and changing local base-level (Latterell et al. 2006). These processes lead to sediment deposition in both upstream pools and downstream eddies (Beechie and Sibley 1997). Both flow diversion and base-level increase will lead to increased floodplain connection and side channel activation/formation (lateral connectivity). Additionally, complex flow patterns will lead to increased flow through gravel bars, channel embankments, and riffles (vertical connectivity). LWD removal adversely affects ecosystem connectivity in the fluvial environment by reversing these effects. LWD removal has been shown to promote scour (Diez et al. 2000) leading to a drop in water surface elevation and lateral disconnection. LWD removal will also reduce flow resistance and simplify flow paths (Curran and Wohl 2003) which could lead to reduced hyporheic exchange. The combination of these processes could drastically alter channel evolution and resource patch dynamics by locally “fixing” the channel in an incised reach. This would result in a lost opportunity for channel evolution and the associated creation and abandonment of vital side-channel habitat (WDFW 2003). This section addresses how the placement and removal of LWD can lead to altered vertical and lateral connectivity and how this may impact local aquatic organisms.

There has been little research on the importance of wood in supporting beach structure and connectivity between estuarine environments. However, many shorelines in the Puget Sound area contain considerable wracked wood in the supertidal zone (Sobocinski 2003) which may serve to reduce shoreline erosion and protect the sediments which are the foundation for the shallow water environment. LWD accumulations on beaches have been anecdotally correlated with increased distribution and suitability of spawning substrate for forage fishes (Herrera 2005), suggesting that the effects of LWD on sediment transport and distribution are meaningful from an ecological perspective. Because there is no available literature documenting the role that wood plays in shoreline structure, this stands as a data gap in the literature.

7.2.1.3.1 Altered Groundwater-Surface Water Interactions

The presence of large woody debris in channels has been linked to increased hyporheic exchange (Mutz and Rohde 2003). LWD causes flow separation (Abbe and Montgomery 1996), of which a part may be directed into the bed and banks of the channel. The addition of LWD to channels has been shown in most cases to increase channel complexity. While a study by Sweka and

Hartman (2006) found that large woody debris additions to eight Appalachian streams did not increase pool area, a number of other studies have shown that LWD presence increases pool frequency (Baillie and Davies 2002; Beechie and Sibley 1997) and area (Brooks et al. 2004; Cederholm et al. 1997; Hilderbrand et al. 1997). Increased pool density will be accompanied by an increase in pool-riffle transition zones. These areas are “hot-spots” of hyporheic exchange because head differential through the transition zone forces surface waters through the stream bed (Tonina and Buffington 2007). Consequently, through pool creation, LWD additions can increase hyporheic exchange rates. Conversely, the removal of LWD will decrease pool density (Ensign and Doyle 2005), act as a catalyst for incision (Diez et al. 2000), and thus reduce hyporheic exchange throughout the channel.

Increased vertical exchange between surface and subsurface waters will benefit aquatic biota by increasing benthic dissolved oxygen levels and promoting solute uptake, filtration, and transformation. Studies have shown that the availability of dissolved oxygen to incubating salmonid embryos is dependent upon hyporheic exchange (Geist 2000; Greig et al. 2007) and that the occlusion of this exchange through siltation can lead to hypoxia within redds and decreased embryo survival (Heywood and Walling 2007). The hyporheic zone does more than promote oxygen exchange in subsurface sediments, it can also act as an effective filter and zone of biogeochemical transformations. Increased hyporheic exchange has been associated with nutrient uptake (Anbutsu et al. 2006; Sheibley et al. 2003) and transformation (Fernald et al. 2006; Lefebvre et al. 2005), and may attenuate the transport of dissolved and particulate metals (Gandy et al. 2007). Elevated metals and nutrients can both have negative ramifications for fish and invertebrate health (see Section 7.10 [*Discussion of Common Stressors*]). Consequently, any activity which impacts the functioning of the hyporheic zone, such as the removal of LWD, could impose an array of stressors on HCP species occurring in the affected environment through a number of related impact mechanisms.

7.2.1.3.2 Altered Terrestrial/Aquatic Connectivity

The presence of LWD within channels has been shown to promote floodplain connection during storm flow conditions by increasing flow resistance within the channel (Dudley et al. 1998). Increased channel roughness promotes backwater conditions which locally connect floodplain and channel habitat. As addressed previously, LWD also promotes floodplain connectivity by diverting flow into side channels (Abbe and Montgomery 1996). Floodplains have been shown to act as nutrient sinks and carbon sources for adjacent channels (Tockner et al. 1999; Valett et al. 2005). Consequently, LWD-induced floodplain-channel connection is expected to augment allochthonous carbon budgets in restored channels and likewise LWD removal and the associated disconnection with floodplain habitat is expected to decrease allochthonous carbon inputs and the storage and cycling of nutrient inputs to the stream channel.

Floodplain connectivity also creates fish forage and refuge habitat. Chinook which rear in connected floodplain habitats have been shown to grow faster than those which rear in adjacent channels (Sommer et al. 2001). Additionally, in a 2004 study of the Sacramento splittail (Ribeiro et al. 2004), it was shown that fishes which reared in floodplain habitat had higher condition and length increment. Because LWD increases the abundance of and access to floodplain habitat (Young 1991), the addition of LWD to a channel will promote floodplain-channel resource exchange and habitat accessibility. These improved conditions will in turn be beneficial to HCP species that occur in riverine environments affected by LWD, especially those which favor floodplain habitat (e.g. coho, sockeye, and Chinook salmon). Conversely, the removal of LWD may limit access to floodplain habitat and impact those species which utilize these areas for foraging, rearing, and refuge.

7.2.1.3.3 Altered Habitat Complexity

Large woody debris addition creates habitat complexity through two primary mechanisms. First, the wood itself provides cover and creates local scour pool habitat and promotes the accumulation of a diverse distribution of substrate types. Second, wood in channels will promote lateral and vertical energy transfer, connecting side channel and floodplain habitat to the mainstem, thus altering the composition and/or abundance of accessible food sources for HCP species and create more accessible habitat for foraging and rearing. The previous sections dealt with the impact of LWD on vertical and lateral connectivity, this section addresses how LWD creates and modifies in-channel habitat.

The presence of LWD within channels creates locally complex geomorphic features, including scour pools and depositional bars. Depending upon channel form, wood size, and orientation LWD-induced pools and bars can occur upstream, downstream, and/or lateral to wood structures. Fish utilize these complex environments and the structure of the LWD itself for cover and refuge (Cederholm et al. 1997; Everett and Ruiz 1993; Harvey et al. 1999). In a study of Smith Creek in northwest California, Harvey et al. (1999) found that tagged adult coastal cutthroat trout moved more frequently from pools without LWD than from pools with LWD. They hypothesized that the habitat created by LWD attracts fish and once fish establish territory within the desirable habitat they remain there longer. A study by Cederholm et al. (1997) on a tributary of the Chehalis River found that LWD additions caused an increase in winter populations of juvenile coho salmon and age-0 steelhead populations. It should be noted that Fauch et al. (1995) and others have criticized studies such as Harvey et al. (1999) because it is difficult to determine if increased abundance in treatment sites is due to increased populations or just concentration of fishes which would have thrived equally well in other habitat. Regardless, removal of LWD would reduce instream habitat for which fishes show a preference.

Woody debris along lakeshores provides important habitat for prey species (Sass et al. 2006) and invertebrate populations (Bowen et al. 1998). In a study of the effects of woody debris on the aquatic food web of Little Rock Lake, Wisconsin, Sass et al. (2006) removed more than 75 percent of the woody debris from a treatment section of the lake. They found that within the treatment section, increased largemouth bass predation caused a decrease in yellow perch abundance; subsequently, bass diets shifted to terrestrial prey and bass growth rates decreased. This study clearly indicates that the cover provided by woody debris plays an important role in lacustrine food webs and that alterations to this habitat will impact resident aquatic species.

LWD itself can serve as a substrate for algal growth and macroinvertebrate substrate habitat (Bowen et al. 1998). In the Ohe River, Germany, Hoffman (2000) showed a intimate connection between all lifestages of the lepidostomatid caddisfly, *Lasiocephala basalis* and LWD. Meanwhile, Hilderbrand et al. (1997) noted no change in macroinvertebrate populations following a wood addition experiment in Virginia, and Spanhoff et al. (2006) noted a net negative impact of wood addition on stream macroinvertebrates. Despite these findings, other studies have shown that wood in channels and on shorelines can serve as a substrate for both periphyton growth (Bowen et al. 1998) and macroinvertebrate habitat (Rolauffs et al. 2001; Warmke and Hering 2000).

7.2.1.4 Aquatic Vegetation Modifications

7.2.1.4.1 Altered Autochthonous Production

Large woody debris acts as a substrate for periphyton growth and secondary production in channels (Atilla et al. 2003; Bowen et al. 1998; Hoffmann 2000; Warmke and Hering 2000) and lakes (Smokorowski et al. 2006), but few studies have shown that the addition of this substrate increases primary productivity in the system as a whole [see (Atilla et al. 2003)] for an exception in marine systems). However, as addressed above, LWD can function to induce floodplain and backwater connection with the main channel. By creating more connectivity with productive backwaters, the presence of wood within the channel can increase aquatic productivity and access to aquatic vegetation. Consequently, LWD removal will be associated with a decrease in access to these productive areas.

There have been few studies of the influence of LWD in marine environments. Depositional coastal areas throughout Washington are replete with large and small wood. Much of this wood has originated from forest harvesting practices from the turn-of-the-century. Therefore, it is difficult to determine a “natural” concentration of LWD for coastal areas. It is generally thought that small quantities of LWD can increase nearshore habitat quality; however, no significant research has been conducted to verify this hypothesis. Maclennan (2005) studied wood dynamics in two sites in Washington: Elger Bay on Camano Island, and Sullivan-Minor marsh in Padilla Bay. She noted that drift logs, or LWD, tend to accumulate in the upper portions of the intertidal zone and that the wracked pieces in the seaward sections of the estuaries became mobilized during storms and high tides. The mobile logs raked the surface of the marsh and prevented the establishment of emergent vegetation. Meanwhile, stable logs in the higher elevation sections of the estuaries acted as substrate for upland vegetation which could not have otherwise become established (Maclennan 2005). Other studies have shown that these stable logs can act as habitat for macroinvertebrates including grass shrimp (Everett and Ruiz 1993), chironomids, other dipterans, talitrids, homopterans, coleopterans, and collembolans and that beaches with abundant wrack have higher taxa richness than equivalent artificially hardened beaches (Sobocinski 2003). Outside of these few studies, little research has measured the ecological importance of LWD for the formation and persistence of marine aquatic vegetation communities.

7.2.1.5 Riparian Vegetation Modifications

7.2.1.5.1 Altered Allochthonous Input

As noted previously, LWD promotes river-floodplain connectivity and thus the export of coarse particulate organic matter (CPOM) to the channel (Junk et al. 1989; Tockner et al. 1999). Floodplains have been shown to produce nutrient-rich organic matter (i.e., more live algae than decaying organic matter) which can serve as an import food resource for zooplankton (Muller-Solger et al. 2002; Schemel et al. 2004) and thus bolster aquatic food webs. The literature indicates that any activity which promotes the reconnection of once severed floodplain-channel pathways can be expected to have a net benefit for aquatic organisms (Crain et al. 2004; Schemel et al. 2004; Tockner et al. 1999). This is partially due to the fact that floodplains are vital for the transfer of energy (in the form of carbon) from terrestrial ecosystems to aquatic, especially in lowland river systems (Junk et al. 1989; Thoms 2003).

In lacustrine and marine environments, LWD may not influence terrestrial-aquatic connectivity the way it does in fluvial environments. Consequently, allochthonous inputs may not be affected by LWD presence or removal. However, it should be noted that in many mountain lakes, logjams form at the lake outlet. If these jams were removed, the lake level would likely drop and aquatic-terrestrial connectivity would be weakened.

7.2.1.6 Water Quality Modifications

7.2.1.6.1 Altered Suspended Solids

LWD placement, movement, and removal will all be associated with construction-related sediment releases. These releases will, in general, be more acute for movement and removal projects than for placement projects, but removal projects will have a continuing negative impact on suspended solids concentrations while movement and placement projects will reduce suspended solids concentrations in the long-term.

Through bank protection (Angradi et al. 2004), increased hyporheic flow (Mutz and Rohde 2003), and increased sedimentation in the channel (Gomi et al. 2001) and adjacent floodplain (Brunet et al. 1994), suspended solids concentrations may be reduced by the placement of LWD within the channel. There have been no studies which have directly measured the effect of LWD on suspended solids partly because of the difficulty of attributing variability in suspended solids concentrations to one facet of the watershed ecosystem. However, studies have indicated an increased deposition of fines associated with LWD (Gomi et al. 2001; Wallace et al. 2000; Wallace et al. 2001); thus, a decrease in suspended solids can be inferred.

LWD removal would have the opposite effect of LWD addition. Increased channel velocities (Curran and Wohl 2003; Ensign and Doyle 2005), would entrain more sediment and increase suspended solids concentrations, while reduced hyporheic exchange and depositional area would further contribute to elevated suspend solids. Additionally, LWD removal may destabilize banks (Diez et al. 2000) and thus increase source areas for suspended solids. This increase in suspended solids may impact HCP species which are sensitive to elevated suspended solids.

(See Section 7.10 [*Discussion of Common Stressors*] for a general discussion of the impacts of suspended solids on HCP species.)

7.2.1.6.2 Altered Pollutant Loading

Large woody debris presence within streams increases channel roughness and complexity and consequently increases transient storage. Increased transient storage will likely increase nutrient uptake (Bukaveckas 2007; Ensign and Doyle 2005; Roberts et al. 2007; Valett et al. 2002) and sedimentation (Worman 1998). The retention of coarse particulate organic matter (CPOM) has been correlated with LWD presence in numerous systems. Jacobson et al. (1999) found that LWD trapped sediment and CPOM which was then incorporated into the benthic biomass, creating islands of organic matter in the channel that became focal points for decomposition and secondary production. This increase in biologic activity would likely be accompanied by an increase in pollutant and nutrient processing.

Water retention from LWD and the presence of CPOM in the channel plays an important role in the fate of nutrients in the stream channel. In a classic study by Mulholland et al. (1985) it was suggested that leaf litter in streams promotes nutrient retention as the leaf pack acts as a substrate for nutrient-hungry microbes. Using solute injection techniques Valett et al. (2002) found that phosphorus uptake in channels with high LWD volumes, frequent debris dams, and fine grained sediments was significantly greater than in channels in younger forests without these characteristics. Corroborating this finding, Ensign and Doyle (2005) conducted phosphorus injections in streams both before and after the removal of LWD and CPOM in the channels and found that phosphate uptake decreased by up to 88 percent after LWD removal. These studies show that LWD increases water retention and thereby contributes to higher nutrient retention in streams that have large volumes of LWD. It follows that LWD removal would have a negative impact on nutrient processing and contribute to eutrophication in nutrient impaired systems. Eutrophication can lead to decreased dissolved oxygen levels which may impact HCP species. (See Section 7.10 [*Discussion of Common Stressors*] for a general discussion of the effect of low dissolved oxygen on fish and invertebrates.)

Marine and lacustrine waters are considered receiving waters and consequently there is limited transient processing of pollutants in these systems. Instead, pollutants are internally cycled within the water bodies until pollutants are metabolized, sequestered, or exported. No research to date has measured the effect of LWD on these internal cycling processes.

7.2.1.6.3 Altered Dissolved Oxygen

As mentioned above, LWD placement will increase nutrient retention, while LWD removal will increase nutrient export. Increased nutrient loading to downstream areas can contribute to eutrophication. Eutrophication is characterized by elevated carbon fixation, and this excess carbon in the aquatic system contributes to elevated levels of respiration. In waters with minimal physical mixing, oxygen consumed through respiration is not readily replaced with oxygen from the atmosphere. The result is a decrease in ambient dissolved oxygen levels which could constitute a stressor for HCP species. (See Section 7.10 [*Discussion of Common Stressors*] for a general discussion of the effect of low dissolved oxygen on fish and invertebrates.)

7.2.2 Summary of Impact on Aquatic Fauna

This section summarizes the current knowledge concerning the impact of large woody debris additions and removal on the 52 HCP species. There has been considerably more research on the impacts of LWD on freshwater organisms; thus, impacts on marine species will be brief and are addressed in Section 10 (*Data Gaps*).

7.2.2.1 Impact on Fishes

There have been a number of studies which have attempted to measure the effects of LWD additions on fish and invertebrate populations. Although the majority of the studies have noted positive results (Brooks et al. 2004; Cederholm et al. 1997; Flebbe 1999; Harvey et al. 1999; Mossop and Bradford 2004; Roni and Quinn 2001), there are a few studies which have concluded that LWD additions do not significantly improve stream conditions. For example, in a study of six Puget Sound lowland streams, Larson et al. (2001) noted only moderate geomorphic response to LWD additions and no significant biological response. Likewise, Chapman (1996) found that numerous structural manipulations in the Columbia River Basin, including LWD addition, did not improve fish production. Meanwhile, Brooks et al. (2004) noted an increase in fish species richness and abundance following the construction of 20 engineered logjams along a 0.7-mile (1.1 km) reach of the Williams River (New South Wales, Australia). And, in a local study on a tributary of the Chehalis River, Cederholm et al. (1997) found that LWD additions caused an increase in winter populations of juvenile coho salmon and age-0 steelhead populations. These conflicting results are due to the many variables involved in experimental design and fish population dynamics. Prominently, variance in interannual abundance caused by factors occurring beyond the scale of the affected reach is difficult to account for in focused reach-scale studies. Additionally, it is difficult to attribute fish abundance at a restored site to increased production because the fishes may just be concentrating at the site from elsewhere in the channel.

It has been suggested that monitoring of restoration activities may take 10 or more years to detect less than a two-fold increase in fish abundance (Korman and Higgins 1997). Roni et al. (2002) purport that monitoring, as it is currently conducted, is not rigorous enough to detect the ecological response to channel restoration. Obviously, it is a difficult task and the lack of consistent results in the literature suggests this. However, unmanaged environments inhabited by many of the HCP species are characterized by abundant LWD, and the literature regarding the influence of LWD on ecological processes in these systems is conclusive. This suggests that the role these features play is important to the ecological health of the HCP species occurring in these environment types. Further, the literature clearly indicates that there are distinct abiotic responses to LWD additions. If these abiotic responses are used as a proxy for restoration success, then we can assume that the majority of the wood additions approved under this subactivity type will be a net benefit to fishes. These benefits will, of course, be site specific and must be weighed against the impacts incurred from construction activities (i.e., increased suspended solids, increased noise, fish handling, and exclusion). For a more general discussion of the stressors which are the end result of construction-related activities see Section 7.10 (*Discussion of Common Stressors*).

The primary construction activity impact which will affect the HCP fish species is bank and channel disturbance caused by the operation of heavy machinery and/or the placement of logs. This disturbance will be weighed against the ecological benefits provided by wood additions when the potential risk of take is assessed in Section 9 (*Potential Risk of Take*).

Mixed results concerning LWD removal impact on fishes have also been reported. Two classic studies which spurred LWD additions beginning in the late 1980s indicated that LWD removal negatively impacted coho salmon and Dolly Varden populations in SE Alaskan streams (Dolloff 1986; Elliott 1986). However, these effects may be site specific and depend upon stream gradient. Warren and Kraft (2003) noted that in an upstate New York stream, LWD removal did not impact trout populations in 1st or 3rd order reaches, but that populations did decrease in the "cleaned" 2nd order stream. LWD removal will have the greatest impact on biota in reaches where the wood has the strongest influence on channel form; research has indicated that this is the middle reaches within a watershed (Beechie and Sibley 1997; Hilderbrand et al. 1997). In summary, LWD removal may affect fish species through the following stressors:

- Loss of instream habitat/cover (increased predation, decreased refuge)
- Increased suspended solids
- Reduced access to off-channel habitat (reduced foraging and refuge).

7.2.2.2 Impact on Invertebrates

As presented in this section, LWD is a stabilizing force in stream channels and thus it can be inferred that LWD additions would benefit the California floater mussel, an organism which requires a stable substrate (WDNR 2006b). Both the California floater and Western ridged mussel have parasitic larval stages which rely on fish gills for gestation and distribution (WDNR 2006b). Consequently, any activity which increases fish abundance may also benefit these invertebrates, while actions that decrease the productivity and abundance of a host fish would be viewed as detrimental. Finally, the California floater and the Great Columbia River spire snail both require clear, well-oxygenated water. LWD additions in degraded channels may be able to induce clear, well-oxygenated waters by contributing to sediment retention and creating localized hydraulic jumps. It can be inferred that LWD removal in areas occupied by these species will be associated with potential adverse impacts on HCP species.

There is no research which has directly measured the impact of LWD additions on any of the HCP invertebrate species. Therefore, potential adverse impacts on HCP invertebrate species associated with this subactivity type must be estimated from the current understanding of preferred habitat and LWD influence on those habitats. The adverse impacts on invertebrates associated with LWD addition will be site specific and must be accounted for along with the impacts incurred from construction activities (i.e., increased suspended solids, increased noise).

LWD removal will have negative impacts on invertebrate species during the construction phase and subsequent to removal. LWD removal may affect invertebrate species through the following stressors:

- Entrainment
- Burial
- Increased suspended solids.

Refer to Section 7.10 (*Discussion of Common Stressors*) for a discussion of research which has specifically addressed the effect of these stressors on invertebrates.

7.3 Spawning Substrate Augmentation

Gravel augmentation for the purpose of spawning habitat improvement has been promoted episodically by various government agencies since the 1960s (Bunte 2004). Since the 1990s, spawning substrate augmentation has become an increasingly popular restoration activity, yet there is little research concerning its ecological ramifications. This section addresses the possible impact mechanisms associated with substrate augmentation but, because the literature is so sparse, many data gaps exist. Spawning substrate augmentation in lacustrine and marine settings is addressed in the beach nourishment/contouring section (Section 7.7 [*Beach Nourishment*]).

7.3.1 Impact Mechanisms

7.3.1.1 Construction Activities

The impact mechanisms associated with construction activities will vary depending on the technique used to place the gravel. The two most common techniques are direct placement of the gravel on the channel bed and passive augmentation (Bunte 2004). The impacts associated with each of these techniques will vary and are discussed below.

7.3.1.1.1 Equipment Operation

Direct gravel placement will involve the use of machinery within the channel and consequently the chance of oil and metals contamination is increased and noise levels may impact aquatic fauna. Passive gravel placement involves the dumping of gravels from a stream bank (Bunte 2004). This technique keeps machinery out of the channel so the chance of contamination will be reduced. Noise levels from the dumping of gravel from high banks however, could impact local aquatic species. The available literature on underwater noise levels associated with this particular activity is limited (as most research has focused on noise sources such as underwater tool use, pile driving, and vessel noise). Therefore, while some general conclusions can be drawn regarding noise and disturbance, the specific effects of noise resulting from this activity are a data gap. For a discussion of the impacts of elevated noise on fish and invertebrates, see Section 7.10 (*Discussion of Common Stressors*).

7.3.1.1.2 Bank, Channel, and Shoreline Disturbance

There is significant benthic disturbance when spawning gravels are placed on the channel bed. Machinery must enter the channel and deposit gravel in various locations. This process involves front-end loaders, excavators, and/or bull dozers repeatedly entering and exiting the channel, usually along a constructed gravel ramp (Bunte 2004). Despite the potential disturbance caused by this activity, research has indicated that benthic invertebrates can recover within 4 weeks (Merz and Chan 2005) of final gravel placement. There has been no research on the impacts of passive gavel placement on bank stability at the augmentation site, but the gravel would most likely armor the bank until the majority of it was mobilized. A discussion of the impact associated with bank armoring is provided in the Channel Modifications white paper.

The placement of gravel within the channel will result in increased suspended solids, both from bank and bed disturbance and from fines associated with the enhanced gravels. This sediment pulse will be short lived (during construction) but may be detrimental to sensitive species. A discussion of the effects of elevated suspended solids on fish and invertebrates is provided in Section 7.10 (*Discussion of Common Stressors*).

7.3.1.2 Geomorphic and Hydraulic Modifications

7.3.1.2.1 Altered Channel Geometry

Gravel augmentation often occurs below dams in sediment starved reaches that have been fragmented from sediment sources in upstream reaches by the interruption of sediment transport. Regulated flows in these reaches may also cause increased scour and removal of existing substrates, leading to channel degradation and changes in substrate composition. Some past augmentations have failed because the practitioners did not correctly account for the shear stresses associated with the tailrace flows and the added gravel was transported out of the augmentation site (Kondolf et al. 1996). Assuming that the project is properly conceived, augmented gravels will remain stable for some time and effectively raise the channel bed elevation (especially if continued passive augmentation is practiced). This aggradation could, in theory, increase river-floodplain connectivity but there is no published evidence of this.

Expected outcomes of gravel augmentation on channel geometry include particle sorting that creates diverse substrate patches, creation of exposed bars (Mesick 2002), increased hydraulic complexity and shear zones, and creation of backwaters and other complex alluvial features (Pasternack et al. 2004). These morphologic changes should increase aquatic and terrestrial habitat quality, quantity, and diversity (Bunte 2004). However, there is some concern that gravel augmentation efforts may cause detrimental changes to channel morphology under a regulated flow regime. These impacts could include reductions in channel width (Miller and Benda 2000), pool filling (Madej and Ozaki 1996), and channel migration (Miller and Benda 2000), due to inadequate transport and routing of these added coarse sediments. A study of a debris flow in

Redwood Creek, California by Madej and Ozaki (1996) indicated that sediment influx can fill downstream pools for a number of years until the sediment wave has passed. Another study of a sediment release from a dam indicated that the majority of deposition occurred in pools, but again the deposition was temporary (Wohl and Cenderelli 2000). If discharge moving into the rehabilitated reach is regulated in a manner where no flushing flows occur, sediment may deposit in pools but never flush out. Obviously, filling of pools will eliminate spawning, rearing, and/or foraging habitat for a variety of species.

Outside of pool filling, the geomorphic ramifications of spawning substrate augmentation are primarily beneficial to aquatic organisms. The potential adverse impacts associated with this impact mechanism will be dependent upon the project. If proper geomorphic analysis has been conducted and gravels of the proper size are augmented in the proper locations, the augmentation will have positive geomorphic results. If these measures are not taken, the project may either fail through mass export of the gravel (Kondolf et al. 1996) or through downstream pool habitat degradation.

7.3.1.2.2 Altered Bank and Shoreline Stability

Gravel augmentation can temporarily reduce bank instability by raising the channel bed elevation. Although there have been no studies that have addressed this process, standard geomorphic models of incision and widening (Schumm et al. 1984) indicate that incised channels induce bank instability. It would follow that channel aggradation will stabilize banks. Increased bank stability will reduce sediment import into the channel and reduce subsequent spawning gravel sedimentation and organism burial. Consequently, increased bank stability is an impact mechanism which will have positive consequences for HCP species.

7.3.1.2.3 Altered Substrate Composition

Spawning substrate augmentation will in most cases induce substrate fining and increase permeability. Substrate augmentations are conducted in degraded channel reaches where substrate is not suitable for spawning due to armoring (Pasternack et al. 2004) and/or coarsening (Mesick 2002). The addition of clean gravel to a reach will create a permeable benthos with high dissolved oxygen levels relative to pre-rehabilitation conditions. Merz and Setka (2004) measured intergravel permeability and dissolved oxygen in enhanced and unenhanced reaches on the Mokelumne River below Camanche Dam, California and found that enhanced reaches had significantly higher permeability and dissolved oxygen levels. At 17.7-in (45 cm) depth, permeability in the enhanced reach was 1.6 in^3/s (26.4 mL/s) versus 0.21 in^3/s (3.48 mL/s) in the unenhanced reach; likewise, dissolved oxygen levels at 17.7-in (45 cm) depth averaged 7.2 ppm versus 6.6 ppm at the enhanced and unenhanced sites, respectively. This study, one of the few that have measured intergravel conditions at a gravel augmentation site, indicates that gravel augmentation will increase the habitat quality of the channel substrate. Organisms which require elevated benthic dissolved oxygen levels will benefit from properly designed and constructed gravel augmentations. These species include all the gravel spawners and all the freshwater invertebrates except the Western ridged mussel which can tolerate siltation and related low dissolved oxygen (WDNR 2006b).

7.3.1.3 Ecosystem Fragmentation

Spawning substrate augmentation leads to the creation of suitable spawning habitat. Suitable habitat has a variety of characteristics including, desirable depths and velocities, and a high rate of hyporheic exchange. An ancillary benefit of gravel augmentation is that connectivity with adjacent floodplain environments may be increased with an associated increase in bed elevation. This section addresses the vertical and lateral connectivity benefits provided by spawning substrate augmentation projects.

7.3.1.3.1 Altered Groundwater-Surface Water Interactions

The primary goal of gravel augmentation is to create suitable spawning habitat both in terms of depth and velocity as well as hyporheic exchange through the gravels. Hyporheic exchange brings oxygen-rich waters into the gravels which promotes spawner embryo survival (Heywood and Walling 2007). Spawning chum and Chinook salmon have been found to preferentially select spawning sites where water is either upwelling or downwelling (Geist et al. 2002) and where benthic dissolved oxygen is elevated (Geist 2000). Also, bull trout redd distribution and abundance have been found to be influenced by hyporheic and groundwater-surface water exchange (Baxter and Hauer 2000). This indicates that fish select for areas with high hyporheic exchange (Mull 2005). Gravel augmentation has been shown to increase hyporheic exchange (Merz and Setka 2004), and this helps to explain why fish are attracted to augmentation sites (Merz and Setka 2004; Mesick 2002).

An active hyporheos not only provides biogeochemical benefits to fish but also to macroinvertebrates. In a study of a gravel augmentation on the Mokelumne River, California, the standing crop, as measured by macroinvertebrate densities and dry biomass, was significantly higher in enhancement sites 12 weeks after augmentation than in unenhanced sites and remained so over the following 10 weeks (Merz and Chan 2005). Thus, it would appear that augmentation may not only provide spawning habitat but also food resources for emerging fry.

7.3.1.3.2 Altered Terrestrial/Aquatic Connectivity

Although the goal of spawning gravel enhancement is to improve benthic habitat, an ancillary benefit may be increased lateral connectivity with adjacent floodplains. Miller and Benda (2000) monitored debris flow sediment wave propagation in the South Fork of Gate Creek, Oregon and found that sediments cause vertical accretion of the valley floor due to increased overbank flooding depositing material across the floodplain. Gravel augmentation will be on a much smaller scale than a debris flow but the same processes may be applicable. Depending upon channel geometry and volume of gravel introduced into the channel, this positive ramification of gravel enhancement may be realized.

Floodplains have been shown to act as nutrient sinks and carbon sources for adjacent channels (Tockner et al. 1999; Valett et al. 2005). Consequently, spawning substrate augmentation may increase allochthonous carbon budgets in restored channels. Floodplain connectivity also creates fish forage and refuge habitat. Chinook which rear on floodplains have been shown to grow faster than those which rear in adjacent channels (Sommer et al. 2001). Gravel augmentation below dams could be combined with flow management to induce periodic floodplain connection.

7.3.1.4 Aquatic Vegetation Modifications

7.3.1.4.1 Altered Autochthonous Production

Aquatic vegetation will initially be destroyed in areas where gravel is placed. But, research has shown that this vegetation recovers quickly (Merz et al. 2004). Many augmentations occur below dams. Dams with hypolimnetic release points can elevate growing-season nutrient concentrations in downstream reaches (Ahearn et al. 2005). Elevated nutrient levels during the growing season will accelerate primary production and post-project vegetation recovery. Consequently, initial impacts on aquatic vegetation may only be ephemeral and thus the associated impact on HCP species will be minimal.

7.3.1.5 Water Quality Modifications

7.3.1.5.1 Altered Suspended Solids

Gravel placement will increase suspended solids during the construction phase through bank and channel bed disturbance and through the wash-off of any fines associated with the gravels. This impact will only occur during the construction phase so increased suspended solids are not expected to be a primary impact mechanism. After the construction phase, the presence of gravel within the channel will likely reduce suspended solids concentration though bank protection and filtration through the hyporheic zone. However, because the majority of gravel augmentations occur below dams, suspended solids levels will likely not be elevated to levels which may harm fish or invertebrates. Dams tend to buffer variations in suspended solids concentrations relative to upstream conditions (Stanford and Ward 2001). Consequently, downstream reaches receive primarily waters with low concentrations of suspended solids. Given these factors, variability in suspended solids will not serve as an important impact mechanism for this subactivity type.

7.3.1.5.2 Altered Dissolved Oxygen

The small amount of research which has been conducted concerning benthic dissolved oxygen levels and gravel augmentation indicates that spawning substrate augmentation will lead to increased intergravel oxygenation (Merz and Setka 2004; Merz et al. 2004). Some studies have shown that salmon preferentially choose nesting sites with elevated benthic dissolved oxygen levels (Geist 2000) or elevated hyporheic exchange (Mull 2005). Elevated benthic dissolved oxygen concentration has been correlated with increase embryo survival (Heywood and Walling 2007) and consequently this impact mechanism is expected to benefit those species that select gravel augmentation sites in which to spawn. Likewise benthic invertebrates which require elevated dissolved oxygen concentrations may benefit from gravel augmentations.

7.3.1.5.3 Altered Pollutant Loading

Bacteria, periphyton, and fungi within an active benthic zone will result in an increase in solute uptake, transformation, and sequestration. Some studies have shown the hyporheic zone to function as a nitrate sink (Lefebvre et al. 2005; Sheibley et al. 2003) while others have indicated that the hyporheic zone is a source of nitrate (Fernald et al. 2006) and soluble reactive phosphorus (Fernald et al. 2006; Lefebvre et al. 2005). What seems evident from the literature is that the hyporheic zone is a dynamic system with biogeochemical properties that vary from site to site and season to season. Anbutsu et al. (2006) monitored interstitial water nutrient concentrations in a high residence time hyporheic zone and noted that the area was a sink for ammonium, nitrate, and phosphorus. Sheibley et al. (2003) noted that when the groundwater is enriched in ammonium, biogeochemical transformation within the hyporheic zone will convert the ammonium to nitrate and also convert a portion of this nitrate to nitrogen gas. And finally, Lefebrve et al. (2005) noted that organic material decomposition deep within the hyporheic zone can act to release ammonium and soluble reactive phosphorus while periphyton near the surface will retain nitrate. These studies all point toward the fact that the hyporheic zone is an area of active biogeochemical transformation. Gravel augmentation will promote increased hyporheic exchange and thus increase the potential for nutrient retention and cycling within the channel. This in turn may reduce nutrient loading to sensitive downstream receiving waters. The impact of excess nutrients on fish and invertebrates is discussed in Section 7.10 (*Discussion of Common Stressors*).

7.3.2 Summary of Impact on Aquatic Fauna

This section summarizes the current knowledge concerning the impact of gravel augmentation on the HCP species.

7.3.2.1 Impact on Fishes

The majority of the research concerning spawning substrate augmentation has addressed the impact of the activity on redd density. However, due to a number of complicating factors this is not an absolute measure of restoration success, and the literature indicates that the majority of spawning substrate augmentations to date are utilized by salmon for spawning (DWR 2004; Merz and Setka 2004) and in some cases have increased redd density (Mesick 2002; Ziller 2005). Merz (2004) noted that Chinook embryos which were planted in enhanced gravels had a mean survival rate of 29 percent while embryos planted in unenhanced gravels had a 22 percent survival rate. Although this is a modest increase it indicates that gravel augmentations may increase spawner productivity within the restored reach even if redd density does not increase relative to pre-project conditions.

Studies by the California Department of Water Resources (DWR 2004) and Merz and Setka (2004) both indicated that although enhanced gravels were utilized by spawners, redd density did not increase relative to pre-project conditions. In a study of gravel replenishment in the Stanislaus River, California, Mesick (2002) found that the project did not increase redd density one year after gravel augmentation but did the following year (an approximate 30 percent increase). Finally, Ziller (2005) noted that gravel augmentation in the Willamette River, Oregon, was associated with increased bull trout redds. The shortcoming of these studies is that there is no way of measuring if increased redd density in a given year is due to external factors or from the gravel replenishment itself. Consequently, it is difficult to attribute a positive benefit to this activity type. If construction activity impacts are minimized through the application of best management practices – including the use of thoroughly cleaned gravels – then the somewhat uncertain positive benefits provided may be enough to assume a net positive effect on HCP species. However, without further research (especially in Washington State), this can not be assumed with any certainty.

In summary, the primary stressors associated with the construction of spawning substrate augmentation projects are:

- Fish handling/exclusion
- Noise (temporary)
- Elevated suspended solids (temporary).

Section 7.10 (*Discussion of Common Stressors*) presents the research to date concerning the effect of these stressors on fishes. These stressors will lead to adverse impacts on HCP species but must be weighed against the potential benefits of spawning gravel augmentation, including:

- Increased high quality spawning habitat

- Decreased suspended solids through increased bank protection (project dependent)

- Increased foraging and rearing habitat through increased floodplain connection (project dependent)

- Increased pollutant and nutrient retention.

7.3.2.2 Impact on Invertebrates

Spawning substrate augmentation projects are not designed to create habitat for invertebrates but some invertebrates may benefit from these activities. Invertebrates that require elevated benthic oxygen levels will likely benefit from the increased hyporheic exchange which will result from gravel augmentation. These species include the California floater, the Great Columbia River limpet, and the Great Columbia River spire snail (WDNR 2006b). Merz and Chan (2005) monitored macroinvertebrate abundance before and after a gravel enhancement project on the lower Mokelumne River. They noted that species richness recovered within 4 weeks and diversity within 2 weeks of project completion. Also, macroinvertebrate density and dry biomass was significantly higher in enhancement sites after 12 weeks than in unenhanced sites and remained so over the following 10 weeks. As this is the only study of its kind, it is difficult to extrapolate these results to other sites and other species (Merz and Chan did not monitor any of the HCP invertebrate species).

The negative impacts of spawning substrate augmentation are clear. Invertebrates with limited motility will be buried (see Section 7.10 [*Discussion of Common Stressors*] for a discussion of the research concerning invertebrate burial) or crushed by gravel and/or construction equipment. This impact must be weighed against the potential benefits of a more active hyporheic environment but, to date, the benefits of enhanced substrates for invertebrate species remains a data gap.

7.4 In-Channel/Off-Channel Habitat Creation/Modifications

This subactivity type is primarily reserved for projects which result in the creation of either in-channel or off-channel refugia. This subactivity type is broad and many of the activities which are categorized as this subactivity type could also be categorized under other subactivity types. This somewhat complicates the discussion of the research that has been conducted on the ecological implications of this subactivity type. To clarify the discussion, this section addresses those activities that result in the creation of off-channel refugia, including side-channel and slough habitat, and those activities that promote in-channel refugia and complexity. Those activities that entail the placement or movement of LWD are addressed in Section 7.2 (*Large Woody Debris Placement/Movement/Removal*).

7.4.1 Impact Mechanisms

This section presents the research which has been conducted addressing the impact mechanisms associated with in-channel and off-channel habitat modification. Subsequently, Section 7.4.2 (*Summary of Impact on Aquatic Fauna*) addresses those studies which have specifically addressed the impact of this subactivity type on fishes and invertebrates.

7.4.1.1 Construction Activities

Impacts associated with construction activities will be highly dependent on the specific activity. For instance, channel realignment and bank contouring will have a greater impact on channel dwelling organisms than reconnecting an isolated floodplain pond. This section addresses the impact from equipment operation, temporary dewatering, and altered stream bank and shoreline stability.

7.4.1.1.1 Equipment Operation

In general, in-channel work will be associated with a greater risk of adverse impacts than off-channel work. Machinery working within the channel poses a high risk of chemical contamination due to accidental spills or leaks of hydrocarbon fuels, hydraulic fluids, and lubricants. Section 7.10 (*Discussion of Common Stressors*) below addresses the stress on fishes and invertebrates associated with elevated hydrocarbon levels. Machinery induced noise may also be associated with adverse impacts during in-channel habitat modification. Most in-channel habitat modification does not involve pile driving but the movement of boulders and gravel will induce elevated noise which may have sublethal impacts on the local biota. For a discussion of the research related to noise-induced stress in fish and invertebrates see Section 7.10 (*Discussion of Common Stressors*).

7.4.1.1.2 Temporary Exclusion/Dewatering

There will be many instances when in-channel habitat modifications will involve temporary dewatering. A discussion of the stressors associated with dewatering and fish handling is provided in Section 7.10 (*Discussion of Common Stressors*).

7.4.1.1.3 Bank, Channel, and Shoreline Disturbance

Impacts associated with construction activities will vary widely depending on how the work is conducted. The most common method of off-channel habitat rehabilitation is to work in a dry off-channel area and then connect the rehabilitated habitat to the main channel once the work is completed. This approach minimizes work in an active channel and reduces construction-related impacts. In general, in-channel work will have a much greater impact on the bank and channel when compared with off-channel work. Channel realignment and bank regrading will destroy bank and bed habitat in the active channel and will temporarily lead to elevated bed load and suspended sediment concentrations. This may result in the downstream burial of invertebrates, elevated suspended solids, and habitat destruction. Although some studies have indicated that biotic communities recover quickly (i.e., within a few weeks) from these disturbances (Merz and Chan 2005; Tikkanen et al. 1994), other studies have indicated that habitat disturbance from in-channel restoration work can impact biota for several years (Laasonen et al. 1998; Frissell and Nawa 1992). This is primarily the result of projects that were incorrectly designed and resulted in structural failures, an outcome that is all too common in channel restoration work (Babcock 1986; Frissell and Nawa 1992). The potential for project failure must be assessed when risk of take is being estimated for a proposed and project, as discussed in more detail in Section 9 (*Potential Risk of Take*).

7.4.1.2 Geomorphic and Hydraulic Modifications

In channel and off-channel habitat modification has the potential to profoundly affect channel form and hydraulics. This section identifies the research that has monitored the effect of these activities on fluvial geomorphology and hydraulics.

7.4.1.2.1 Altered Channel Geometry

The creation of off-channel habitat will affect channel geometry through two primary mechanisms. Side channel creation will produce a more complex braided system with increased wetted perimeter and bank habitat and off-channel pools, depressions, and channels will increase the flood capacity of the river-floodplain systems and thus decrease peak flows. This will, in turn, reduce shear stresses and limit channel incision. Incision can lead to a reduction in gravel bar habitat, abandonment of side channels, narrowing of the active channel, substrate coarsening, and lowering of riparian groundwater levels (Bravard et al. 1999). All of these processes will impact the HCP species. Thus, activities which inhibit channel incision have the potential to have a positive impact on stream biota.

In-channel work can range from the placement of rock weirs which will have minimal impact on channel form, to complete channel realignment which will drastically alter the channel form. A goal of most in-channel habitat modification is to create habitat diversity and, in particular sheltered areas where organisms can reside during both high and low flow conditions. Many instream structures such as weirs are designed to locally elevate base-level and promote aggradation and pool formation. Studies have indicated that most in-channel habitat modifications accomplish the goal of increasing habitat heterogeneity (Lepori, Palm, Brannas et al. 2005) and retention of sediments (Lepori, Palm and Malmqvist 2005), but other studies have questioned the longevity of these structures (Babcock 1986; Thompson 2002) and indicate that failure of instream structures can lead to habitat which is actually less desirable than pre-project conditions (Frissell and Nawa 1992). Frissell and Nawa (1992) examined 161 structures in 15 streams in southwest Oregon and Washington after flooding events with a 2- through 10-year recurrence interval and found that 60 percent of the structures had failed and caused damage to the streams they were located in. Roper et al. (1998) found instream structures to be more durable. In a study of 3,946 structures in 94 streams across the Pacific Northwest, they found that 80 percent of the monitored structures were stable and functioning as designed. However, the majority of these structures were built on the channel margin in low-order streams. When analyzing structures that were built directly in the channel and structures that were built in 5th and 6th order rivers, they found that the failure rate exceeded 50 percent and was as high as 83 percent.

Studies such as these highlight the need for improved restoration techniques, many of which have been adopted since the publication of these studies. When assessing potential impacts, the durability and quality of the project design must be taken into account. Those instream projects that are proposed for high-order stream and highly urbanized streams should be more closely scrutinized than projects in less severe environments. Additional discussion pertaining to this topic is provided in Section 11 (*Habitat Protection, Conservation, Mitigation, and Management Strategies*).

7.4.1.2.2 Altered Bank and Shoreline Stability

Frequently, a goal of in-channel habitat modification is to increase bank stability. This is done through a variety of methods, including bank recontouring, planting (Sudduth and Meyer 2006), and armoring (Schmetterling et al. 2001). Riprap protection of banks is less common today than it once was (Palmer et al. 2005). This practice effectively armors the bank and reduces erosion but at the same time accelerates flows downstream and provides low-quality habitat (Schmetterling et al. 2001). Today, a widely applied bank protection measure is bioengineering and recontouring (Palmer et al. 2005). This approach stabilizes banks while adding roughness and habitat. In theory this approach should benefit aquatic organisms but there is little research to support this. Sudduth and Meyer (2006) monitored aquatic insect biomass in four bioengineered banks and two reference sites and found that only two of the four sites exhibited elevated biomass when compared with an unrestored reach. Although bioengineered banks may not always provide habitat, they are effective at reducing sediment loading (Barrett et al. 2006) and this should benefit those HCP species that require low turbidities and clean spawning gravels.

As discussed above, off-channel habitat modifications will increase bank stability by reducing peak flood levels in the main channel. The associated reduction in shear stresses will result in increased bank stability.

7.4.1.3 Ecosystem Fragmentation

By altering the channel and floodplain form, habitat modifications will change how water, organisms, and food resources are transferred through the mosaic of habitat patches that constitute the river-floodplain system. This section reviews the research that has addressed how habitat modifications may ameliorate the impacts associated with habitat fragmentation.

7.4.1.3.1 Altered Terrestrial/Aquatic Connectivity

Depending on the project, in-channel habitat modifications may or may not increase river-floodplain connectivity. Projects that increase local base level through increased channel roughness or constriction may locally increase the potential for flooding (Young 1991) and thus increase aquatic terrestrial resource exchange and off-channel habitat accessibility. However, projects that do not alter channel hydraulic to such a degree will likely not increase river-floodplain connectivity.

Off-channel habitat modification will always be associated with increased lateral connectivity within the river corridor. Side-channel, slough, and floodplain pond creation and reconnection will promote the distribution of channel waters across the width of the valley floor and in the process impede flows (Wyzga 1996), increase organic matter recruitment (Tockner et al. 1999; Valett et al. 2005), and provide access to valuable foraging and rearing habitat (Henning et al. 2006). It has been estimated that in the Skagit Valley, 41 percent of sloughs and 31 percent of small tributary habitat has been lost to channelization for agricultural purposes (Beechie et al. 1994). This highlights the importance of rehabilitating off-channel habitat in Washington's waterways. Side channels create refugia for juvenile fish (Jungwirth et al. 1993), while floodplain ponds and backwater sloughs create zones of high retention and productivity that are vital rearing habitat (Hall and Wissmar 2004; Sommer et al. 2005) and important sources of organic material for the channel (Tockner et al. 1999).

7.4.1.3.2 Altered Groundwater-Surface Water Interactions

Many in-channel and off-channel habitat modification projects result in an increase in flowpath complexity. Boulder placement creates divergent flow, rock weirs force water through pool-riffle transition zones, and side channels increase hyporheic exchange through bars and islands (Tonina and Buffington 2007).

Increased vertical exchange between surface and subsurface waters will benefit aquatic biota by increasing benthic dissolved oxygen levels and promoting solute uptake, filtration, and transformation. Studies have shown that the availability of dissolved oxygen to incubating salmonids embryos is dependent upon hyporheic exchange (Geist 2000; Greig et al. 2007) and that the occlusion of this exchange through siltation can lead to hypoxia within redds and decreased embryo survival (Heywood and Walling 2007). The hyporheic zone does more than promote oxygen exchange in subsurface sediments, it can also act as an effective filter and zone of biogeochemical transformations. Increased hyporheic exchange has been associated with nutrient uptake (Anbutsu et al. 2006; Sheibley et al. 2003) and transformation (Fernald et al. 2006; Lefebvre et al. 2005), and may attenuate the transport of dissolved and particulate metals (Gandy et al. 2007). Elevated concentrations of metals and nutrients can both have negative ramifications for fish and invertebrate health (see Section 7.10 [*Discussion of Common Stressors*]).

7.4.1.3.3 Altered Habitat Complexity

Side channel habitat provides low energy refugia for fishes and is largely viewed as a net benefit to stream organisms (Jungwirth et al. 1993). Rock weirs create low velocity zones in the lee of the structures and accelerate flow between the rocks. These variable habitats are utilized by different species during various lifestages. For instance, juvenile Chinook salmon have been shown to take refuge in low velocity habitat behind rock weirs, while steelhead parr utilize deep water habitat between the rocks during summer low flow periods (Fuller 1990). The increased habitat complexity which is a goal of most in-channel habitat modification will, in theory, have a positive impact on aquatic species. However, the success of an individual project can not be guaranteed and in-channel restorations to date have not been thoroughly monitored (Bernhardt et al. 2005) and have been applied with mixed success (Babcock 1986; Frissell and Nawa 1992; Moerke and Lamberti 2004; Roper et al. 1998). Consequently, the potential benefits of in-channel restoration may not outweigh the impacts associated with the construction phase and potential for project failure.

7.4.1.4 Aquatic Vegetation Modifications

7.4.1.4.1 Altered Autochthonous Production

The creation of shallow water edge habitat (a goal of some in-channel and off-channel habitat modifications) will generally lead to increased autochthonous production. In a study of rehabilitated incised streams in Denmark, Pederson et al. (2006) found that a re-profiling of the stream bank to create shallow water habitat resulted in increased macrophyte densities. The study concluded that shallow and wide banks allowed for increased autogeny and for a larger migration of macrophytic species from the stream banks into the streams, thereby enhancing species diversity within the stream channel. Rehabilitation of off-channel habitat will promote the exchange of aquatic vegetation between the channel and the floodplain. Schemel et al. (2004) noted a 2-fold increase in chlorophyll-a concentrations (a measure of algal biomass) in a floodplain in California versus the adjacent Sacramento River. Meanwhile, Ahearn et al. (2006) noted chlorophyll-a concentrations five times greater in a Cosumnes River, California floodplain than in an adjacent channel. These studies and others (Hein et al. 2004; Tockner et al. 1999) indicate that autochthonous production is elevated in floodplains relative to channels. This biomass is transported between backwater areas and the main channel during floods, and the resultant increase in food resources within the channel can bolster aquatic food webs and benefit the HCP species.

7.4.1.4.2 Altered Habitat Complexity

Freshwater aquatic vegetation provides shelter and clinging substrate for a variety of prey of the HCP species, including mollusks and many fishes (nonsalmonids) with a strong association with this vegetation (Petr 2000). Some of the HCP species which have been shown to commonly utilize vegetated habitat in off-channel areas include cutthroat trout, bull trout, sculpins, Dolly Varden, sockeye and coho salmon, and dace species (Pollock et al. 2003). In fluvial systems, slack water productive patches provide habitat diversity in systems that are otherwise dominated by high velocity, less-productive habitat (Johnston and Naiman 1990). This is also likely the case in estuarine/slough areas. The creation of off-channel habitat will increase access to aquatic vegetation and benefit many of the HCP species.

7.4.1.5 Riparian Vegetation Modifications

7.4.1.5.1 Altered Allochthonous Input

The creation of off-channel habitat and the placement of in-channel structure that promote river-floodplain connectivity will likely increase the export of coarse particulate organic matter (CPOM) from the floodplain to the channel (Junk et al. 1989; Tockner et al. 1999). The literature indicates that any activity which promotes the reconnection of once-severed floodplain-channel pathways can be expected to have a net benefit for aquatic organisms (Crain et al. 2004; Schemel et al. 2004; Tockner et al. 1999). This is partially due to the fact that floodplains and riparian areas are vital for the transfer of energy (in the form of carbon from leaf litter and other organic material) from terrestrial to aquatic ecosystems, especially in lowland river systems (Junk et al. 1989; Thoms 2003). However, it should be noted that if instream structures fail and act to catalyze channel incision, the result could be decreased connectivity with the riparian zone and decreased system productivity.

7.4.1.6 Water Quality Modifications

A primary goal of most in-channel and off-channel habitat modifications is to create habitat but many of the same projects may also have ancillary water quality benefits. These benefits, depending upon the nature of the project, include reduced stream temperatures and reduced pollutant loadings.

7.4.1.6.1 Altered Temperature Regime

The creation of in-channel structures and side-channel habitat has the potential to create cool water refugia which can be utilized by temperature sensitive species. An experimental shading study by Ebersole et al. (2003), concluded that shading from riparian vegetation can cool surface waters by 3.6–7.2°F (2–4°C). In-channel shading can come from structures that provide cover such as engineered logjams (Abbe and Montgomery 1996). In-channel structures can also direct flow into the hyporheic zone and thus potentially lower stream temperatures (Grant et al. 2006). In addition, side-channels are usually characterized by narrow stream widths and dense riparian vegetation. Consequently, these habitats tend to provide cool water refugia. Ebersole et al. (2003) observed this when analyzing where cold water patches naturally occur in the Grande Ronde basin in northeast Oregon; they found cool water patches associated with seeps, side channels, alcoves, and floodplain spring tributaries. The objective of many in-channel and off-channel stream rehabilitation projects is to mimic this thermal heterogeneity. However, Moerke and Lamberti (2004) found that of the 10 channel rehabilitation sites analyzed in streams across Indiana (primarily channel relocation and floodplain reconnection projects), the general trend was for reduced riparian vegetation along the restored reach. Consequently, the impact of in-channel and off-channel habitat modification on water quality will be project specific and depend on riparian cover and hyporheic exchange dynamics.

7.4.1.6.2 Altered Pollutant Loading

The effect of an in-channel or off-channel habitat modification project on pollutant loading is difficult to predict. Most projects aim to increase channel roughness and create more slack water habitat. Ecohydrologic theory dictates that these activities would increase transient storage and likely increase pollutant and nutrient retention. Studies by Vallett (2002) and Ensign and Doyle (2005) both indicate that nutrient retention is elevated in streams with more pools and fine benthic material (impounded within the pools). It can be inferred that projects which increase the retention of water and organic material will also increase pollutant retention. In eutrophic and urban systems these ecosystem alterations would benefit the HCP species.

7.4.1.6.3 Altered Suspended Solids

In-channel and off-channel habitat modification will increase suspended solids during the construction phase through bank, channel bed, and/or floodplain disturbance. This impact will only occur during the construction phase (assuming the project is well constructed), so increased suspended solids are not expected to be a primary impact mechanism. After the construction phase and dependent on the project, total suspended solids concentrations will likely be reduced relative to preproject conditions. Floodplains have consistently been shown to be sediment sinks (Ahearn et al. 2006; Florsheim and Mount 2002; Tockner et al. 1999; Valett et al. 2005); thus, projects that enhance lateral connectivity can be expected to reduce suspended solids concentrations within the main channel. Likewise, in-channel projects that create complex flow paths and thus decrease mean velocities can be expected to increase within channel sediment retention and decrease suspended solids concentrations (Shields et al. 1995). Lastly, projects that enhance bank stabilization and protection will likely decrease sediment source areas and thus decrease in-channel suspended solids concentrations (Sear et al. 1994).

7.4.2 Summary of Impact on Aquatic Fauna

It is difficult to predict what impact in-channel and off-channel habitat modification, creation, and enhancement will have on aquatic organisms because there does not seem to be a clear pattern in the literature indicating that these activities are a net benefit or detriment to aquatic biota. This section presents those studies that have specifically analyzed fish and invertebrate response to those types of projects classified under this subactivity type.

7.4.2.1 Impact on Fishes

There are numerous studies indicating that salmonids densities in restored reaches increase after project completion (Fuller 1990; Jungwirth et al. 1993; Roni et al. 2006). Additionally, research has clearly shown that fishes prefer the naturally occurring habitat that rehabilitation projects are attempting to mimic. Swales and Levings (1989) found that off-channel habitat in the Coldwater River, British Columbia were vital rearing areas for coho, while juvenile Chinook, steelhead, and Dolly Varden were most abundant in floodplain ponds. These off-channel habitat are unequivocally important for these species and, given the historic destruction of these habitat in Washington State (Beechie et al. 1994) and the relatively low impact associated with construction, these types of restoration activities should be encouraged. In-channel habitat modification will not have as predictable a result as off-channel because in-channel structures have to withstand the erosive forces of large flood events moving through the channel. Babcock (1986) monitored numerous rehabilitation sites after a 25-year flood event and found no measurable improvement to fish populations, and a 68 – 93 percent failure rate depending upon the structure. In one of the most extensive assessments of restoration success, Frissell and Nawa (1992) examined 161 structures in 15 streams after flooding events and found that 60 percent of the structures had failed and damaged the stream. Finally, a number of studies have also shown mixed results, with some restored sites showing increased fish diversity and abundance and others showing no change or even a decrease in fish populations (Shields et al. 1998; Sudduth and Meyer 2006).

7.4.2.2 Impact on Invertebrates

The impact of in-channel and off-channel habitat modification on invertebrates is also not well known. This is most likely because variability in project design and channel processes produces highly variable responses in the biotic community. Laasonen et al. (1998) found that macroinvertebrate abundance in restored streams in Finland was lowest in streams that were restored 1 month prior to sampling. They also found that there was no difference in macroinvertebrate populations between channelized reaches and reaches restored 0-16 years prior to sampling. Likewise, Suren and McMurtrie (2005) found that invertebrate communities did not improve following riparian planting and channel modifications in urban New Zealand streams. They recommended that restoration activities should focus on watersheds where external factors such as elevated sediment loading and urban runoff pollution will not impact the restored reach. Other studies have shown more positive results concerning macroinvertebrate response to channel alterations (Nakano and Nakamura 2006; Sudduth and Meyer 2006). Regardless, the impact will not be certain and each project must be considered on a case-by-case basis, with projects that feature complex yet stable designs using organic materials (e.g., engineered logjam) more likely to have a positive invertebrate community response than designs that lack these elements (e.g., rock weir, bank barb) (Sudduth and Meyer 2006).

In summary, the primary fish and invertebrate stressors associated with the construction of in-channel habitat modification projects are:

- Fish handling/exclusion
- Elevated suspended solids (temporary)
- Elevated noise (temporary).

If the project fails, which given the history of in-channel restoration will occur more than half the time (Babcock 1986; Frissell and Nawa 1992), the following stressors will occur:

- Burial
- Elevated suspended solids
- Decreased refuge.

Section 7.10 (*Discussion of Common Stressors*) presents the research to date concerning the effect of these stressors on fish and invertebrates. These stressors will lead to potential adverse impacts on HCP species but must be weighed against the potential benefits of in-channel restoration success, including:

- Increased refugia

- Decreased suspended solids through increased bank protection (project dependent)

- Increased foraging and rearing habitat through increased floodplain connection (project dependent)

- Increased pollutant and nutrient retention.

Off-channel habitat modification will likely result in fewer construction-related stressors. These stressors may include:

- Fish handling/exclusion
- Elevated suspended solids (temporary).

Finally, project success will potentially result in the following benefits, which must be weighed against construction-related stressors when assessing project impacts:

- Increased refugia

- Increased foraging and rearing habitat through increased floodplain connection
- Increased pollutant and nutrient retention.

7.5 Riparian Planting/Restoration/Enhancement

One of the most common restoration practices is the restoration and planting of riparian environments. This activity does not involve work within the channel and, thus, is not generally associated with construction phase impacts. Additionally, the failure of riparian planting projects will not generally be associated with a risk of take. Therefore, it is a low risk activity with the potential for substantial habitat improvement.

7.5.1 Impact Mechanisms

This section addresses the potential impacts (both beneficial and detrimental) of riparian planting and restoration. Subsequently, Section 7.5.2 (*Summary of Impact on Aquatic Fauna*) addresses those studies that have specifically addressed the impact of this subactivity type on fishes and invertebrates.

7.5.1.1 Construction Activities

7.5.1.1.1 Bank, Channel, and Shoreline Disturbance

As noted previously, this subactivity type is not generally associated with impacts due to construction-related activities. The only potential for impacts on the channel would come from bank erosion from planting activities (e.g., digging, foot traffic), and erosion from invasive vegetation removal. For example, Himalayan Blackberry can encroach and grow in dense patches along stream banks and lake shorelines. The removal of this vegetation can temporarily destabilize the bank by removing root structure and through mechanical erosion from worker activities in the riparian area (Bennett 2007). Except in projects such as these, the impacts associated with construction-related activities will be negligible.

7.5.1.2 Geomorphic and Hydraulic Modifications

7.5.1.2.1 Altered Bank and Shoreline Stability

One of the primary purposes of riparian planting is to increase bank stability through root cohesion. Roots grow through the soil matrix and give structure to banks, thus reducing the potential for mass wasting (Schmidt et al. 2001; Wang et al. 2002) and sedimentation within the channel and along the shoreline. Increased bank stability will benefit aquatic organisms by decreasing sediment loading which can clog spawning gravels (Zimmermann and Lapointe 2005) and, in catastrophic events, bury invertebrate species.

7.5.1.3 Ecosystem Fragmentation

7.5.1.3.1 Altered Terrestrial/Aquatic Connectivity

Channel restoration through riparian planting develops on a time scale which is much longer than the other activities discussed in this review. However, once vegetation has become established, bank roughness will increase and flood water velocity will decrease. This will, in turn, promote overbank flooding of riparian areas and increase connection with floodplain environments. Additionally, mature riparian vegetation will increase allochthonous input and augment aquatic food webs (Wipfli 2005). It has been shown that in the Pacific Northwest the relationship between riparian vegetation, instream wood, and channel geomorphology is complex and essential to natural system functioning. Riparian forest structure and distribution is controlled by catastrophic processes such as flooding, landslides, and wind storms. The associated recruitment of felled trees alters channel form and redistributes flow paths, creating new zones of deposition and vegetation establishment (Fetherston et al. 1995). In this way the vegetation influences the channel while channel response influences the vegetation, resulting in a complex productive system in which native aquatic organisms thrive. A primary goal of riparian planting is to create mature forests where they have been removed and, to the extent possible, rehabilitate this complex dynamic between the channel and adjacent vegetation.

7.5.1.4 Aquatic Vegetation Modifications

7.5.1.4.1 Altered Autochthonous Production

There is a growing body of literature indicating that riparian vegetation <u>removal</u> increases stream productivity. In headwater systems (which are generally oligotrophic), this increase in productivity is seen as a benefit to stream biota. Hetrick et al. (1998) studied riparian canopy removal in Eleven Creek, Alaska, and concluded that:

> *Based on higher abundance of aerial invertebrates above the water surface and increased standing crop of benthic invertebrates that we observed in open- versus closed-canopy sections of Eleven Creek, it appears that canopy removal has the potential to increase the carrying capacity of juvenile coho salmon in streams where populations are food limited.*

Findings such as these indicate that riparian plantings in headwater food limited reaches may be a detriment to juvenile fishes within the channel. In a similar study, Fuchs et al. (2003) found that streams flowing through newly logged forests in British Columbia (where the riparian zones were harvested within 5 years of the study) had nearly twice the macroinvertebrate biomass as those in unlogged or older logged sites, and a higher chlorophyll a concentration. Finally, in a study of open canopy and closed canopy patches by Zalewski et al. (1998), it was found that macroinvertebrate density was highest in mixed cover reaches which received both incident light and allochthonous input. Fish biomass followed the same trend, being lowest in heavily shaded areas and in open channels without riparian vegetation, but highest in ecotones of intermediate complexity. These findings indicate that riparian patch dynamics are vital to a healthy stream ecosystem. Riparian canopy provides shade and litter input, while open canopy patches are characterized by increased solar radiation, warm waters, and autochthonous production. A goal of riparian planting should be to increase the frequency of these habitat patches within degraded reaches with little canopy cover, while acknowledging that the increase in shading associated with riparian vegetation may locally decrease productivity within that patch.

7.5.1.5 Riparian Vegetation Modifications

The most obvious impacts of riparian planting and restoration are associated with the changes to the riparian vegetation and the relationship between this vegetation and adjacent open water habitat. This section addresses the impact of riparian planting on carbon budgets, primary production, stream temperatures, and bank stability.

7.5.1.5.1 Altered Allochthonous Input

Invasive plant removal may initially be associated with reduced allochthonous inputs, but as the planted riparian community matures it is anticipated that allochthonous inputs would increase above pre-project levels (Bennett 2007). Certain macroinvertebrate functional feeding groups, rely on organic input from riparian vegetation as a food source and/or food substrate (Parkyn et al. 2005). Increased allochthonous input would then conceivably increase macroinvertebrate populations and increase the foundation of the food web for fishes. Indeed, in a study of 36 sites with riparian buffers and 12 reference sites, Teels et al. (2006) observed increased macroinvertebrate density and diversity response at sites with highly disturbed local conditions prior to buffer establishment.

7.5.1.5.2 Altered Shading and Solar Input

Increased shading caused by riparian canopy cover has both positive (LeBlanc and Brown 2000) and negative (Hetrick et al. 1998) ramifications for aquatic biota. The shading can decrease stream temperature by between 3.6 and 7.2°F (2 and 4°C) (Ebersole et al. 2003), which will benefit cold water species (Opperman and Merenlender 2004); conversely shading will decrease autotrophic production within the channel and possibly impact macroinvertebrate populations. Canopy removal studies have indicated that macroinvertebrate populations increase after riparian vegetation is removed (Hetrick et al. 1998; Wipfli 1997). Thus, it can be inferred that canopy closure may be accompanied by a decrease in macroinvertebrate populations. The mixed results from riparian buffer studies, such as those mentioned above, indicate that there are complex interactions between the channel and the riparian zone and that the ideal riparian environment may be a mix of closed canopy and open canopy patches (Zalewski et al. 1998).

There has been little research regarding the impact of riparian shading in marine systems. However, one study which entailed sampling at sites at northern Bellingham Bay, Dugualla Bay, northern Camano Island, and the west shore of Port Susan found that surf smelt eggs deposited in unshaded beaches had nearly twice the mortality of eggs deposited in shaded beaches. This study indicates that thermal cooling from riparian vegetation is important in marine as well as freshwater environments (Rice 2006). It has also been shown that juvenile salmonids prefer estuarine habitat with overhanging vegetation (Quinones and Mulligan 2005). The cover and shading provided by the vegetation apparently creates conditions favorable for salmonids. These studies indicate that riparian vegetation is important for fish species in estuarine as well as freshwater habitat.

Little research has been conducted on the effect of riparian vegetation on lake temperatures. Lake surface area is usually dominated by shade-free open water zones, and thus the shaded margin does not have a large impact on overall lake temperatures (Lauck et al. 2005). As a result, riparian rehabilitation activities are not expected to alter lake temperatures.

7.5.1.5.3 Altered Buffering Capability

Riparian zones are an ecotone between open water and terrestrial environments. When the vegetation in riparian areas is removed, the connection between upland areas and downslope receiving waters becomes short circuited. Once convoluted flow paths become simplified, the transfer of sediment, nutrient, and pollutants from terrestrial to aquatic systems increases. In theory, the restoration of riparian areas will decrease pollutant loading to the channel and benefit aquatic organisms. Considerable research regarding riparian buffers and pollutant loading has been conducted and although the results have been mixed there has been a general trend observable in the data. Riparian buffer widths play an important role in determining the efficacy of a buffer at removing pollutants. Reviews of the literature have indicated that the most effective buffers are greater than 98 ft (30 m) in width (Hickey and Doran 2004) and this applies to all streams, including first order tributaries (Mayer et al. 2005). Riparian buffers which meet these criteria have been shown to remove as much as 95 percent of the influent total phosphorus (Hickey and Doran 2004). In lowland eutrophic systems this would serve as a net benefit to the aquatic ecosystem, especially in nutrient impacted lakes.

7.5.1.6 Water Quality Modifications

7.5.1.6.1 Altered Temperature Regime

As noted above, if invasive species clearing is part of the riparian management plan, the project may be associated with initial increases in instream temperature (Bennett 2007). However, once the riparian plantings mature, shading can be expected to decrease temperatures (LeBlanc and Brown 2000; Opperman and Merenlender 2004) by between 3.6 and 7.2^{o}F (2 and 4^{o}C) (Ebersole et al. 2003). This temperature decrease would benefit sensitive aquatic organisms. For a discussion of the impact of elevated temperatures on fish and invertebrates see Section 7.10 (*Discussion of Common Stressors*).

7.5.1.6.2 Altered Suspended Solids

If constructed correctly, riparian buffers are effective filters which can reduce sediment loading to adjacent aquatic environments. In a review of six studies, Hickey and Doran (2004) found that between 84 and 90 percent of influent total suspended solids can be removed by riparian buffers. Reduced sediment loading would benefit aquatic organisms that are sensitive to elevated turbidity. For a discussion of the impacts of elevated suspended sediment on fish and invertebrates see Section 7.10 (*Discussion of Common Stressors*).

7.5.1.6.3 Altered Pollutant Loading

Once riparian vegetation is established, an effective buffer between the aquatic and upland terrestrial environments will exist. This buffer, depending upon its geometry, preferential flow, and pollutant loading, may have a significant effect on pollutant attenuation through shallow groundwater and overland flow. Although there has been little research concerning urban runoff attenuation through riparian buffers, studies have examined filter strips along highways. Wu et al. (2003) found that highway filter strips can remove 60 percent of influent copper, while Barrett (2005) found that bio-filters remove 75 percent of influent zinc on average. Bio-filtration is becoming widely adopted for urban stormwater management, and the same principal should and will be applied to riparian buffers in the near future. Riparian planting in urban areas will benefit aquatic biota that have already shown signs of impairment due to urban pollution in western Washington (PSAT 2007).

7.5.2 Summary of Impact on Aquatic Fauna

7.5.2.1 Impact on Fishes

Construction-related impacts associated with riparian vegetation planting/enhancement are minimal and consequently there is less risk associated with projects of this type. The research that has monitored fish response to riparian restoration is sparse and equivocal. For instance, Bjornn et al. (1991) found that age-0 coho did not respond to either riparian vegetation removal or artificial cover creation in an Alaskan stream. Despite this data gap, there is substantial research that has monitored physical and macroinvertebrate response to riparian vegetation alteration (see above). Most of these studies infer that the monitored environmental variables will have a direct impact on fishes (Broadmeadow and Nisbet 2004; Opperman and Merenlender 2004; Whitledge et al. 2006), but few studies are able to quantitatively measure this. Despite the lack of data, it can be assumed that riparian planting will do little harm to aquatic biota and potentially could have positive benefits for many of the 52 HCP species.

7.5.2.2 Impact on Invertebrates

There has been considerable research on the effect of riparian vegetation on macroinvertebrate populations. There is a body of research which suggests that riparian deforestation might actually increase macroinvertebrate abundance and stream productivity (Fuchs et al. 2003; Wipfli 1997), but other authors have countered, noting that deforestation may cause temporary increases in productivity but that the stream incision resulting from the deforestation will eventually degrade the system and adversely impact biota (Sweeney et al. 2004). In a Virginia study of 36 sites with riparian buffers and 12 reference sites, Teels et al. (2006) observed increased macroinvertebrate density and diversity response at sites with highly disturbed local conditions prior to buffer establishment. Studies such as this indicate that riparian planting efforts will likely result in increased macroinvertebrate density, but no studies have specifically monitored the effect of riparian vegetation on the HCP mollusk species. Consequently, the impact of riparian planting on the HCP invertebrate species must be inferred from applicable research.

If a riparian restoration project does not involve invasive species removal, then the construction-related impacts will be negligible. If, however, invasives are removed the following fish and invertebrate stressors would be applicable:

- Increased temperature
- Increased suspended solids from bank erosion (temporary).

Section 7.10 (*Discussion of Common Stressors*) presents the research to date concerning the effect of these stressors on fish and invertebrates. These stressors will lead to potential adverse impacts on HCP species but this must be weighed against the potential long-term benefits of riparian restoration, including:

- Decreased temperature
- Decreased suspended solids through increased bank protection
- Decreased pollutant loading from upland sources.

7.6 Wetland Creation/Restoration/Enhancement

Wetlands provide multiple environmental services for adjacent aquatic systems. Wetlands have been shown to function as effective buffers, attenuating pollutant loading from upland and upstream sources (Vellidis et al. 2003). Wetlands are also highly productive when compared with adjacent slackwater (Bayley 1995) and channel (Tockner et al. 1999) habitat. When wetlands are hydraulically linked with adjacent open water habitat they will export food resources (Ahearn et al. 2006; Junk et al. 1989) and bolster the aquatic food web.

Wetlands serve as habitat for many aquatic species. Riverine and estuarine wetlands play important roles in providing food, protection, and spawning areas for a number of fish species. Wetlands are vital nursery and feeding areas for resident fish and anadromous fish such as salmon and steelhead trout (USGS 1997). Numerous studies have indicated that juvenile fish will seek cover and foraging opportunities in both estuarine (Franco et al. 2006; Stevens et al. 2006) and riparian (Crain et al. 2004; Sommer et al. 2001) wetlands.

As of 1980, Washington State had lost an estimated 31 percent of its 1.35 million acres of wetlands (Dahl 1990). Continued wetland filling and ditching in Washington has resulted in a decrease of up to 50 percent of the state’s wetland acreage with reductions of between 70 and 100 percent in some urbanized areas (Ecology 2005; USGS 1997). Estimates of continuing wetland loss range from 700 to 2,000 acres per year. In addition, most of the State's remaining wetlands have been significantly degraded (Ecology 1992a, 1992b).

The principal historical causes of wetland loss and degradation are the expansion of agriculture and the siting of ports and industrial facilities. The major causes of continuing loss and degradation of wetlands are urban expansion and the consequent alterations in wetland hydrology and water quality (Azous and Horner 2001), forestry and agricultural practices, and the invasion of exotic plants and animals (Canning and Stevens 1989; Ecology 1992a, 1992b). Changes in land use frequently diminish infiltration in wetland watersheds. This can also reduce stream baseflows and groundwater supplies to wetlands, lengthening dry periods and eliminating macrophyte species (Azous 1991; USEPA 1985).

Because many fish depend on both estuarine and riverine wetlands for the successful completion of their life cycle, historic and continued reductions in wetland area may be contributing to the decline of fisheries in the state of Washington. It is the goal of wetland creation and enhancement projects to restore some of this lost habitat along with the ecosystem functions wetlands provide. The HPAs issued under this activity type will need to weigh these ecosystem benefits against the potential impact associated with the construction of the project.

This section addresses the impact of wetland creation and enhancement on the 52 HCP species. The majority of these impacts will be beneficial to the HCP species, but construction activities will be associated with potential adverse impacts. The research that can be used to assess the degree and form of these impacts is presented below, while the risk of take analysis itself is presented in Section 9 (*Potential Risk of Take*).

7.6.1 Impact Mechanisms

The impact mechanisms associated with wetland creation and enhancement are presented in this section. These impact mechanisms have been categorized into six primary mechanisms and multiple submechanisms.

7.6.1.1 Construction Activities

Wetland creation and enhancement usually requires a considerable construction effort involving heavy machinery, the construction or alteration of weirs and other flow control structures, and/or planting. The impact of these activities will be proportional to the degree of wetland connectivity with adjacent water bodies which may harbor HCP species. For example, the impact on HCP species from creating wetlands in an agricultural field which is rarely flooded will be less than the impact associated with regrading an existing riparian wetland. In the latter case, wetland filling may be required in portions of the project area. As discussed below, the specific impact mechanisms associated with wetland construction activities can be classified under Equipment Operation, Bank Channel and Shoreline Disturbance, and Temporary Dewatering.

7.6.1.1.1 Equipment Operation

The operation of equipment in and near water will always be associated with a risk of chemical contamination from spills. Accidental spills will have a greater impact on the aquatic system if they occur while machinery is either in or immediately adjacent to a water body. Conversely, spills which occur well away from any water body may be contained and removed before any contact with water occurs. Because of this, wetland creation or restoration work located immediately adjacent to a water body has a greater potential for adverse impacts than work which occurs in more distal areas of the floodplain or nearshore environment. If spills do occur, the impacts on HCP species will be immediate and proportional to the volume of the spill. Details concerning the impacts of hydrocarbons on aquatic species are presented in Section 7.10 (*Discussion of Common Stressors*).

Noise associated with construction activities will only be a factor when the work is immediately adjacent to or within the channel or nearshore environment. Pile driving has been cited as the primary source of noise which may be associated with lethal effects (Hastings and Popper 2005) in fishes and invertebrates. Wetland creation, restoration, and enhancement rarely involves pile driving. Therefore, this impact mechanism is not expected to be a primary pathway for risk of take associated with this activity.

7.6.1.1.2 Bank, Channel, and Shoreline Disturbance

Wetland creation and restoration in riparian systems will occur via three primary methods:

- Floodplain activation through the removal of levees (Florsheim and Mount 2002)
- Floodplain activation through base level or floodplain elevation alteration (which may require wetland filling) (Collins and Montgomery 2002)
- Channel realignment to connect a channelized reach to an active river-floodplain system (Whalen et al. 2002).

Of these three, floodplain restoration through the removal of levees will likely have the least impact on the bank and channel. This type of wetland restoration usually involves regrading a hydraulically disconnected floodplain and subsequently removing portions of the levee. Consequently, the impact on the channel occurs only at the points where the levee is breached. Other riparian wetland restoration projects will involve a more continuous disruption of the channel and bank, either through regrading, channel realignment, or wetland filling. These projects will likely have a much greater impact on species within the channel.

All wetland creation/restoration/enhancement projects that involve the use of heavy machinery have the potential to increase soil compaction. Compaction of riparian soils may lead to various forms of aquatic habitat degradation, but this impact pathway has not been well studied. Soil compaction can lead to decreased plant growth and increased runoff (Greacen and Sands 1980).

Decreased plant growth would impact the riparian vegetation and lead to decreased shading, while increased runoff could cause altered geomorphology and increased pollutant/nutrient loading. Although this impact pathway may indeed exist, no studies have evaluated the severity or frequency of the impact in the context of floodplain or estuarine work zones.

Wetland creation and restoration of estuarine wetlands typically involves the removal of dikes or levees, regrading to restore dendritic channels, and sometimes the installation of self-regulating tide gates. Shoreline disturbances are temporary and will vary in extent depending on the site's design.

Wetland enhancement activities in riparian and estuarine wetlands will typically involve removing noxious weeds, and replanting areas to improve native habitat and species diversity. Occasionally, enhancement includes changing the site's water regime through excavation, construction of weirs, or removal of ditches and drains. Enhancement has historically focused on habitat, but other wetland functions can also be enhanced.

The primary stressor associated with bank, channel, and shoreline disturbance may be temporary and/or permanent destruction of habitat, burial of invertebrates, and increased suspended solids. The details of how these stressors affect fish and invertebrates are provided in Section 7.10 (*Discussion of Common Stressors*).

7.6.1.1.3 Temporary Exclusion/Dewatering

In some instances wetland creation or enhancement may require that a side channel or tributary be rerouted and/or temporarily dewatered. This could result in short term impacts on invertebrate and fish communities from habitat removal and may produce fish stranding. A discussion of the impact of dewatering and fish handling is presented in Section 7.10 (*Discussion of Common Stressors*).

7.6.1.2 Geomorphic and Hydraulic Modifications

7.6.1.2.1 Altered Bank and Shoreline Stability

Riparian wetlands serve an important geomorphic and hydraulic function in unconfined river systems. Floodplain wetlands have been identified as sinks for sediment and water. Florsheim and Mount (2003) noted that floodplain sedimentation in the lower Cosumnes River, California was elevated in the pre-agricultural era and then rapidly decreased following the leveeing of the mainstem. Subsequent to levee breaching on an experimental floodplain, the sedimentation processes resumed. The same floodplain has been shown to be a net sink for suspended solids (Ahearn et al. 2006) and bedload (Florsheim and Mount 2002), thus indicating that riparian wetland restoration can restore the geomorphic functioning of a river-floodplain system. Increased sediment deposition on floodplains will reduce sediment loading to downstream systems and perhaps reduce turbidity levels to below thresholds which may harm HCP species. Section 7.10 (*Discussion of Common Stressors*) provides a discussion of the available research regarding turbidity thresholds for fish and invertebrates.

One of the most important ecosystem functions that riparian wetlands provide is water retention and infiltration. Due to high width to depth ratios, riparian wetlands can efficiently infiltrate floodwater and attenuate flood peaks. Wyzga (1996) noted that when floodplains were disconnected from a reach of the Raba River in Poland, flood peaks and velocities increased. He concluded that reduced floodplain water storage and self-acceleration of flows within channelized reaches make flood waves progressively more flashy as they propagate downstream. This process can induce further incision downstream and lead to the degradation of channel habitat. Incision can lead to a reduction in gravel bar habitat, abandonment of side channels, narrowing of the active channel, substrate coarsening, and lowering of riparian groundwater levels (Bravard et al. 1999). All of these processes can either directly or indirectly impact HCP species (see the Channel Modifications white paper [Herrera 2007b] for a detailed discussion) and further degrade downstream floodplain habitat. The restoration of riparian wetlands would serve to reduce flood velocities and thus inhibit channel incision and the many impacts associated with it.

Estuarine wetlands are a vital component of coastal shoreline stabilization and storm surge protection. Vegetation functions as the primary stabilizing element of coastal shorelines (Soil Conservation Service 1968). Restoration, creation, or enhancement of estuarine wetlands may produce temporary impacts on shoreline vegetation, thus temporarily destabilizing its protective functions. However, once the wetland becomes established this function is expected to return.

7.6.1.3 Ecosystem Fragmentation

Wetlands are ecotones between terrestrial and aquatic environments (Mitsch and Gosselink 2000), and consequently the restoration of wetlands will promote terrestrial and aquatic connectivity. There are a number of ecosystem benefits which are derived from this connectivity in both marine and freshwater systems. This section presents the research which has been conducted regarding river-floodplain connectivity and open water-terrestrial connectivity. Research into the ecology of these ecotones is presented in the context of impacts on HCP species.

7.6.1.3.1 Altered Terrestrial/Aquatic Connectivity

<u>Fresh Water</u>

Shallow flooded riparian areas are some of the most productive habitat within a watershed (Bunn et al. 2003; Junk et al. 1989; Schemel et al. 2004; Sommer et al. 2005; Sommer et al. 2001). Consequently, access to and resource transport through this zone is essential for the healthy functioning of river-floodplain systems. Research has indicated that riparian wetlands are nutrient sinks and carbon sources for adjacent channels (Tockner et al. 1999; Valett et al. 2005). In this fashion, wetlands function as zones of transformation, converting inorganic nutrients to organic forms which can be consumed and transferred up the food chain. Organic material is exported from the floodplain in four primary forms, coarse woody debris, coarse particulate organic matter, dissolved organic matter, and suspended algal biomass. Suspended algal biomass represents one of the most important forms of carbon export from floodplains because of the high nutrient content of the algal cells (Muller-Solger et al. 2002). Studies have indicated that when hydraulic residence time on floodplains is in the range of 2 days (Ahearn et al. 2006), algal biomass concentrations may begin to increase, reaching a maximum level at approximately 10 days (Hein et al. 2004). Although site specific, these studies indicate that riparian wetlands with extended hydraulic residence times will produce high levels of algal biomass. This algal biomass is an important food resource for organisms in both the wetland itself and the connected channel or open water habitat.

Riparian wetlands provide not only food resources for adjacent, less productive aquatic ecosystems, they also function as habitat for fish and invertebrates. Although floodplain areas are typically thought of as important rearing habitats for coho (Beechie et al. 1994; Swales and Levings 1989) and Chinook salmon (Sommer et al. 2001), off-channel areas also offer spawning habitat for sockeye salmon (Hall and Wissmar 2004). Whether for rearing or spawning, the viability of these habitats hinges upon connectivity with the adjacent open water system. Too much connectivity, and productivity of the wetland decreases (Tockner et al. 1999). Too little connectivity and the stranding of organisms may become a problem (Henning et al. 2006; Sommer et al. 2005).

Restoration of nearshore habitat or coastal wetlands has received more attention lately as issues of density dependent mortality have become apparent in Washington State. Years of restoration efforts have focused on increasing spawning habitat in upland systems, yet the resultant increased populations will not thrive if there is not adequate rearing habitat to support the population. It has been suggested that density dependent mortality, that is the mortality of fishes due to too many individuals and not enough habitat, is a factor in both the Skagit and Duwamish Rivers (Greene and Beechie 2004). This indicates that estuarine wetland rehabilitation and the increased rearing habitat availability associated with it will be vital to the rehabilitation of degraded fisheries in the State. The following section provides additional information regarding the studies that have addressed connectivity in estuarine wetland systems.

<u>Marine</u>

Estuarine marshes moderate the connection of terrestrial resources to the open sea (Tanner et al. 2002). These areas are highly productive, providing a wide range of food sources to littoral fishes. The elimination of marshes decreases channel complexity and reduces the productivity of the nearshore zone (Ferraro and Cole 2007; Hood 2004).

Several researchers have pointed out that the complexity of undisturbed systems is not easily recovered from altered environments (Simenstad et al. 2006; Simenstad and Thom 1996; Thom et al. 2002; Williams and Orr 2002). Subsidence of pre-development wetland areas during times when land-use was intensive means that many restored areas are now too low to provide the proper physical conditions (Thom et al. 2002; Williams and Orr 2002). While this problem can be pronounced in settings where the sediment supply is limited, most geomorphic situations where estuarine marshes are found in Washington State exhibit large sedimentation rates [e.g., the Skagit River: (Hood 2006)] where this issue is either not applicable or ameliorated after only a few years (Thom et al. 2002).

7.6.1.4 Aquatic Vegetation Modifications

Riparian and coastal wetlands provide extensive shallow water habitat where macrophyte and algal species may thrive. Due to shallow water depths, warm temperatures, and protection from the erosive power of flooding and wave action, wetlands are ideal habitat for aquatic vegetation. In turn, aquatic vegetation provides food resources and structural habitat for both fish and invertebrate species. Wetland creation, restoration, and enhancement will increase aquatic vegetation habitat and the ecosystem functions associated with it.

7.6.1.4.1 Altered Autochthonous Production

The creation, restoration, and enhancement of riparian wetlands will produce additional protected, shallow water habitat which will promote increased macrophyte and algal production. Schemel et al. (2004) noted a 2-fold increase in chlorophyll-a concentrations (a measure of algal biomass) in a floodplain in California when compared with the adjacent Sacramento River. Meanwhile, Ahearn et al. (2006) noted chlorophyll-a concentrations five times greater in a Cosumnes River, California floodplain than in an adjacent channel. These studies and others (Hein et al. 2004; Tockner et al. 1999) indicate that autochthonous production is elevated in floodplains relative to channels. This production can bolster aquatic food webs and benefit many of the HCP species, especially in areas where aquatic productivity within the channel is low. Nutrient-poor, or oligotrophic systems are common in Washington State, especially since a major pathway of nutrient import, namely marine-derived nutrients from salmon spawning, has drastically decreased over the past 100 years (Naiman et al. 2002). Consequently, any habitat modification measure which increases productivity in waters connected to these oligotrophic systems will benefit aquatic species.

Riparian and estuarine wetlands are also characterized by abundant macrophyte growth which has been shown to provide habitat for coho (Swales and Levings 1989), marine invertebrates (Seitz et al. 2005), and numerous other species. The creation, restoration, or enhancement of estuarine and riparian wetlands will increase the amount of, and improve access to, this habitat. The potential increase in habitat may alleviate any density dependent mortality which may be occurring within the system (Greene and Beechie 2004).

Organisms which can access floodplain wetland habitat will benefit from the increased productivity which characterizes those systems by taking advantage of improved foraging and hunting opportunities. However, organisms that remain within the channel may also benefit from riparian wetland productivity because the systems tend to be hydraulically linked and carbon export to the channel will occur during periods of high flow. This pathway for energy transfer, from the floodplain to the channel, is addressed in the Section 7.6.1.5 (*Riparian Vegetation Modifications*).

7.6.1.4.2 Altered Habitat Complexity

Freshwater aquatic vegetation in riparian wetlands provides shelter and clinging substrate for a variety of prey of HCP species, including mollusks and many fishes (nonsalmonids) with a strong association with this vegetation (Petr 2000). Some of the HCP species which have been shown to commonly utilize vegetated habitat in off-channel areas include cutthroat trout, bull trout, sculpins, Dolly Varden, sockeye and coho salmon, and dace species (Pollock et al. 2003). In fluvial systems slack water productive patches provide habitat diversity in systems that are otherwise dominated by high-velocity, less-productive habitat (Johnston and Naiman 1990). The creation of off-channel habitat will increase access to aquatic vegetation and benefit many of the HCP species.

In estuarine environments, aquatic vegetation plays a vital role as habitat, food source, and biogeochemical filter. A goal of estuarine restoration is to maximize vegetated aquatic habitat. The benefits this habitat provides for fish and invertebrates are discussed in Section 7.9 (*Eelgrass and Other Aquatic Vegetation Creation/Restoration/Enhancement*).

7.6.1.5 Riparian Vegetation Modifications

Wetland creation, restoration, or enhancement will have a wide variety of impacts on riparian vegetation and the ecologic functioning of the riparian zone. Activity-induced increases of the wetted perimeter of the channel during flooding will enhance the recruitment of terrestrial organic material. Additionally, the creation, restoration, and enhancement of wetlands in both coastal and riparian environments will typically produce a biogeochemical buffer between terrestrial pollution sources and aquatic environments.

7.6.1.5.1 Altered Allochthonous Export

Most riparian wetland enhancement activities entail the promotion of river-floodplain connectivity and thus the export of coarse particulate organic matter (CPOM) to the channel (Junk et al. 1989; Tockner et al. 1999). Floodplains have been shown to produce nutrient-rich organic matter (i.e., more live algae than decaying organic matter) that can serve as an important food resource for zooplankton (Muller-Solger et al. 2002; Schemel et al. 2004) and thus bolster aquatic food webs. The literature indicates that any activity which promotes the reconnection of once severed floodplain-channel pathways can be expected to have a net benefit for aquatic organisms (Crain et al. 2004; Schemel et al. 2004; Tockner et al. 1999). This is partially due to the fact that floodplains are vital for the transfer of energy (in the form of carbon) from terrestrial ecosystems to aquatic, especially in lowland river systems (Junk et al. 1989; Thoms 2003).

Estuarine wetland enhancement will also likely increase the productivity and connectivity between shallow water and open water habitat. The transfer of energy (in the form of carbon) between these habitats is complex. Initially it was assumed that shallow water habitat exported detrital carbon to open water systems thus forming the base of the detrital food web. However, later research indicated that this transfer was highly variable from one estuary to the next (Stevens et al. 2006). Recent research has indicated that a pathway for energy transfer between these systems may be found through trophic pathways. Piscivorous fishes which reside in open water habitat frequently feed on small fishes which reside in shallow water habitat. The result is a transfer of biomass which can amount to 2 percent of shallow habitat primary productivity

(Stevens et al. 2006). Restored estuarine wetlands would, in theory, increase productivity and thus augment this trophic transfer of energy.

7.6.1.5.2 Altered Buffering Capability

Wetlands along riverine corridors and shorelines are an ecotone between upland and aquatic environments. Wetlands have been called the kidney of the landscape (Mitsch and Gosselink 2000) because of the ability of these ecotones to sequester and transform nutrients and pollutants. Wetland creation, restoration, and enhancement in riparian and coastal zones may contribute to the increased retention of pollutants within those systems. In a comprehensive literature review by Hickey and Doran (2004) it was noted that buffer widths need to be in excess of 98 ft (30 m) wide to protect the chemical and physical integrity of the stream. This width ensures that the hydraulic residence time within the buffer zone is sufficiently high for the treatment processes–including sedimentation, uptake, and sequestration–to be effective. This research is applicable to wetlands because both buffer areas and wetlands must be designed with a sufficiently high hydraulic residence time to allow pollutants to be processed.

If designed correctly, wetland creation, restoration or enhancement activities can reduce upland pollutant loadings, including sediment, nutrients, and toxic substances, to downstream aquatic resources. This in turn will benefit any HCP species which may reside within the downstream freshwater or marine system. Consequently, this benefit must be accounted for when assessing project-related impacts.

7.6.1.6 Water Quality Modifications

As noted above, riverine and estuarine wetlands are effective pollutant filters which have been shown in numerous studies to reduce metals (Sheoran and Sheoran 2006), nutrients (Vellidis et al. 2003), and sediment (Tockner et al. 1999) loading. Because wetlands are located between uplands and water resources, they can intercept runoff from the land before it reaches open water. As runoff and surface water pass through these systems, wetlands remove or transform pollutants through physical, chemical, and biological processes. In aquatic systems that exhibit degraded water quality, the reduction of these pollutants through wetland creation, restoration or enhancement would benefit many of the HCP species.

7.6.1.6.1 Altered Suspended Solids

Riverine wetlands are areas of river channels that are occasionally-to-permanently flooded. These areas can be nonvegetated or vegetated by submersed and nonpersistent emergent aquatic plants. Estuarine wetlands are typically found on the deltas and in the lower reaches of most of the rivers in western Washington and are also nonvegetated or vegetated by submersed and nonpersistent emergent aquatic plants (Ecology 2005; USGS 1997). Emergent vegetation slows water velocities and decreases wind induced mixing. This results in quiescent waters and an associated settling of suspended particles (Kadlec and Knight 1996). Studies have indicated that riparian wetlands can decrease influent suspended solids loadings and concentrations by 90 percent or more (Michael 2003; Tockner et al. 1999). Wetland creation, restoration, or enhancement activities intended to reduce suspended solids would reduce suspended solids in adjacent waters and likely benefit HCP species that are sensitive to elevated turbidity.

During the construction phase, wetland activities will temporarily increase suspended solids concentrations in hydraulically connected waters. The increased concentrations of suspended solids will have a short term impact on fish and invertebrates. A discussion of increased suspended solids impacts on fish and invertebrates is presented in Section 7.10 (*Discussion of Common Stressors*).

7.6.1.6.2 Altered Pollutant Loading

There is a wealth of literature which has dealt with the use of wetlands for pollutant reduction in aquatic systems. Wetlands are characterized by quiescent waters and thus sedimentation is a primary mechanism of pollutant treatment (Kadlec and Knight 1996). Wetlands have been used in Washington to reduce nutrient loading from fish hatcheries (Michael 2003), and to reduce metals and nutrient loading from urban areas (Reinelt and Horner 1995). In each case, the wetlands proved to be effective sinks for the study's constituents. Wetland creation, restoration, and enhancement would increase the area of wetland where this treatment could be implemented. Historic draining and infilling of wetlands in the state of Washington (Ecology 2005; USGS 1997) has reduced the capacity of the landscape to process pollutants. This has resulted in increased pollutant loading and the degradation of aquatic ecosystems. Activities that result in the increase of wetland habitat will result in reduced pollutant loading to adjacent water bodies that may be inhabited by HCP species. The stressors associated with degraded water quality (i.e., elevated suspended solids and pollutants) are discussed in Section 7.10 (*Discussion of Common Stressors*).

7.6.2 Summary of Impact on Aquatic Fauna

7.6.2.1 Impact on Fishes

When riparian wetlands are properly functioning they become productive habitats that benefit HCP species (Feyrer et al. 2006; Gray, Simenstad et al. 2002; Hall and Wissmar 2004; Swales and Levings 1989). Chinook salmon that rear on floodplains have been shown to grow faster than those rearing in adjacent channels (Sommer et al. 2001). In a 1995 study, Bayley (1995) found that multispecies fish yields from over 40 floodplains from around the world were 50 to 200 percent higher than in equivalent slackwater habitat (e.g., impoundments, nonfloodplain lakes). Wetland creation, restoration, and enhancement will benefit HCP species by promoting lateral exchange between the river and its floodplain. This lateral exchange will create more access to productive habitat and act as an avenue for the transport of food resources to the channel. This connectivity between riparian wetlands and adjacent waters is vital for fishes which utilize both habitats. However, too much connectivity can result in productivity decreases (Ahearn et al. 2006), and if there is too little connectivity in the system, stranding could become an issue. In a study in the lower Chehalis River, Henning et al. (2006) collected data on juvenile coho salmon in both natural wetlands and wetlands that were enhanced with weirs designed to promote connectivity. They found that enhanced wetlands had significantly higher age-1 abundance of coho than untouched wetlands that were a similar distance from the main-stem river. This study provides direct evidence that wetland enhancement can benefit HCP species in Washington. HPAs issued under this activity should account for this potential benefit when assessing the project impacts.

Estuarine wetlands and salt marshes are used by juvenile coho, Chinook, and chum salmon for rearing (Hood 2004; Salo 1991). Salt marshes also represent a food source to these fishes and other HCP species (Tanner et al. 2002). Therefore, restoring marshes does not negatively impact fish. Even in worst-case scenarios where invasive species have compromised the original design function, invasive species (e.g., *Spartina lateriflora*) may also provide some of the habitat functions of a natural marsh (albeit more limited than from undisturbed settings) (Ferraro and Cole 2007).

The negative impacts on fish associated with wetland creation, restoration, and enhancement will be generated primarily from construction activities. These impacts included increased noise, suspended solids, and fish handling and exclusion. These impacts will, however, be ephemeral and will likely be outweighed by the ecosystem benefits the wetland provides.

7.6.2.2 Impact on Invertebrates

There is considerably less research on riparian wetland habitat and invertebrates. The HCP freshwater invertebrate species will not utilize riparian wetland habitat, however they will benefit from the ecosystem functions provided by wetland habitat. It can be inferred that those activities that improve water quality will also benefit the invertebrates that require clear water (e.g., Great Columbia River spire, California floater). Additionally, both the California floater and Western ridged mussel have parasitic larval stages that rely on fish gills for gestation and distribution (WDNR 2006b). Consequently, any activity that increases fish habitat and therefore abundance, such as wetland creation or restoration, may also benefit these invertebrates. Finally, Gray et al. (2002) conducted a comparative analysis of restored estuaries in the lower Salmon River, Oregon and found that invertebrates significantly increased within 2 or 3 years after the estuaries were enhanced.

Invertebrates will be negatively impacted during the construction phase due to elevated suspended solids, but these short-term impacts will likely be outweighed by the ecosystem benefits the wetland provides.

In summary, the primary stressors to fish and invertebrates associated with the creation, restoration, and enhancement of wetlands are:

- Fish handling/exclusion
- Noise (temporary)
- Elevated suspended solids (temporary).

These stressors will likely be associated with minimal impacts because the majority of the work will occur away from sensitive habitat areas and will occur over a relatively short duration.

Section 7.10 (*Discussion of Common Stressors*) presents the research to date concerning the effect of these stressors on fishes and invertebrates, while Section 9 (*Potential Risk of Take*) assesses the potential for take. The potential benefits of wetland creation include:

- Increased refugia
- Increased foraging and rearing habitat through increased floodplain connection
- Increased pollutant and nutrient retention.

7.7 Beach Nourishment

This section addresses the impact mechanisms associated with beach nourishment. Beach nourishment has been practiced on the East and Gulf Coast of the US and in Europe for at least 50 years (Komar 1998; NRC 1995). These environments are significantly different than most of Washington's marine shorelines (Finlayson 2006), with the exception of the outer coast. Regardless of the differences between these environments, these long-term, large-scale studies provide insight into the potential ramifications of expanding beach nourishment activities in Washington. The impact mechanisms cited by these studies, as well as the few studies conducted in Washington waters, are weighed against the beneficial impact of beach nourishment on HCP species, and an estimate of the effect on fish and invertebrates is presented.

7.7.1 Impact Mechanisms

There are five primary mechanisms of impact in marine environments due to beach nourishment activities: construction activities, hydraulic and geomorphic modifications, riparian vegetation modifications, aquatic vegetation modifications, water quality modifications and habitat accessibility modifications. Beach nourishment is specifically designed to initiate hydraulic and geomorphic changes. As a result, most of the direct mechanisms of impact are hydraulic and geomorphic in nature. However, most of the effects on fish and invertebrates arise primarily due to the other submechanisms that occur as a result of those hydraulic and geomorphic changes. As a result, there is a substantial amount of cross-referencing in this section. Section 7.7.2 (*Summary of Impact on Aquatic Fauna*) deals with the associated impact on aquatic fauna.

7.7.1.1 Construction Activities

Construction activities will be highly site specific. If the nourishment occurs from a barge using dredged sediments from offshore, there will be no impact associated with vehicles or riparian disturbance; however, vessel impacts will be important. The opposite would be true if the nourishment project is staged onshore (Speybroeck et al. 2006). Most likely, the greatest construction-related impact from beach nourishment activities will come from increased turbidity and burial of invertebrate organisms during the construction phase.

7.7.1.1.1 Bank, Channel, and Shoreline Disturbance

Studies have indicated that invertebrate populations decline after beach nourishment activities due to burial. On average, beach nourishment activities involve the deposition of 3.2–8.2 ft (1–2.5 m) of sediment on the nearshore. This results in a burial depth that no invertebrate can withstand, and thus a complete die-off of the resident benthic macrofauna (Speybroeck 2006). The recolonization of the added sediment is not always rapid. Peterson et al. (2006) noted a dramatic reduction in macroinvertebrate population for more than a year after construction of a course beach in North Carolina. Consequently, burial is one of the primary impact mechanisms associated with beach nourishment activities.

For the large majority of projects, elevated turbidity associated with construction activities will not pose a great threat to aquatic organisms because the turbidity levels do not reach lethal levels (Wilber et al. 2006) and the pulse of suspended solids will be short-lived (Speybroeck et al. 2006).

7.7.1.2 Geomorphic and Hydraulic Modifications

Beach nourishment, as it is practiced in Washington State, is primarily designed to restore a more natural (gradual) beach profile in response to either the loss of sediment supply (usually by dams or armored bluffs), increased wave energy associated with shoreline armoring, or to supplement and protect placed fill (Shipman 2001). Because the geometry of the shoreline and beach profile is changed, these modifications can produce the same submechanisms of impact as shoreline modifications (as described in Herrera [2007a]), albeit to a lesser extent because wave reflection should not occur as a result of beach nourishment. Some of these hydrogeomorphic modifications may be a net benefit to certain HCP species, while others may disturb them.

7.7.1.2.1 Altered Wave Energy

Generally speaking, the steeper the beach, the more reflective it is (Komar 1998). As beach nourishment typically lowers the beach slope (or at least minimizes and smoothes over any vertical segments), wave energy will be diminished due to this subactivity. The degree to which this occurs is strongly site dependent (NRC 1995). In many instances, the effects will be insignificant, but where beach nourishment drapes a previously armored shoreline, the potential for the restoration of a pre-development wave environment is possible.

7.7.1.2.2 Altered Nearshore Circulation

The addition of beach nourishment material will alter incoming and reflected wave energy. However, it is expected that these alterations will be insignificant. For shorelines that presently do not possess wave-driven nearshore circulation due to shoreline armoring [i.e., those in the Strait of Juan de Fuca or the outer coast (Komar 1998)], the return of a mobile substrate has the potential to restore more natural circulation patterns that could be beneficial to fish.

7.7.1.2.3 Altered Sediment Supply

The addition of mobile, or possibly more mobile, material to a shoreline has the obvious impact of increasing the sediment supply to an area in and around the nourishment activity. In areas that have been previously armored, this can regenerate a more natural beach profile (Dean and Dalrymple 2002). However, if there is significant export of sediment from the activity, adjacent areas can be detrimentally affected by burial of existing benthic communities.

It has been suggested that adding coarser material than naturally exists is a way to reduce the effects of nourishment activities on adjacent sites (NRC 2007). However, the coarsening of shorelines through nourishment activities has been shown to reduce invertebrate numbers (Peterson et al. 2006; Peterson et al. 2000), and has been discouraged by the findings of other studies (Speybroeck et al. 2006).

7.7.1.3 Ecosystem Fragmentation

The ability of beach nourishment to reconnect or disconnect pre-existing shoreline communities depends on the nature of the shoreline adjacent to the activity site. If the substrate is significantly different than the shoreline adjacent to it, or if added sediment buries aquatic vegetation, the activity may fragment the alongshore transit of HCP species (Beamer et al. 2005). This is why some researchers have recommended that the substrate used in beach nourishment activities be as close to the adjacent shorelines as possible (Speybroeck et al. 2006). Conflicting recommendations calling for the installation of a coarser substrate have been based primarily on engineering grounds (NRC 2007).

It has been well documented that beach nourishment projects can negatively impact the prevalence of invertebrates on the shoreline (Peterson et al. 2006; Peterson et al. 2000; Rakocinski et al. 1996). Furthermore, it has been shown that these reductions can also impact invertebrate predators (Peterson et al. 2006). However, invertebrate communities respond quickly to disturbance and may, in certain situations, rebound quickly from these impacts (Dernie et al. 2002). The impact of these disruptions of food sources on HCP fish is currently a data gap.

7.7.1.4 Aquatic Vegetation Modifications

The primary potential impact on aquatic vegetation from beach nourishment is burial. Eelgrass, the dominant seagrass in western Washington waters, is sensitive to large sedimentation rates (Mills and Fonseca 2003). Therefore, if there is eelgrass present near the activity site, it is possible that the activity will cause an aquatic vegetation loss. As eelgrass is a crucial component to the life history of several HCP species (Phillips 1984), these activities would likely limit or reverse gains in fish populations from the addition of loose, mobile foreshore materials.

7.7.1.5 Riparian Vegetation Modifications

As beach nourishment is primarily an activity that is staged offshore, there are limited riparian impacts. If an offshore sediment source is used, there may be no riparian impacts. In certain circumstances, beach nourishment can actually rebuild a riparian corridor lost to shoreline armoring (Nordstrom 2005). However, care should be used when significantly changing the shape of the shoreline. The shoreline in most locales in western Washington is shaped by extreme events (Finlayson 2006), and much of the fill material may be eroded extremely quickly during such events (Seymour et al. 2005). Provided construction impacts are small, beach nourishment would most likely result in a potential gain in riparian vegetation.

7.7.1.6 Water Quality Modifications

7.7.1.6.1 Suspended Solids and Turbidity

Beach nourishment activities will result in some temporary elevation of turbidity after construction activity has ceased (Wilber et al. 2006). It has been proposed that coarser sediments than occur under natural conditions can be placed to counteract the problem of turbidity and nourishment loss (NRC 2007). However, this can have a detrimental effect on nearshore life, as those species that prefer naturally finer-grained substrates are lost (Peterson et al. 2006). These recommendations have emerged from work on open, sandy coasts. For environments more like the Puget Sound and large lakes (steep, coarse, quiescent shorelines), it is less clear whether the impact on aquatic organisms would be as significant due to the diminished importance of waves and wave-induced circulation at depth (Jackson et al. 2005).

7.7.1.6.2 Altered Pollutant Loading

Although there are strong political and economic temptations to use dredged materials for large beach nourishment projects (Dobkowski 1998; Yozzo et al. 2004), extreme caution should be exercised when these types of materials are used in beach nourishment projects. Fine-grained sediments found in subtidal areas preferentially adsorb pollutants that may have accumulated during historical times when controls on pollution were not as tight as today. There is a significant risk of remobilizing pollutants into the water column both during dredging operations and during sediment resuspension events during storms (Petersen et al. 1997). In fact, it is possible to pollute the water column with naturally occurring trace metals even when the sediments have not been previously contaminated (Saulnier and Mucci 2000).

7.7.2 Summary of Impact on Aquatic Fauna

This section summarizes the current knowledge concerning the impact of beach nourishment on the 52 HCP species. There has been considerably more research on the impacts of beach nourishment to marine organisms; thus, impacts on freshwater species will be brief and are addressed in Section 10 (*Data Gaps*). Unlike most other HPAs, most of the impacts of beach nourishment can be avoided if the implementation follows certain guidelines (see Section 11 [*Habitat Protection, Conservation, Mitigation, and Management Strategies*]).

In sum, the literature suggests that beach nourishment activities provide benefits to fish that may be made at the expense of invertebrates. Because of these trade-offs, each site must be scrutinized in detail with respect to the present prevalence of invertebrates and the potential gain by fishes.

7.7.2.1 Effects on Fishes

Provided that the measures described in Section 11 (*Habitat Protection, Conservation, Mitigation, and Management Strategies*) are followed, the only hydrogeomorphic impacts on fishes will primarily be related to the restoration of a mobile substrate to the beach. Loose, mobile materials are spawning habitat for a number of HCP forage fish species (Penttila 1978; Penttila 1995). If the nourishment is done in such a way as to restore forage fish numbers, it may be possible that nourishment may also increase predator (i.e., salmonids) numbers.

In lakes, there is far less information. However, hard surfaces have been shown to be the nexus of invasive communities that compromise fish numbers in lakes (Marsden and Chotkowski 2001; Meadows et al. 2005). Beach nourishment would bury these surfaces and prevent these sorts of invasions. Nourishment would also provide the potential to restore finer-grained substrates preferred by sockeye and Chinook (Sergeant and Beauchamp 2006).

These benefits will be site specific and must take account of the impacts incurred from construction activities (i.e., increased suspended solids, increased noise, and interruption of food sources). For a more general discussion of the stressors that are the result of construction-related activities, see Section 7.10 (*Discussion of Common Stressors*). The primary construction activity impact which will affect the HCP fish species is shoreline disturbance caused by the operation of heavy machinery or large offshore vessels. This disturbance is weighed against the ecological services provided by altering nearshore substrate when the potential take is assessed in Section 9 (*Potential Risk of Take*).

7.7.2.2 Effects on Invertebrates

There have been a number of studies in the marine environment that have documented the loss of invertebrates associated with beach nourishment activities (Peterson et al. 2006; Peterson et al. 2000; Rakocinski et al. 1996). It has also been shown that these changes in invertebrates can propagate through the food web, which ultimately affects the density of their avian predators (Peterson et al. 2006). However, other studies have shown that recolonization of invertebrates is rapid when perturbed by sediment inputs (Dernie et al. 2002).

None of these studies demonstrated a loss of HCP species. However, there are stressors that result from this activity which have been shown to affect the survival of HCP species. For instance, Olympia oysters have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b). Burial of other species of mollusks has also been addressed empirically (Hinchey et al. 2006). These studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Mechanical and physiological adaptations contribute to this tolerance. If the placement location and type of materials placed as part of a beach nourishment project are chosen improperly, sedimentation rates could exceed the criterion set forth by Hinchey et al. (2006).

In lakes, there are less data. From work in the Great Lakes, beach nourishment has been shown to reduce invertebrate numbers (Garza and Whitman 2004). However, this study is from a particular area in the Great Lakes (southern Lake Michigan) which may be significantly different than the lacustrine environments often found in Washington State. Most lake shorelines in Washington that would undergo nourishment activities would be more similar to the marine shorelines in Puget Sound and the northern Great Lakes. Therefore, there is a large data gap when it comes to the effects on invertebrates in these sorts of shorelines.

In summary, the primary stressors associated with beach nourishment projects are:

- Burial
- Elevated suspended solids (temporary).

Section 7.10 (*Discussion of Common Stressors*) presents the research to date concerning the effect of these stressors on fish and invertebrates, while Section 9 (*Potential Risk of Take*) assesses the potential for take. The potential benefits of beach nourishment include:

- Increased spawning habitat
- Increased foraging and rearing habitat (if seagrasses colonize the area).

7.8 Reef Creation/Restoration/Enhancement

Artificial reefs have been placed in Washington waters for more than 70 years (NSC 2007), and several state parks (e.g., Tolmie, Fort Worden, and Saltwater state parks) contain reefs from downed vessels and other placed debris. This section addresses the mechanisms of impact on HCP species associated with reef installation. Because reefs preferentially favor particular species over others, emphasis will be placed on the trade-offs associated with the ecological transition that occurs when reefs are placed. Often in the scientific literature, the terms reefs and breakwaters are used interchangeably (Pondella and Stephens 1994). Strictly speaking, there is no difference between these terms – both are structural elements seaward of the shoreline, and often permanently submerged. However, their purposes are distinctly different. Breakwaters are employed to protect the shoreline from wave energy (Dean and Dalrymple 2002), while reefs are placed to create habitat and to potentially increase the numbers of fish and invertebrates (West et al. 1994). As a result, a reef could be installed that has no effect on the wave environment. Because of this, the discussion of wave influences is limited in this section. A more complete treatment of the hydraulic and geomorphic modifications of offshore structures that attenuate waves is provided in the Breakwaters subsection of the Shoreline Modifications white paper (Herrera 2007a).

7.8.1 Impact Mechanisms

There are two widely recognized hypotheses to explain increases in fish abundance at artificial reefs. One states that fish abundance at artificial reefs is caused by the attraction and redistribution of existing individuals, with no net increase in overall abundance. The other states that fish abundance at artificial reefs is caused by the addition of new individuals by production, leading to a net increase in overall abundance (Brickhill et al. 2005). Regardless, artificial reef placement is, in general, specifically designed to attract, collect, protect and increase the number of fishes and invertebrates that utilize hard-substrate. As a result, the primary impact of reef creation is to change the community structure of the nearshore. Other impacts are primarily incidental and unintentional. Well designed reefs will often be able to avoid these impacts altogether. Guidance for artificial reef design is provided in Section 11 (*Habitat Protection, Conservation, Mitigation, and Management Strategies*). Section 7.8.2 (*Summary of Impacts on Aquatic Fauna*) deals with the associated effects on aquatic fauna.

7.8.1.1 Construction Activities

The mechanisms of impact are highly dependent on the details of reef placement. In some cases, infrastructure is already present (e.g., the dry dock that was used to create the original reef at the Edmonds Underwater Park) and simply needs to be dismantled. In this case, there may be no impacts or only those related to temporary noise impacts associated with deconstruction. If new structures are placed, the primary impact will be burial of invertebrates. However, even in this case, artificial reefs are typically placed at depths greater than where the HCP species are found (e.g., Olympia oyster: [Baker 1995]). For details regarding noise-related impacts, see Section 7.10 (*Discussion of Common Stressors*).

7.8.1.2 Geomorphic and Hydraulic Modifications

The geomorphic and hydraulic modifications of reefs depend strongly on their depth and wave environment. If the reef is located above the closure depth, there could be effects associated with alterations in wave and nearshore circulation (discussed in detail below). If not, the effects of artificial reefs on waves and nearshore circulation can be considered negligible (Pondella and Stephens 1994).

7.8.1.2.1 Altered Wave Energy

The impact associated with artificial reefs is related to how close the top of the reef is to the closure depth. Closure depth can be calculated using a formulation posed by Hallermeier (1981):

$$h_c = 2.28H_e - 68.5\left(\frac{H_e^2}{gT_e^2}\right)$$

where h_c is the closure depth in meters, g is the gravitational acceleration 32.18 ft/s^2 (9.81 m/s^2), H_e is the wave height in meters exceeded only 12 hours per year, and T_e is the associated wave period of those waves. If the top of the reef is above the closure depth, the reef functions as a submerged breakwater. In this case, there will be hydraulic and geomorphic alterations. In sum, these alterations will diminish wave energy shoreward of the reef, while wave energy will be increased seaward of the reef (Dean and Dalrymple 2002). For details regarding wave energy alterations and their effects on fish and invertebrates, see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007a).

7.8.1.2.2 Altered Nearshore Circulation

If the reef protrudes above the closure depth, there will be an impact on nearshore circulation. Again, in this instance, the reef functions as a submerged breakwater. Breakwaters have a number of effects on nearshore circulation, including producing potentially damaging changes in water quality (Bordalo 2003). For details about the way breakwaters affect nearshore circulation, and their effects on fish and invertebrates, see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007a).

7.8.1.2.3 Altered Sediment Supply

If the reef protrudes above the closure depth, sediment transport alongshore will be disrupted and the reef will function as a breakwater. Breakwaters have been shown to disrupt the littoral transport of sediments by cutting off downdrift shorelines to sediment supply (Bowman and Pranzini 2003; Sane et al. 2007; Thomalla and Vincent 2003). For more details about the effects on fish and invertebrates from an altered sediment supply due to artificial reefs, see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007a).

7.8.1.3 Ecosystem Fragmentation

7.8.1.3.1 Altered Habitat Complexity

It is clear that more fish and invertebrates are present at reefs than in open water (Pickering and Whitmarsh 1997). The physical presence of a solid surface enables a greater diversity of organisms to grow and be protected. However, a remaining question from the hundreds of studies of artificial reefs around the world is whether reefs produce more biomass than would exist without the reef or whether they simply concentrate the existing biomass (Pickering and Whitmarsh 1997). In other words, do reefs produce or attract targeted species? Regardless of whether absolute production has increased, it has been suggested that artificial reefs can harbor significant fractions of total fish populations, particularly where natural environments have been declining (Love et al. 2006).

Rockfish are opportunistic piscivores (Yang et al. 2006). Although there have been no studies documenting rockfish preying on juvenile salmon, it is certainly possible given an increase in rockfish numbers near shore. Predation on salmonids by rockfish is currently a data gap and should be considered when siting an artificial reef in marine waters.

As newly available habitat, reefs have a tendency to attract invasive species. Similar hard structures have been the site of invasive communities, both in fresh water and salt water (Marsden and Chotkowski 2001; Wasson et al. 2005). The threat appears to be somewhat correlated to the degree of human alteration of the ecosystem (Wasson et al. 2005). This implies that estuaries and lakes are more prone to invasive species than exposed marine settings. In the case of freshwater invaders, there are species that can disrupt if not eliminate resident fish populations (Marsden and Chotkowski 2001).

Finally, artificial reefs have the capability to connect existing rocky habitats, leveraging the gain from their installation (Thompson et al. 2002).

7.8.1.4 Aquatic Vegetation Modifications

Depending on the depth of placement, artificial reefs could bury or block light to aquatic vegetation. However, this would only occur in the footprint of the proposed reef. Therefore reefs should not be placed in seagrass meadows (see Section 11 [*Habitat Protection, Conservation, Mitigation, and Management Strategies]* for details).

7.8.1.5 Riparian Vegetation Modifications

Reefs, by definition, are installed away from the shoreline and therefore do not have an influence on the riparian zone.

7.8.1.6 Water Quality Modifications

Water quality modifications come from two primary sources. The first is associated with the material used to construct the reef. If the material used leaches potentially harmful chemicals into the water column, losses of fish and invertebrates could result. Also, if the material used is toxic to species that burrow, species diversity on the reef will, at a minimum, be compromised

The second source of modifications can arise from changes in nearshore circulation and wave energy. These effects will be negligible if the reef is placed entirely below the closure depth. For details about how to calculate closure depth, see the hydraulic and geomorphic modification subsection above. If the reef is placed above the influence of surface gravity waves, there will be water quality modifications associated with turbidity and nearshore circulation. These are treated in detail in the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007a), but a brief summation of impacts is described below.

7.8.1.6.1 Altered Suspended Solids

As the shoreline adapts to the change in wave energy and nearshore circulation, there is a potential for an increase in suspended solids as sediment is resuspended and redistributed. Further, the restricted circulation behind the structure could initiate eutrophication and heighten concentrations of biological colloids. Enhanced turbidity associated with shoreline erosion and accretion is discussed in depth in the Shoreline Modifications white paper (Herrera 2007a), while the affect of elevated turbidity on aquatic organisms is discussed in Section 7.10 (*Discussion of Common Stressors*).

7.8.1.6.2 Altered Pollutant Loading

Reefs have been constructed virtually out of every solid material known (Baine 2001). Therefore, it is impossible to cover all of the potential sources of contamination. However, concrete forms, used tires, and derelict vessels seem to be the most popular reef materials and these have been addressed specifically in the literature (Baine 2001).

Discarded tires are a common substrate for artificial reefs. Tires have been shown to be relatively benign from a water quality perspective (Hartwell et al. 1998); however, they can have a tendency to be mobilized during storms, resulting in the destruction of any community that has colonized the reef (USA-Today 2007). As a result, they are not recommended for artificial reef creation.

Sinking of vessels for reefs can introduce pollutants to the water column. Vessels can contain many toxic compounds including many polycyclic aromatic hydrocarbons and heavy metals. Although these sources of pollutants are supposed to be reported to the Washington State Derelict Vessel Program, small reservoirs of toxic materials may be difficult to find and may present a risk to HCP species in the vicinity of the vessel placement.

Concrete forms are usually benign if the buffering capacity of the water in question is great. Generally speaking, marine waters are sufficiently buffered to ameliorate these effects, while freshwaters (rivers and lakes) are not buffered and can experience important pH effects (Webster and Loehr 1996). The construction of freshwater reefs using concrete can affect the pH of surrounding waters if the uncured cement is allowed to contact the receiving water body. Uncured concrete can dissolve in water and, depending on the temperature, can raise the pH level to as high as 12, which is far outside the livable range for all of the HCP species (Ecology 1999). This impact will be greatest during construction when concrete wash-off and slurries come into contact with water (Dooley et al. 1999), but once construction is complete concrete may still affect the surrounding environment. Curing concrete surfaces can exhibit pH values as high as 13 during the 3 to 6 months it takes for concrete to cure underwater (Dooley et al. 1999). This elevated pH prevents attached macroalgae growth during this period.

It should be noted that these impacts will only occur when fresh concrete is used in reef creation, and artificial reefs do not usually require concrete during construction. More frequently, material (both large and small) is deposited in the nearshore without concrete footings or ballast. Even household refuse has been examined as an artificial reef material (Chapman and Clynick 2006). These authors are careful not to advocate ocean dumping of trash, but they consider the ecological consequences of removing existing trash piles. This extreme case is useful to identify the degree to which stability is a key component to artificial reef success.

Finally, there is potential for reefs to alter nearshore circulation so as to increase stratification and the potential for eutrophication (Fischer et al. 1979). For a full description of the effects of eutrophication-related low dissolved oxygen on aquatic biota see Section 7.10 (*Discussion of Common Stressors*).

7.8.2 Summary of Impacts on Aquatic Fauna

This section summarizes the current knowledge concerning the impact of reef creation on the 52 HCP species. Most of the work regarding the effects on fish and invertebrates from artificial reefs has come from studies outside of Washington State. However, many of these studies have been concerned with HCP species [as in the case of rockfishes on abandoned oil platforms (Helvey 2002; Love and York 2006)] or similar hydrogeomorphic settings [as with work conducted in the Adriatic (Clynick 2006; Guidetti et al. 2005)]. These studies have shown that rockfishes are, at a minimum, attracted to artificial reef structures. There exists the potential that reefs can increase production of these species, although this is much more controversial (Pickering and Whitmarsh 1997). Certain invertebrates are also concentrated, though there have been no studies that have documented increased concentrations of HCP species.

7.8.2.1 Effects on Fishes

The primary mechanism of impact of reef creation will be to concentrate and possibly increase the numbers of rockfish and other related piscivores in the vicinity of the reef. It has been well documented that rockfish are attracted to artificial reefs, including many HCP species (Baine 2001; Chapman and Clynick 2006; Guidetti 2004; Guidetti et al. 2005; Love et al. 2006; Love and York 2006; Pickering and Whitmarsh 1997). There could also be effects associated with hydraulic and geomorphic modifications. However, as long as the reef is placed below the closure depth, there will be no effects from hydraulic and geomorphic modifications. If the reef is above the closure depth, even at low tides, it should be considered a breakwater. The effects on fish and invertebrates from breakwaters are discussed in the Shoreline Modifications white paper (Herrera 2007a).

The primary negative effect on fish is related to the attraction of rockfish and other piscivores to nearshore locations where predation of juvenile salmonids and forage fish can occur. Because juvenile salmonids remain close to the shoreline, the effect of a reef on salmonids will be greater if the reef is placed extremely close to shore (e.g., within 100 ft). If the reef is located sufficiently far from shore, this effect is likely to be negligible.

Other negative impacts could also arise from pollution by leachates and biological invaders (Hartwell et al. 1998; Marsden and Chotkowski 2001). In both instances, freshwater reefs appear to be more prone to these negative impacts. However, well-designed reefs that take proper account of the environment that they are being deployed in should be able to avoid these effects (Pickering and Whitmarsh 1997). See Section 11 (*Habitat Protection, Conservation, Mitigation, and Management Strategies)* for details.

If properly designed and implemented, artificial reef habitat will benefit fish by providing additional foraging and refuge habitat. Artificial reefs can also provide a wide range of ecological niches as well as habitat partitioning thus allowing a greater variety of species to coexist (Brickhill et al. 2005; Oren and Benayahu 1998) as they do in natural reefs (see Shpigel and Fishelson 1989).

7.8.2.2 Effects on Invertebrates

The impact on HCP invertebrate species is less clear than for fishes. Reefs and breakwaters have been shown to collect urchins, mussels, and oysters (Bombace et al. 1994; Ponti et al. 2002). However, the oysters that have been shown to benefit most from artificial reefs are Pacific oysters (Bombace et al. 1994) which have had a tendency to displace native oysters in the Pacific Northwest and Europe (Baker 1995; Diederich 2006). Artificial reefs have also been shown to collect ascidians (Oren and Benayahu 1998) including a nonnative invasive ascidian species (*Didemnum* sp.) that is now abundant in parts of Puget Sound and southwest British Columbia (Bullard et al. 2007). However, the direct impact on potentially covered invertebrates remains a data gap.

In summary, the primary stressor which may be associated with artificial reef habitat is:

- Increased predation
- Increased suitable substrate for invasive species.

The potential for this stress on the HCP species must be weighed against the potential benefits of artificial reef habitat. These benefits include:

- Increased foraging and rearing habitat for rockfish and potentially other species.

7.9 Eelgrass and Other Aquatic Vegetation Creation/Restoration/Enhancement

Aquatic vegetation planting is the least often used technique among all habitat modification subactivities. This rehabilitation technique has been applied with mixed results in Puget Sound (Thom et al. 2005), but it is an attractive alternative considering the relative lack of impacts as compared to other nearshore restoration techniques (e.g., beach nourishment). In the nearshore, eelgrass is the dominant species of macrophyte in Puget Sound (Phillips 1984). Consequently, this section focuses on eelgrass-related research while addressing the impacts associated with aquatic vegetation creation, restoration, and enhancement.

7.9.1 Impact Mechanisms

Eelgrass has been shown to increase water clarity (Hiratsuka et al. 2007), decrease the amount of wave energy reaching the shoreline, and shown to serve as the basis for a variety of epiphytes used by several species juvenile salmonids and forage fish (Phillips 1984). In short, the presence of aquatic vegetation creates a geographically complex nearshore environment capable of sustaining a productive and diverse ecosystem (Ferraro and Cole 2007). There are relatively few impacts on HCP species owing to the lack of construction machinery and relatively small geomorphic impact the activity has on fish and invertebrates.

Macrophytes populate many floodplain ponds and are particularly abundant in the littoral zones (Ahearn et al. 2006). Consequently, any activity resulting in pond dewatering may impact macrophyte species. This can result in a substantial decrease in aquatic vegetation and the standing vegetation stock (Naiman et al. 1988). This decrease, coupled with the loss of shallow water refugia, may represent the single greatest impact on fish and invertebrates HCP species that depend on macrophyte communities.

7.9.1.1 Construction Activities

The planting of aquatic vegetation by hand typically would have a negligible impact on the nearshore environment. The only impact is the disturbance of the seabed in the vicinity of the seeding. This may increase turbidity temporarily, but it will not initiate a permanent change in the activity site. In fact, if the activity site is seeded from a buoy there are essentially no planting impacts (Pickerell et al. 2005).

7.9.1.2 Geomorphic and Hydraulic Modifications

Eelgrass has been shown to regulate current velocities adjacent to eelgrass beds. Eelgrass has also been shown to interact with waves and diminish wave energy shoreward of eelgrass meadows (Fonseca and Cahalan 1992). Although eelgrass interacts with waves and currents, it is unclear whether it is an active hydrogeomorphic agent, particularly in the Pacific Northwest where sediment transport is intense (Finlayson 2006). Given that it is buried and uprooted quite easily (Mills and Fonseca 2003), eelgrass is unlikely to survive in areas of rapid shoreline change. Further, because it is found only in limited bands in shallow nearshore areas (Boese et al. 2005), it is unlikely to affect large-scale circulation patterns.

7.9.1.3 Ecosystem Fragmentation

Eelgrass meadows are one of the most productive environments in the temperate coastal ocean (Ferraro and Cole 2007; Phillips 1984). These meadows are host to a wide variety of organisms and thereby have the capability to connect less productive environments. Because of its modest hydrogeomorphic impact, eelgrass planting is not expected to fragment existing ecosystems.

7.9.1.4 Aquatic Vegetation Modifications

Eelgrass is the dominant species of macrophyte in Puget Sound, and is also an important member of the nearshore ecosystem elsewhere in Washington marine waters (Phillips 1984). The effects of introducing eelgrass on other aquatic plant communities are unknown. However, it is clear that eelgrass provides important surface for epiphytes which serve as an important food source for juvenile salmonids and forage fish (Phillips 1984). There are numerous synergistic and competitive interactions between eelgrass and other aquatic flora and fauna (Nelson and Lee 2001). These interactions control the relative abundance of each particular species. As a result, when eelgrass in not present, the likelihood of phytoplankton blooms markedly increases (Hiratsuka et al. 2007).

7.9.1.5 Riparian Vegetation Modifications

Because eelgrass (as well as other aquatic vegetation) is prone to desiccation, it only grows at elevations well below mean tide level (Boese et al. 2005). Therefore, the restoration of aquatic vegetation does not have an impact on the riparian zone.

7.9.1.6 Water Quality Modifications

The processing and retention of sediment, nutrients, and pollutants in aquatic systems is accelerated by the presence of aquatic vegetation (Clarke 2002). Numerous studies have shown that macrophytes and algae in marine environments act to reduce ambient concentrations of suspended sediment (Abdelrhman 2003; Moore 2004), nutrients (Moore 2004), and metals (Fritioff and Greger 2003). Seagrasses have also been linked to improved water quality. As an example, Moore (2004) noted decreased nutrient concentrations and turbidity levels in seagrass beds relative to areas outside the beds along the littoral zone of the Chesapeake Bay National Estuarine Research Reserve. However, aquatic vegetation not only reduces nutrient and sediment concentrations, the plants themselves can sequester harmful trace metal pollutants and are frequently planted in wetland treatment systems with that intended function. In a comparative study of heavy metal uptake in terrestrial, emergent, and submerged vegetation, Fritioff and Greger (2003) noted that submerged vegetation was efficient at removing zinc, copper, cadmium, and lead from influent stormwater.

7.9.2 Summary of Impact on Aquatic Fauna

Eelgrass and other aquatic vegetation are an important component to a diverse and productive nearshore. Eelgrass is used extensively by salmonids and many other HCP species (Phillips 1984), although no peer-reviewed study has documented the return of these species to restored meadows.

7.9.2.1 Impact on Fishes

It has been well documented that eelgrass meadows represent important habitat for juvenile salmonids (Phillips 1984; Thom 1990). Although the efficacy of eelgrass restoration programs has recently been documented by Thom et al. (2005), this study does not report whether or not the restored areas were actually used by salmonids. However, as eelgrass communities are under continual threat from shoreline development and competition from macroalgae (Beamer et al. 2005), it is most likely that restoring eelgrass would increase the survival of juvenile salmonids.

Forage fish (e.g., Pacific herring, surf smelt) also use eelgrass meadows extensively (Johnson and Thedinga 2005). However, due to the lack of successful of eelgrass restoration projects, it has not been documented in the peer-reviewed literature whether or not these restored meadows are used by forage fish. Despite this lack of direct evidence, it is likely that the restoration of eelgrass to nearshore areas would increase the numbers of forage fish.

7.9.2.2 Impact on Invertebrates

Less work has been conducted documenting the use of eelgrass meadows by HCP invertebrate species. However, the diversity of benthic invertebrates has been shown to be correlated with eelgrass in Willapa Bay (Ferraro and Cole 2007). Also, controlled experiments of artificial seagrass beds in Portugal showed that snail populations were increased through protection from epibenthic predators, such birds and fish (Cardoso et al. 2007). Considering that eelgrass is a dominant macrophyte, it is likely that the planting and expansion of eelgrass meadows will increase invertebrate numbers.

7.9.2.3 Summary of Stresses

There are no significant construction-related stressors associated with eelgrass planting, especially if a buoyed broadcast system is used (see above).

The potential benefits of eelgrass planting include:

- Increased refugia
- Increased foraging and rearing habitat through increased floodplain connection
- Decreased pollutant and nutrient loading
- Increased beach stability through wave energy attenuation.

7.10 Discussion of Common Stressors

This section addresses the research that has monitored how fish and invertebrates respond to various stressors. When applicable, thresholds are presented beyond which there are either lethal or sublethal affects in the monitored organisms. These stressors can results from many of the previously discussed impact mechanisms. For a discussion of those stressors applicable to a specific subactivity type, see Sections 7.1 through 7.9 and the exposure-response matrices (Appendix A).

7.10.1 Elevated Temperature

Temperature is a primary metric of aquatic ecosystem health, as aquatic organisms have adapted to live within specific thermal regimes. Alterations to these thermal regimes occur at the detriment of local organisms. Thermal stress can occur through multiple direct and indirect pathways in fish and invertebrates. These include direct mortality, altered migration and distribution, increased susceptibility to disease and toxicity, and altered development, spawning, and swimming speeds (Sullivan et al. 2000). Motile organisms have the ability to avoid or evacuate those areas of extreme temperature, but even then the stress induced from periodic exposure and resulting habitat avoidance can affect organism health and contribute to mortality (Groberg et al. 1978). Each of the HCP species is ectothermic (cold-blooded); consequently, temperature is a resource that organisms use for energetic means. With organism metabolism dependent on water temperature, thermal regime may be the single-most important habitat feature controlling aquatic organisms.

A substantial amount of information is available regarding tolerances of HCP species (particularly salmonids) to thermal stress. For instance, it has been found that coho egg, alevin, and fry development is most rapid at 39°F (4°C), while alevin and fry of pink and chum salmon develop fastest at 46°F (8°C) (Beacham and Murray 1990).

Elevated water temperatures can also impair adult migration and spawning. Adult migration blockages occur consistently when temperatures exceed 70–72°F (21–22°C) (Poole and Berman 2001). Thermal barriers to migration can isolate extensive areas of potentially suitable spawning habitat and contribute to prespawning mortality. If salmon are exposed to temperatures above 57°F (14°C) during spawning, gametes can be severely affected, resulting in reduced fertilization rates and embryo survival (Flett et al. 1996). Ideal temperatures for salmonid spawning are in the range of 44–57°F (7–14°C) (Brannon et al. 2004; McCullough et al. 2001).

The majority of research on temperature impacts on aquatic species has focused on salmonids. Different species of salmonids have evolved to use different thermal regimes. Despite these differences, the majority of salmonids prefer the same temperature ranges during most life-history stages. The primary exception to this is that char (bull trout and Dolly Varden) require lower temperatures for optimal incubation, growth, and spawning (Richter and Kolmes 2005). An optimal temperature matrix is presented in Table 7-2; different species have different requirements at various life-history stages. These same temperature ranges have been adopted by Ecology and incorporated into the state water quality standards (WAC 173-201A 2006). Table 7-3 presents highest 7-day average maximum thresholds as promulgated in the state standards.

Table 7-2 indicates that there are water quality thresholds for different life-history stages which are considerably lower than the lethal limit. Fish are susceptible to a number of sublethal effects related to temperature. For instance, elevated but sublethal temperatures during smolting may result in desmoltification, altered emigration timing, and emigration barriers. Temperatures that impair smolting are above a range of between 52 and 59°F (11 and 15°C) (Poole and Berman 2001; Wedemeyer et al. 1980). Temperatures in this range have been shown to reduce the activity of gill ATPase (McCullough et al. 2001), an enzyme that prepares juvenile fish for osmoregulation in saline waters (Beeman et al. 1994). Temperature-induced decreased gill ATPase has been correlated with loss of migratory behavior in numerous salmonid species (Babanin 2006; Marine and Cech 2004; McCormick et al. 1999) and constitutes a significant impairment to juvenile survival.

Table 7-2. Estimates of thermal conditions known to support various life-history stages and biological functions of bull trout (a species extremely intolerant of warm water) and anadromous (ocean-reared) salmon.

Consideration	Anadromous Salmon	Bull Trout
Temperature of common summer habitat use	10–17°C (50–63°F)	6–12°C (43–54°F)
Lethal temperatures (1-week exposure)	Adults: >21–22°C (70–72°F) Juveniles: >23–24°C (73–75°F)	— Juveniles: 22–23°C (72–73°F)
Adult migration	Blocked: >21–22°C (70–72°F)	Cued:10–13°C 50–55°F)
Swimming speed	Reduced: >20°C (68°F) Optimal: 15–19°C (59–66°F)	— —
Gamete viability during holding	Reduced: >13–16°C (55–61°F)	—
Disease rates	Severe: >18–20°C (64–68°F) Elevated: 14–17°C (57–63°F) Minimized: <12–13°C (54–55°F)	— — —
Spawning	Initiated: 7–14°C (45–57°F)	Initiated:<9°C (48°F)
Egg incubation	Optimal: 6–10°C (43–50°F)	Optimal: 2-6°C (36–43°F)
Optimal growth	Unlimited food: 13–19°C (55–66°F) Limited food: 10–16°C (50–61°F)	Unlimited food: 12–16°C (54–61°F) Limited food: 8–12°C (46–54°F)
Smoltification	Suppressed: >11–15°C (52–59°F)	—

Source: Poole et al. 2001.
Note: These numbers do not represent rigid thresholds, but rather represent temperatures above which adverse effects are more likely to occur. In the interest of simplicity, important differences between various species of anadromous salmon are not reflected in this table, and requirements for other salmonids are not listed. Likewise, important differences in how temperatures are expressed are not included (e.g., instantaneous maximums, daily averages).

Table 7-3. Aquatic life temperature criteria in fresh water.

Category	Highest 7-DADMax
Char spawning	9°C (48.2°F)
Char spawning and rearing	12°C (53.6°F)
Salmon and trout spawning habitat	13°C (55.4°F)
Core summer salmonid habitat	16°C (60.8°F)
Salmonid spawning, rearing, and migration	17.5°C (63.5°F)
Salmonid rearing and migration **Only**	17.5°C (63.5°F)
Non-anadromous interior redband trout	18°C (64.4°F)
Indigenous warm water species	20°C (68°F)

Source: WAC 173-201A 2006 Table 200(1)(c).
Note: Aquatic life temperature criteria. Except where noted, water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax). Table 200(1)(c) lists the temperature criteria for each of the aquatic life use categories.

Additional studies, mainly in the laboratory, have developed limits for other HCP species. Wagner et al. (1997), showed that rainbow trout mortality occurred at temperatures of 67.8 to 73.0°F (19.9 to 22.8°C). Temperatures above 71.6°F (22°C) can cause deformities in developing white sturgeon, with best performance between 59 and 66°F (15 and 19°C) (Mayfield and Cech 2004). Furthermore, elevated temperatures can make white sturgeon more susceptible to infection from viruses (Watson et al. 1998). Temperatures between 73 and 79°F (23 and 26°C) can cause complete mortality in developing green sturgeon embryos, with upper limits for survival around 63–64°F (17–18°C) (Van Eenennaam et al. 2005). Dolly Varden show decreased appetite above 61°F (16°C) and lethal temperatures are observed above 68°F (20°C) (Takami et al. 1997). A lab study of the early lifestages of Pacific lamprey and western brook lamprey showed that the temperature for zero development for Pacific lamprey was 40.7°F (4.85°C) and for western brook lamprey it was 40.9°F (4.97°C), with survival greatest for both at 64°F (18°C) and lowest at 71.6°F (22°C) and abnormalities in the larval stage greatest in the 71.6°F (22°C) treatment (Meeuwig et al. 2005).

Elevated water temperatures can impair adult migration. Adult migration blockages occur consistently when temperatures exceed 69.8–71.6°F (21–22°C) (Poole and Berman 2001). Thermal barriers to migration can isolate extensive areas of potentially suitable spawning habitat and contribute to prespawning mortality. Elevated temperature regimes also affect salmonid species by altering behavior and reducing resistance to disease and toxic substances. Studies have indicated that under chronic thermal exposure conditions, aquatic organism susceptibility to toxic substances may increase. Because elevated temperatures increase metabolic processes, gill ventilation also rises proportionately (Heath and Hughes 1973). Black et al. (1991) showed that an increase in water flow over the gills that results from increased gill ventilation at increased temperature, resulted in the rapid uptake of toxicants including metals and organic chemicals via the gills. Salmonids also become more susceptible to infectious diseases at elevated temperatures (57–68°F [14–20°C]) because immune systems are compromised (Harrahy et al. 2001), while bacterial and viral activity is accelerated (Tops et al. 2006). In nearshore areas where temperature (as well as pollutant levels) may be elevated, the combined effect of thermal and water pollution may be a primary driver of salmonid decline.

Considerably less research exists defining thermal criteria for invertebrates, although marine invertebrates can generally withstand higher temperatures. Gagnaire et al. (2006) noted that elevated temperatures caused blood cell mortality in Pacific oysters but not until temperatures exceeded 104°F (40°C), which is unlikely even in altered settings. In studies on the northern abalone, optimal growth rates were found between 44 and 62°F (7 and 17°C) (Hoshikawa et al. 1998) with significant mortality at 32.9°F (0.5°C) and 79.7°F (26.5°C) (Paul and Paul 1998). It is unclear, however, what sublethal effect(s) may be a significant factor with invertebrate populations.

7.10.2 Elevated Suspended Solids

Increased turbidity has a number of effects on HCP species. In general, the response of aquatic biota to elevated suspended solids concentrations is highly variable and dependent upon life-history stage, species, background suspended solids concentrations, and ambient water quality. Appendix A provides summary tables of the research that has been conducted on the effects of suspended solids on fish and invertebrates. The following sections provide detailed information on some of those findings.

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

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

7.10.2.1 Effects of Suspended Solids on Fish

7.10.2.1.1 Lethal Effects

Although juveniles of many fish species thrive in rivers and estuaries with naturally high concentrations of suspended solids, studies have shown that the suspended solids concentration (as well as the duration of exposure) can be an important factor in assessing risks posed to salmonid populations (McLeay et al. 1987; Newcombe and MacDonald 1991; Servizi and Martens 1987). Lake and Hinch (1999) found suspended solids concentrations in excess of 40,000 ppm to elicit stress responses in juvenile coho salmon. Suspended solids concentrations this high would likely only be associated with construction activities. However, other studies have shown lethal effects at much lower concentrations.

Servizi and Martens (1991) exposed juvenile coho salmon to natural Fraser River suspended solids and found a 96-hour LC_{50} (the concentration at which a 50 percent population mortality was observed) of only 22,700 ppm. Using the identical apparatus and sediment source, juvenile sockeye salmon had a 96-hour LC_{50} of 17,600 ppm (Servizi and Martens 1987), and juvenile Chinook salmon had an LC_{50} of 31,000 ppm (Servizi and Gordon 1990). With lethal effects at concentrations as low as 17,600 ppm it is obvious that, for at least some species, the sublethal effects of suspended solids occur at even lower concentrations.

For white sturgeon, laboratory studies have shown that the survival of developing embryos was reduced to 5 percent in the presence of 0.19–0.8 in (5–20 mm) thick layers of sediment compared to over 80 percent survival in controls (Kock et al. 2006).

7.10.2.1.2 Sublethal Effects

Studies on a variety of fishes, including sockeye and Chinook (Newcomb and Flagg 1983), coho, four-spine stickleback, cunner, and sheepshead minnow (Noggle 1978), attribute the observed chronic and acute impacts from high suspended solids to a reduced oxygen uptake (Wilber and Clarke 2001). Fish must keep their gills clear for oxygen exchange. In the presence of high loadings of suspended solids, they engage a cough reflex to perform that function. Due to increased metabolic oxygen demand with increased temperatures and the need to keep pathways free of sediments for oxygen uptake, increased temperature and reduced oxygen levels combine to reduce the ability of fish to cough and maintain ventilation rates. The stress induced by these conditions can lead to compromised immune defenses and reduced growth rates (Au et al. 2004). Sigler et al. (1984) noted reduced growth rates in juvenile steelhead and coho salmon at suspended solids concentrations as low as 100 ppm, while Servizi and Martens (1992) noted increased cough frequency in juvenile coho at concentrations of approximately 240 ppm.

Indirect effects on fish through alteration of their food source have been documented. Suttle et al. (2004) observed that steelhead trout were affected by increased sediments because it caused a shift to burrowing macroinvertebrate taxa that then became unavailable to them as a food source.

7.10.2.1.3 Behavioral Effects

Aksnes and Utne (1997), Mazur and Beauchamp (2003), and Vogel and Beauchamp (1999) all report that suspended solids at sublethal concentrations have been shown to affect fish functions such as avoidance responses, territoriality, feeding, and homing behavior. Similarly, Wildish and Power (1985) reported avoidance of suspended solids by rainbow smelt and Atlantic herring to be at 20 ppm and 10 ppm, respectively. However, it also appears that under certain circumstances elevated suspended solids may actually benefit salmonids by providing cover (Gregory and Levings 1998) or triggering a sense of predation cover for salmonids (Gregory 1993). The studies of Gregory and Northcote (1993) indicated that when suspended solids concentrations exceeded 200 ppm, juvenile salmon increase their feeding rates while demonstrating pronounced behavioral changes in prey reaction and predator avoidance.

In studies of coho behavior in the presence of short-term pulses of suspended solids, Berg and Northcote (1985) found that territorial, gill flaring, and feeding behaviors were disrupted. At turbidity levels of between 30 and 60 nephelometric turbidity units (NTUs), social organization broke down, gill flaring occurred more frequently, and only after a return to a turbidity of 1–20 NTUs was the social organization re-established. Similarly, feeding success was also found to be linked to turbidity levels, with higher turbidity levels reducing prey capture success.

Finally, in a study of dredging impacts on juvenile chum in Hood Canal, Salo et al. (1980) found that juvenile chum salmon showed avoidance reactions to high turbidity levels. These behavioral thresholds vary across species and life-history stages. Consistent with their early reliance on nearshore estuarine habitats with relatively high turbidities compared to pelagic or freshwater habitats, juvenile chum are classified as turbidity tolerant compared to other fishes (Salo et al. 1980).

7.10.2.1.4 Habitat Effects

Increased suspended solids are known to compromise submerged aquatic vegetation (Parkhill and Gulliver 2002; Terrados et al. 1998) such as eelgrass (Erftemeijer and Lewis 2006) which is associated with important rearing habitats for a suite of marine fishes including Pacific cod, Pacific salmon, rockfish, Pacific herring, and walleye pollock (Nightingale and Simenstad 2001a; Simenstad et al. 1999). In a study of the impact of sedimentation on seagrass in Southeast Asia, Terrados et al. (1998) noted approximately a 50 percent decline in the number of seagrass species and a 150 percent decline in seagrass biomass with a 15 percent increase in clay content of the sediments. Numerous studies have shown increased biomass within seagrass beds for invertebrates (Cardoso et al. 2007; Seitz et al. 2005) and vertebrate species (Ferraro and Cole 2007; Pihl et al. 2006); thus, sedimentation-related negative impacts on seagrass arising from the construction or presence of flow control structures would likely affect the HCP species by decreasing available nearshore habitat.

7.10.2.2 Effects of Suspended Solids on Invertebrates

Burial of invertebrate species which have limited motility can lead to organism mortality as a direct effect from increased suspended sediments. Burial of invertebrate species will occur most frequently during the construction phase of a project. Limpets in intertidal habitat are affected by smothering and interference with feeding activity. In a field study in the UK, grazing by limpets (*Patella vulgata*) was decreased by 35 percent after the addition of fine sediments, to as little as 0.04 in (1 mm) thick (equivalent to 1.02 x 10^{-5} lb/ft^2 [50 mg/m^2]) with mortality and inhibition of feeding at higher levels of fine sediment (4.09 x 10^{-5} lb/ft^2 200 mg/m^2]) (Airoldi and Hawkins 2007). The burial of mollusks and related stress or mortality resulting from partial and complete burial have been addressed empirically (Hinchey et al. 2006). Results of these studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Mechanical and physiological adaptations contribute to this tolerance. Olympia oysters have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b) Thus, it can be inferred that burial of these organisms would lead to mortality.

As with dissolved oxygen, invertebrates tend to thrive across a wide range of suspended solids concentrations. Negative impacts on eastern oyster egg development have been shown to occur at 188 ppm total suspended solids (Cake 1983). Hardshell clam eggs appear to be more resilient, with egg development affected only after total suspended solids concentrations exceeded 1,000 ppm (Mulholland 1984). Mulholland (1984) showed that suspended solids concentrations of

<750 ppm allowed for continued larval development but higher concentrations for durations of 10–12 days showed lethal effects for both clams and oysters.

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

Thresholds for lethal effects on clams and eastern oysters have been reported, with negative impacts on eastern oyster egg development occurring at 188 ppm of silt (Cake 1983) compared to a 1,000 ppm threshold for hardshell clam eggs (Mulholland 1984). Suspended solids concentrations of <750 ppm allowed for continued larval development, but higher concentrations for durations of 10–12 days showed lethal effects for both clams and oysters.

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

7.10.3 Decreased Dissolved Oxygen

Dissolved oxygen (DO) content is critical to the growth and survival of all 52 HCP species. The amount of oxygen dissolved in water is dependent on temperature, physical mixing, respiration, photosynthesis, and, to a lesser degree, atmospheric pressure. These parameters can vary diurnally and seasonally and depend on activities such as daytime photosynthesis oxygen inputs and night-time plant respiration processes that deplete dissolved oxygen levels. Dissolved oxygen concentration is temperature dependent; as temperatures rise, the gas-absorbing capacity of the water decreases and the dissolved oxygen saturation level decreases. Reduced dissolved oxygen levels can be due to increased temperature (Snoeyink and Jenkins 1980), organic or nutrient loading (Ahearn et al. 2006), increased benthic sedimentation (Welch et al. 1998), or chemical weathering of iron and other minerals (Schlesinger 1997).

Juvenile salmon are highly sensitive to low dissolved oxygen concentrations (USFWS 1986) and, consequently, are among the more vulnerable HCP species with regard to dissolved oxygen impairment. Salmon generally require dissolved oxygen levels of greater than 6 ppm for optimal survival and growth, with lethal 1-day minimum concentrations of around 3.9 ppm (Ecology 2002). Different organisms at different life-history stages require different levels of dissolved oxygen to thrive. Tolerance for low oxygen levels varies across other species as well. For example, pygmy whitefish can withstand dissolved oxygen conditions below 5 ppm (Zemlak and McPhail 2006). Table 7-4 lists the minimum recommended dissolved oxygen concentrations for salmonids and stream-dwelling macroinvertebrates (Ecology 2002). The dissolved oxygen thresholds presented in this table were derived from more than 100 studies representing over 40 years of research.

It should be noted that recommendations are presented in Table 7-4 for dissolved oxygen thresholds in categories other than lethality. Fish are motile organisms and, where possible, will avoid dissolved oxygen levels that would cause direct mortality. (Fish eggs, of course, are not motile and mortality will result if eggs are exposed to dissolved oxygen concentrations below the thresholds indicated for eggs in Table 7-4.) However, this avoidance behavior in and of itself can affect fishes. Stanley and Wilson (2004) found that fish aggregate above the seasonal hypoxic benthic foraging habitat in the Gulf of Mexico, while Eby et al. (2005) found that fish in the Neuse River estuary (North Carolina) were restricted by hypoxic zones to shallow, oxygenated areas where in the early part of the summer about one-third fewer prey resources were available. Studies such as these reveal how dissolved oxygen can change fish distributions relative to habitat and potentially exclude fishes from reaching spawning, foraging, and rearing areas. Sublethal dissolved oxygen levels can also cause increased susceptibility to infection (Welker et al. 2007) and reduced swim speeds (Ecology 2002), both of which may cause indirect impacts on HCP fish species.

Little consensus exists concerning low dissolved oxygen criteria for macroinvertebrates, and tolerances to hypoxic conditions are taxonomically specific. Many invertebrates are adapted to live in benthic, low-energy environments where dissolved oxygen concentrations are naturally low; consequently, these organisms can withstand hypoxic conditions. Other taxa, including Hirudinea, Decapoda, and many aquatic insects, tolerate dissolved oxygen levels below 1.0 ppm (Hart and Fuller 1974; Nebeker et al. 1992). Kaller and Kelso (2007) found benthic macroinvertebrate density, including mollusks, greatest in low dissolved oxygen areas of a Louisiana wetland, while a literature review by Gray et al. (2002) noted that in marine environments, invertebrates were not affected by low dissolved oxygen until concentrations fell below 1–2 ppm. Benthic dissolved oxygen levels can seasonally drop below this threshold in productive systems that receive high biochemical oxygen demand (BOD) loadings. For instance, depressed benthic dissolved oxygen levels in Hood Canal, Washington, have been associated with spot shrimp decline (Peterson and Amiotte 2006). This dissolved oxygen decline in turn has been linked to BOD loadings from leaking or improperly functioning on-site wastewater systems. These conditions in Puget Sound highlight the importance of reducing anthropogenically generated BOD.

Table 7-4. Summary of recommended dissolved oxygen levels for full protection (approximately less than 1 percent lethality, 5 percent reduction in growth, and 7 percent reduction in swim speed) of salmonid species and associated macroinvertebrates.

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

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

7.10.4 Elevated Pollutants and Nutrients

7.10.4.1 Hydrocarbons

Operation of backhoes, excavators, and other equipment will require the use of products such as fuel and lubricants that, if spilled into a water body or the adjacent riparian zone, can injure or kill aquatic organisms (NMFS 2005). Petroleum based contaminants, such as fuel, oil, and some hydraulic fluids, contain polycyclic aromatic hydrocarbons (PAHs) that could be acutely toxic to salmonids at high levels of exposure and could also cause chronic lethal, and acute and chronic sublethal effects to aquatic organisms (Hatch and Burton 1999). Misitano et al. (1994) exposed larval surf smelt to Puget Sound (Eagle Harbor) sediments with high concentrations of PAHs and found 100 percent mortality after 96 hours of exposure. After diluting the sediments and repeating the experiments, they found that those larvae that did not expire within 96 hours suffered from decreased growth rates. Table 7-5, adapted from Jones & Stokes (2006) and Stratus (2005), depicts effects thresholds for PAHs in surface water for Pacific herring, zooplankton, mysids and marine amphipods, and trout.

Table 7-5. Effects thresholds for PAHs in surface water.

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

Sources: Jones & Stokes 2006 and Stratus 2005.

Organic chemical contaminants can also impact prey production by limiting the suitability of substrates in the impacted area. Fish eggs can be particularly vulnerable to chemical contaminant exposure due to their inability to move out of the impacted area. Invertebrates can be similarly vulnerable due to the inability to move (or move quickly) out of the impacted area.

7.10.4.2 Eutrophication

Eutrophication occurs when limits to vegetative growth are reduced. When nutrient limitations are eliminated, vegetative growth increases. This process accelerates carbon fixation; the additional carbon loading to the aquatic system increases respiration as heterotrophs use carbon for energy. Through the process of carbon oxidation, oxygen is converted to carbon dioxide (CO_2) and ambient dissolved oxygen levels decrease. Eutrophication-induced hypoxia is a nationwide problem (Scavia and Bricker 2006). In Washington, low dissolved oxygen episodes in Hood Canal have resulted in widespread fish and invertebrate kills (Peterson and Amiotte 2006). These low dissolved oxygen episodes have been linked to excess carbon loading due to nutrient enrichment. Resultant algal blooms may not only impact dissolved oxygen levels but may also, if certain species flourish, contribute to paralytic shellfish poisoning (Horner 1998). The ramifications of low dissolved oxygen on the 52 HCP species are addressed above and in Section 9 (*Potential Risk of Take*).

7.10.4.3 Metal Toxicity

In urban environments, metals loading to local waterways and water bodies from anthropogenic sources is a major pathway for aquatic habitat degradation. The primary metals of concern in the surface waters of Washington State are copper, zinc, arsenic, lead, and nickel (Embrey and Moran 2006). Metals above threshold concentrations act as carcinogens, mutagens, and teratogens in fish and invertebrates (Wohl 2004). Additionally, the sublethal effects of copper toxicity have been extensively studied with reported effects including impaired predator avoidance and homing behavior (Baldwin et al. 2003). The Washington State Department of Ecology has established water quality standards for marine and fresh waters for each of these constituents. These standards, issued in WAC 173-201A, are listed in Table 7-6. Freshwater toxicity thresholds are hardness-dependent and can vary widely depending on calcium and magnesium carbonate concentrations. The standards presented here are based on median hardness concentrations estimated from an extensive 3-year data set (2001–2003) from the Green River watershed (Herrera 2007c).

Table 7-6. Water quality criteria for metals in marine and fresh waters of the state of Washington.

Constituent	Freshwater		Marine	
	Acute	Chronic	Acute	Chronic
Arsenic	360	190	69	36
Copper	7	7.5	4.8	3.1
Lead	22.9	1.5	210	8.1
Nickel	640	104	74	8.2
Zinc	51.6	69.2	90	81

Units: ports per billion (ppb).
Adapted from: WAC 173-201A.

7.10.5 Elevated Underwater Noise

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

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

7.10.5.1 Measurement of Underwater Noise

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

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

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

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

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

7.10.5.2 Project-Related Noise Sources

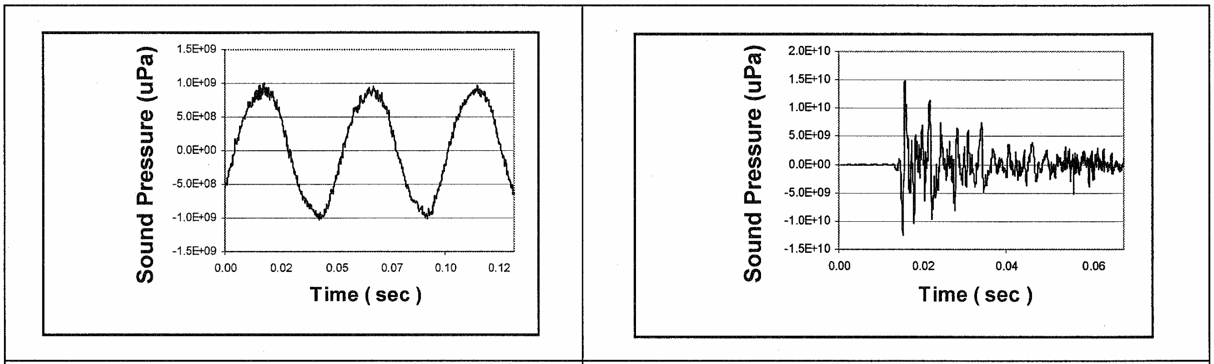
The underwater noise produced by an HPA permitted project, either during construction or operation, is defined by the magnitude and duration of underwater noise above ambient noise levels. The action area for underwater noise effects in ESA consultations is defined by the distance required to attenuate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

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

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

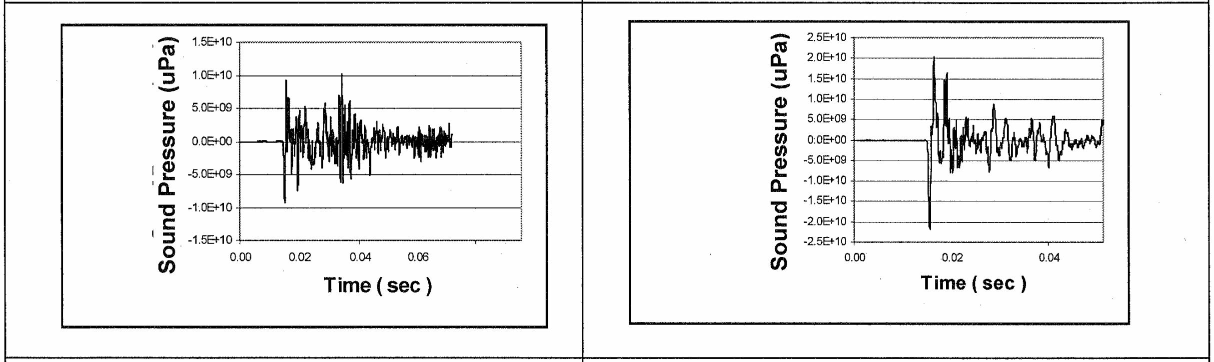
Piling composition also influences the nature and magnitude of underwater noise produced during pile driving. Driven piles are typically composed of one of three basic material types: timber, concrete, or steel (although other special materials such as plastic may be used). Steel piles are often used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

In comparison to pile driving, data on noise levels produced by placement of other construction related materials is limited. For example, measured noise levels associated with work on the Friday Harbor ferry terminal ranged between 133 dB_{peak} and 140 dB_{peak}, excluding pile driving. These noise levels were slightly higher than ambient levels, which include routine vessel traffic (Laughlin 2005). Nedwell et al. (1993) measured noise produced by underwater construction tools such as drills, grinders, and impact wrenches at 3.28 ft (1 m) from the source. When corrected for a reference distance 32.8 ft (10 m) from the source using the practical spreading loss model, the noise associated with these sources ranged from approximately 120 to 165 dB_{peak}. These data suggest that noise associated with these activities, such as in-water tool use, placement of large rock and similar material, vessel operation, and in-water operation of heavy machinery, will generally produce substantially lower noise levels than those associated with pile driving. However, other construction-related noises may generate continuous noise for longer periods with the effect of elevating ambient noise levels or masking ambient noises in the aquatic environment that fish would ordinarily use to identify prey and predators.



Vibratory Hammer wave form—set duration

Air or steam-driven hammer wave form—single strike



Diesel hammer wave form—single strike

Hydraulic hammer wave form—single strike

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

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

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

[a] Metric distances are listed as they were provided in the source material; 9 m = 29.5 ft; 10 m = 32.8 ft; 11 m = 36 ft; 30 m = 98 ft; 100 m = 328 ft.

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

7.10.5.3 Direct and Indirect Effects on Fish

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

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

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

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

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

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

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

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

7.10.5.4 Direct and Indirect Effects on Invertebrates

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

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

7.10.6 Fish Handling/Exclusion

In many cases, construction of HPA-permitted projects may require the exclusion of streamflows or even the dewatering of the work area to protect aquatic life and/or provide a suitable environment for construction. These activities have the potential to cause direct and indirect effects on HCP species. Fish exclusion and dewatering involve the placement of barriers (e.g., block nets, temporary berms, cofferdams) around a work area and the capture and removal of fish and other aquatic life within the work area. Electrofishing is a common practice used for fish capture in freshwater environments, as is the use of minnow traps, hand nets, beach seines, and other net-based capture methods. As electrofishing is ineffective in brackish or salt water, net-based capture methods are used in these environment types.

The direct effects of fish exclusion and dewatering include:

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

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

7.10.6.1 Direct and Indirect Effects on Fish

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

It is notable that electrofishing capture typically has a low direct mortality rate, but it is reasonable to conclude that injuries induced by electrofishing could have long-term effects on survival, growth, and fitness. The few studies that have examined this question found that few juvenile salmonids die as a result of electrofishing-induced spinal injury (Ainslie et al. 1998; Dalbey et al. 1996). However, fish with more injuries demonstrated a clear decrease in growth rates, and in some cases growth was entirely arrested (Dalbey et al. 1996). In the absence of additional supporting information, it is reasonable to conclude that these same effects would affect many of the HCP fish species.

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

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

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

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

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

Rewatering of the exclusion area following construction is generally expected to result in a temporary increase in turbidity. The in-water installation and removal work poses the highest risk of disturbing the stream bank and substrate, thereby resuspending sediments and increasing turbidity. Fish may experience short-term, adverse effects as a result of increased turbidity. The effects of increased turbidity during rewatering were discussed in Section 7.10.2 (*Elevated Suspended Solids*).

7.10.6.2 Direct and Indirect Effects on Invertebrates

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

The sensitivity of other HCP invertebrate species, such as giant Columbia River limpet and Columbia River spire snails is somewhat less certain. Adults may be easily removed and relocated during dewatering, but juveniles and eggs may be difficult to locate and remove effectively. This suggests the potential for mortality from stranding.

While handling related injury and mortality are relatively unlikely, relocation may lead to significant non-lethal effects. For example, scattering of closely packed groups of adult mussels may affect reproductive success. Female mussels filter male gametes from the water column, and successful fertilization is thereby density dependent for species that occur in flowing water environments (Downing et al. 1993).

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

7.10.7 Decreased Refuge

Studies have indicated that decreased habitat complexity negatively impacts the survival and growth of aquatic organisms. Reduced shelter availability will increase predation and is energetically unfavorable for fishes. In a recent study by Finstad et al. (2007) it was found that juvenile Atlantic salmon exhibit accelerated mass loss rates with decreasing access to shelter, indicating that the juvenile fish had to expend greater energy when there was no available shelter. In another study by Babbitt and Tanner (1998), tadpole survival was 32 percent greater under high than under low cover, suggesting that increased cover decreased predator foraging efficiency. Although the prey in this study were not HCP species, the effect of cover on predation rates can be extrapolated to HCP species that use vegetated cover during early life-history stages. Finally, limited habitat availability will lead to density dependent mortality for those species which cannot find unoccupied cover and may be exposed to increased predation or high energy environments (Forrester and Steele 2004).

7.10.8 Burial

Burial of invertebrate species which have limited motility can lead to organism mortality. Burial of invertebrate species will occur most frequently during the construction phase of the project. This stressor is of particular relevance for beach nourishment and spawning gravel augmentation activities. The burial of mollusks and related stress or mortality resulting from partial and complete burial have been addressed empirically (Hinchey et al. 2006). Results of these studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Mechanical and physiological adaptations contribute to this tolerance. Olympia oysters have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b). Thus, it can be inferred that burial of these organisms would lead to mortality.

8.0 Cumulative Effects

This section provides an assessment of the cumulative effects that each of the subactivity types may have on the HCP species. Each of the habitat modifications presented in this white paper will have cumulative effect ramifications. All of the habitat modification subactivity types except beaver dam and large woody debris removal aim to restore habitat function to a condition which supports a sustainable, diverse, and abundant array of native flora and fauna. Consequently, the cumulative effect of these activities is to create diverse, productive, and connected habitat mosaics which bolster the HCP species and ameliorate human impact on the environment. The full potential of these habitat modifications may not be realized until the application of the activities becomes so wide spread as to minimize the existence of the degraded habitat which today serves to fragment aquatic ecosystems across the state.

The majority of the negative impacts associated with habitat modification activities occur during the construction phase. Because the construction phase is of a short duration, these impacts tend to be ephemeral. Consequently, cumulative impacts associated with construction phase activities are unlikely to occur unless multiple projects are being constructed simultaneously and in close proximity to each other. As this is an unlikely scenario, the cumulative impacts of construction-related activities are not discussed in this section.

8.1 Beaver Dam Removal/Modifications

Before European settlement in North America, beaver populations were estimated to be between 60 and 400 million individuals (Seton 1929 in Naiman et al. 1988). Today *Castor* spp. are estimated to number between 6 and 12 million (Ringelman 1991). This represents a significant reduction in the number of impoundments which serve as habitat for beaver. The reduction in hydraulic and resource retention provided by beaver impoundments has been partially counter-balanced by the impounding of the nation's waterways for resource extraction and recreational purposes. Consequently, humans have unintentionally mitigated for a portion of the negative impact of beaver dam removal on carbon, nutrient, and water retention in watersheds.

The potential for cumulative impacts associated with beaver dam removal cannot be assessed without accounting for the cumulative impacts associated with the elimination of other barriers such as dams, diversions, and culverts. The combined effects associated with these activities will act to reduce system retentiveness and thus decrease secondary production. Additionally, a reduction in lentic habitat and access to floodplains for cover, rearing, holding, and foraging will impact numerous aquatic species. These cumulative impacts will be realized unless parallel habitat modification activities are enacted which increase retention, floodplain connection, and slack water habitat. Many of the activities discussed below will serve these functions.

8.2 Large Woody Debris Placement/Movement/Removal

The cumulative effects of reintroducing wood to rivers, streams, and shorelines is generally viewed as a positive step toward offsetting the habitat degradation resulting from the effects of historical logging, river snagging, and splash damming. Most riparian forests in Washington currently lack trees large enough to serve as key members in the formation of stable logjams (Beechie et al. 2001; Collins et al. 2002). Thus, engineered jams with large key members will serve a vital function as points of stability within fluvial systems. The cumulative effects of both wood reintroduction and the natural recovery of riparian forests will include an increase in habitat diversity (Bryant and Sedell 1995; Warren and Kraft 2003), the reconnection of floodplain and off-channel habitats (Abbe and Montgomery 1996; Fetherston et al. 1995; Warren and Kraft 2003), the moderation of punctuated sediment inputs to river systems due to sediment retention (Massong and Montgomery 2000), and an increase in the frequency and spatial extent of habitat-forming channel migration (Brummer et al. 2006).

The increase in hydraulic roughness and resident time of water following the reintroduction of wood to rivers, streams, and shorelines can have positive cumulative effects on water quality and nutrient retention. Decomposition and grazing of coarse particulate organic matter trapped with sediment behind accumulations of woody debris has been found to increase the retention of dissolved organic carbon (Lampert 1978; Sinsabaugh et al. 1994). Organic material and sediment storage resulting from increased wood loading should also promote nutrient retention (Mulholland et al. 1985) and increased uptake of phosphorus (Ensign and Doyle 2005; Valett et al. 2002). The more convoluted flow paths and more organic fines in more numerous pools provided by wood will also create increased pollutant retention while increasing ecosystem productivity (Ensign and Doyle 2005). The result will be decreased pollutant loadings to downstream systems and increased stream carrying capacity.

The cumulative effects of large woody debris removal are well known because our present day waterways have been shaped by a legacy of large scale wood removal. The removal of LWD on the watershed scale disconnects channels from floodplains (Fetherston et al. 1995), promotes channel incision (Diez et al. 2000), reduces habitat complexity (Warren and Kraft 2003), and decreases organic matter retention and pollutant removal capacity (Ensign and Doyle 2005; Valett et al. 2002). If LWD removal cannot be avoided, then mitigation strategies should be employed to ensure that there is no net decrease of wood within the water body.

8.3 Spawning Substrate Augmentation

Spawning substrate augmentation is in most cases an ephemeral solution to a lasting problem. Degraded substrate in channels is usually associated with reduced sediment supply and/or flow alteration. Gravel augmentation does not address these issues but instead provides a remedy for the effect, while the cause (i.e., geomorphic and hydrologic processes) goes untreated. In this way, spawning substrate augmentation measures are by design short-lived. If the potential positive benefits of gravel augmentations are to be realized, then continual maintenance of the site is required. Maintenance may come in the form of passive or active gravel replenishment (Bunte 2004) and will be expensive, but the cumulative effects of continual replenishment (i.e., an active, well oxygenated, and dynamically stable riffle habitat) will be the only way to prolong the life of the project to a temporal scale that will benefit salmonid spawners and their off-spring through multiple life cycles. This suggests that isolated gravel replenishments which are not maintained may not meet the restoration goals and indeed, if improperly implemented, may cause more ecosystem harm than good.

8.4 In-Channel/Off-Channel Habitat Creation/Modifications

As with most fluvial restoration projects, the more widespread the application the more likely a measurable effect will be realized. One of the primary difficulties associated with assessing the impact of in-channel and off-channel habitat modification efforts is that the biotic response may be subtle and/or not measurable in the reach where the project was initiated. This helps explain the mixed results from numerous restoration monitoring efforts (Fausch et al. 1995; Larson et al. 2001; Pretty et al. 2003). However, as the number of successful in-channel and off-channel restoration projects increase, the likelihood of observing a measurable response also increases, (Korman and Higgins 1997). There are many factors which will determine the health of a fishery and many of those factors cannot be addressed on the reach scale. Consequently, the cumulative effect of restoration efforts in channels and floodplains will not be fully realized until whole watershed and marine life-stage problems are addressed.

8.5 Riparian Planting/Restoration/Enhancement

Riparian planting in highly degraded systems needs to be conducted within the context of larger watershed restoration efforts. Riparian rehabilitation efforts that create a corridor of improved habitat downstream of a degraded watershed may not ameliorate stream conditions (Teels et al. 2006). In a study of forest fragments in agricultural areas of the South Island, New Zealand, Harding et al. (2006) found that forest fragments of 5-7 ha, located in the lower reaches of the study catchment did not mitigate the negative effects of upstream agriculture on stream functioning. They concluded that fragment size (i.e., riparian forest length), riparian forest width and vegetation type, and fragment location in the catchment may have critical roles in enabling forest fragments to reset the negative impacts of agriculture. This study suggest that in highly impacted watersheds, the cumulative impact of multiple riparian planting projects is vital for the improvement of the stream and its biota and indeed, improvement may not be measurable until the cumulative effect of multiple projects is realized. However, in less impacted environments, riparian restoration may serve to create a continuous buffer between the uplands and fragile stream habitat. Many of the riparian planting impacts discussed in Section 7 (*Direct and Indirect Impacts*) are subtle at the reach scale, but as riparian rehabilitation continues throughout a watershed the impacts will become more significant and measurable.

8.6 Wetland Creation/Restoration/Enhancement

Research has indicated that floodplain wetlands are most productive when hydraulic residence time on the floodplain is on the order of 2 to 10 days (Ahearn and Dahlgren 2005; Hein et al. 2004). Additionally, studies have indicated that when residence time on floodplains is below this threshold the floodplain becomes a net sink for algal biomass instead of a net source (Ahearn and Dahlgren 2005; Tockner et al. 1999). This suggests that small floodplain restorations may not increase food resources within the waterway and that restoration efforts should focus on large floodplains (or small floodplains which receive relatively low volumes of water). These studies also indicate that if small projects are constructed then the cumulative effect of numerous small projects is vital for optimal ecosystem functioning. Floodplain habitat has been reduced dramatically due to agricultural (Beechie et al. 1994) and urban development (USGS 1997). To restore the ecosystems services these habitats once provided is vital for the survival of native aquatic fauna including the 52 HCP species. The cumulative effect of numerous created or rehabilitated wetlands will be to restore this habitat on a scale that will measurably improve ecosystem health and watershed carrying capacity.

Coastal wetlands are the most common type of wetland in Washington (USGS 1997), but the areal extent and quality of these habitats have been impacted by anthropogenic activities. Coastal wetland rehabilitation and the increased rearing habitat availability associated with it will be vital to the rehabilitation of degraded fisheries in the state. The importance of this habitat for the restoration of the state’s fisheries came to light with the realization that density dependent mortality brought on by a limited availability of rearing habitat may be reducing the efficacy of other restoration efforts in upland waterways (Greene and Beechie 2004). Consequently, the cumulative effect of coastal wetland rehabilitation efforts may be not only to augment rearing habitat but also to improve the effectiveness of other restoration efforts which share the goal of increasing native fish populations.

8.7 Beach Nourishment/Contouring

Although there is limited information on the cumulative impacts of numerous small activities along a given long stretch of shoreline (Speybroeck et al. 2006), there has been recent work that has demonstrated the cumulative environmental impact of beach nourishment (Peterson et al. 2006). Peterson et al. (2006) documented the loss of benthic macroinvertebrates on a stretch of beach in North Carolina from a number of smaller nourishment projects. Several earlier studies have shown that invertebrates can be harmed by nourishment projects (Diaz et al. 2004; Peterson et al. 2000; Rakocinski et al. 1996), but Peterson et al. (2006) was the first show that cumulative damage could occur due to multiple ongoing projects, and could overcome the rapid recolonization typical of invertebrates. However, it is important to mention that these studies have been in open coast environments. These would be relevant to the outer coast or possibly the Strait of Juan de Fuca, but not within the confines of Puget Sound. No information exists regarding the cumulative impacts of beach nourishment on protected shorelines.

There is the potential that the cumulative effect of numerous augmentations of a sandy, pebbly nearshore typical in pre-development Puget Sound could bolster the populations of many HCP species, including forage fish and salmonids (Beamer et al. 2005). There is substantial anecdotal evidence that forage fishes will use placed materials for spawning (Penttila 2007). For example, a beach nourishment project in Silverdale Waterfront Park, Kitsap County, continues to be used by surf smelt. Further, shorelines that have been cut into man-made fill in Commencement Bay are also designated forage fish spawning areas (Penttila 2007). Consequently, the cumulative impacts of beach nourishment may be positive for some fish species, but more research is needed to inform future beach nourishment activities.

8.8 Reef Creation

There have not been enough artificial reefs created anywhere in the world to warrant a cumulative impact study. Given the limited number of HPAs issued and the relatively limited number of documented impacts of created reefs, it is unlikely that cumulative impacts of this subactivity are significant in Washington waters. However, if there were enough reefs created to generate a cumulative impact, it is likely that the nature of the impact would be an ecological shift from soft-substrate to hard-substrate organisms observed in the Adriatic associated with shoreline armoring (Guidetti 2004).

8.9 Eelgrass and Other Aquatic Vegetation Enhancement

Because there have been few eelgrass restoration projects in any environment, there have been no studies regarding the cumulative effects with regard to eelgrass restoration. However, based upon the importance of eelgrass to the life cycle of many HCP species, it is expected that if large-scale eelgrass planting were to occur, there would be substantial gains in several of the HCP species.

9.0 Potential Risk of Take

This section provides an assessment of the risk of take resulting from the impact mechanisms associated with the construction of habitat modification projects and related subactivity types (e.g., beaver dam removal, in-channel/off-channel habitat creation or enhancement).

First, habitat modification projects are typically designed with the intent of modifying the environmental characteristics of the project site and the surrounding area. The majority of the subactivity types addressed in this white paper are intended to promote beneficial improvements in habitat conditions for a range of species. Exceptions to this intent include, beaver dam modification/removal and wood removal, a component of large woody debris placement/movement/removal. The former subactivity type is typically intended to address problematic flooding caused by beaver dams and not necessarily to improve habitat conditions. The latter is often promoted for the purpose of fish passage, flood protection, and infrastructure protection. When viewed in a broad ecological context, these subactivity types typically do not produce beneficial results from a habitat perspective, as they are interfering with natural processes of habitat formation. Therefore, the impact mechanisms associated with these subactivity types are expected to impose stressors that lead to possible take of HCP species.

In contrast, the nonconstruction-related impact mechanisms associated with the remaining subactivity types will not generally impose stressors that result in potential take. While these subactivity types will act on the environment through the same impact mechanisms, these mechanisms are not expected to expose HCP species to stressors after construction (and an ephemeral recovery period) is completed. For example; off-channel habitat creation will result in altered habitat complexity through hydraulic and geomorphic modification, but this impact submechanisms will not impose a stressor because habitat complexity will realize a beneficial increase. Therefore, there is no risk of take associated with the impact mechanism. This position is predicated on two key assumptions: (1) the project in question has been conceived and designed with proper consideration of the broader ecosystem context in which it will be implemented; and (2) the project is constructed properly and performs as expected.

Regardless of subactivity type, construction-related impact submechanisms will impose stressors on HCP species that may occur in the affected environment. In addition, as noted above, impact mechanisms caused by beaver dam modification and large woody debris removal will continue to impose stressors after the action itself is completed. The risk of take resulting from exposure to these various stressors will vary, depending on the nature of stressor exposure, as well as the sensitivity of the species and life-history stage exposed to the stressor. The magnitude, timing, duration, and frequency of each impact mechanism will vary widely with the project scale and location. Therefore, the risk of take assessment for each impact mechanism is necessarily broad and applies a “worst-case scenario” standard. This assessment is conditioned by the species occurrence and life-history specific uses of habitats where the subactivity types addressed in this white paper typically occur. For example, beaver dam removal and in-channel/off-channel habitat creation do not occur in marine and lacustrine environments. Therefore, species and species life-history stages that occur only in these environments will not be exposed to related impact mechanisms and stressors, and there is no resulting risk of take. In contrast, large woody debris removal/placement/modification can occur in any environment type. Therefore, the risk of take in this case must be considered more broadly.

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

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

The risk of take assessment is organized by impact mechanism category and environment type. In cases where the physical effects and related risk of take are similar between environment types, the risk of take discussion is grouped to avoid redundancy. Each of the following subsections provides a general description of the risk of take associated with each impact mechanism and submechanism, as well as a discussion of the differences in the resulting risk of take for each subactivity type. This assessment is supported by risk of take matrices (Tables 9-1 through 9-9, presented at the end of the narrative) identifying the risk of take to each of the 52 HCP species resulting from each subactivity type by impact mechanism and environment type. These matrices consolidate the risk of take at the mechanism of impact level.

9.1 Beaver Dam Removal/Modifications

Unlike other habitat modification subactivity types addressed in this white paper, the removal or modification of beaver dams in Washington State is not, by design, intended to improve habitat conditions. The purpose of this subactivity type is to address flooding caused by the beaver dam impoundment or to avoid the potential for catastrophic dam failure with the potential to threaten infrastructure, property, or public health in downstream areas. Because beaver dam structures are a normal constituent of riverine environments in the Pacific Northwest, the removal or modification of these structures represents the management or alteration of a natural habitat forming process that HCP species occurring in these environments have adapted to throughout their evolutionary history. Therefore, the impact mechanisms imposed by the activity would be expected to impose a number of stressors on aquatic species occurring in the affected environment resulting in a broad potential for risk of take. Because beaver dams occur only in riverine environments and associated habitats, the risk of take resulting from removal applies only to this environment type.

Species-specific risk of take ratings for beaver dam removal and modification are presented by impact mechanism in Table 9-1. The specific stressors and related risk of take from impact mechanisms caused by this subactivity type are described in the following subsections.

9.1.1 Construction Activities

Beaver dam removal or modification is typically a relatively low intensity exercise primarily involving the use of chainsaws and other hand held machinery per typical permitting requirements. In some cases, vehicle winches and/or heavy equipment may be also be used to dislodge larger wood elements. Human activity and equipment operation during dam removal imposes stressors in the form of visual and physical disturbance in the vicinity of the structure. Levels of underwater noise produced by this type of activity are uncertain, but given the scale of activities and tools used in comparison to known reference values for underwater construction activities, noise levels would not be expected to exceed tolerance thresholds capable of causing injury. Disturbance related activities imposed by construction would be expected to cause behavioral modification, increased stress, and displacement for those aquatic species exposed to these stressors, and could affect their survival, growth, and productivity. This equates to a moderate risk of take.

Accidental spills from in-water tool use presents a potential for the introduction of toxic substances to the aquatic environment. The risk of take associated with these water quality related stressors is discussed in Section 9.1.6 (*Water Quality Modifications*).

9.1.1.1 Dewatering

Once a beaver dam is breached, the impoundment behind the structure will drain. Aquatic species in the impoundment that are trapped in rapidly dewatering habitats face a risk of mortality from stranding, particularly non-motile species and life-history stages. Motile species able to avoid stranding will be rapidly displaced from existing habitats and forced to relocate within disturbed habitat that may present limited foraging opportunities, which could similarly limit survival as well as growth and productivity. These combined stressors equate to a high risk of take for species that utilize beaver dam impoundments.

9.1.2 Hydraulic and Geomorphic Modifications

Beaver dam removal substantially modifies hydraulic and geomorphic conditions both in the impoundment area and the downstream reach. Breaching a beaver dam, particularly dams that have been in place for extended periods, will convert a standing water environment with large amounts of fine sediments to a flowing water environment. Fine sediments in the channel bed will be scoured and mobilized, and the channel downstream of the impoundment will be forced to adjust to a rapid increase in sediment loading. The channel within the impoundment area will remain dynamic for an extended period until it reaches a stable gradient, and the fine sediments that compose the banks become stabilized.

9.1.2.1 Altered Channel Geometry, Altered Stream Bank Stability, Substrate Composition and Stability

Following dam removal or modification, open water impoundment and wetland areas upstream of beaver dams will be converted into flowing water environments with unstable channels forming in the impoundment bed. The stream channel in the former impoundment area will seek to find an equilibrium condition. The channel will erode to a stable gradient within the fine sediment bed, creating unstable vertical banks with little or no riparian vegetation to provide root cohesion. These banks will remain in an unstable condition until sufficient erosion and vegetation growth has occurred. This will limit the availability of underbank habitat, and contribute chronic, fine sediment loading to the channel. In systems where sediment loading exceeds transport capacity, the detrimental effects of increased fines on substrate composition may persist for some time. These conditions typically result in poor habitat suitability for HCP species occurring in riverine environments where beaver dam removal is likely to occur, resulting in conditions that are limiting to survival, growth, fitness, and spawning productivity. Species exposed to these stressors face a moderate risk of take.

9.1.3 Ecosystem Fragmentation

The draining of beaver dam impoundments represents a significant modification of the aquatic environment which fragments ecological connectivity in the longitudinal, lateral, and vertical dimensions. These impact mechanisms have been demonstrated to produce a number of ecological stressors with the potential to impose a risk of take on HCP species.

9.1.3.1 Altered Longitudinal Connectivity

On initial consideration, breaching of beaver dams may appear to improve longitudinal connectivity in riverine systems. Beaver dams represent a potential barrier to fish passage as well as a zone of hydraulic complexity which sequesters sediment, wood, organic material, and water. However, beaver dams are typically semipermiable and do not pose total barriers to fish passage. As a natural feature of the landscape, the hydraulic and structural complexity provided by beaver dams supports a broad array of species during different stages of their life history, including HCP species. The distribution of these features along a longitudinal gradient in riverine ecosystems is an important measure of ecological connectivity, particularly for species such as coho salmon that prefer slow water habitats like beaver ponds for rearing habitat. Altering the longitudinal connectivity of complex, diverse habitats in a riverine environment by draining beaver ponds represents a form of ecosystem fragmentation. Reducing the total area of suitable habitat and increasing the distance between habitat patches limits the abundance and productivity of affected populations, which represents a moderate risk of take.

9.1.3.2 Altered Terrestrial and River-Floodplain Connectivity

The draining of beaver dam impoundments eliminates open water habitats and causes the channel system to withdraw from riparian and floodplain areas. Depending on where the stream channel stabilizes in the impoundment area, riparian habitats may be separated from the channel by open ground. This effect fragments the channel from floodplain habitats, reducing the connectivity between terrestrial and aquatic habitats which are highly productive. The reduced availability of these productive habitats may limit survival, growth, and fitness of those species that utilize the affected riverine habitats.

An additional related effect that must be considered is the vulnerability of disturbed habitats to invasion by exotic plant species. Exposed impoundment beds are likely sites for colonization by invasive species. Once these species become established, they may create a barrier to riparian recovery and a dispersal source for additional colonization. Invasive species may reduce the suitability of floodplain and riparian habitat for refuge, food production, and other ecological functions. These effects would also be considered likely to limit the survival, growth, and fitness of species that utilize the affected riverine habitats.

Collectively, these stressors would be expected to impose a moderate risk of take on those HCP species occurring in the affected area.

9.1.3.3 Altered Groundwater-Surface Water Interactions

Beaver dams play an active role in hyporheic exchange in riverine environments. The hydraulic head created by the impoundments has been shown to cause downwelling upstream of the structure, which emerges in downstream areas. This vertical connectivity between surface and groundwaters is associated with a number of important ecological processes, including the biogeochemical processing of nutrients and pollutants, and the creation of zones of upwelling that are preferential spawning habitats for salmonids and other species. Consequently, any activity that disrupts vertical connectivity will disrupt these processes, reducing water quality and affecting the availability of suitable habitats. These effects will limit the survival, growth, fitness, and in some cases spawning success. This represents a moderate risk of take for species utilizing these habitats

9.1.4 Riparian Vegetation Modifications

The removal of beaver dams weakens the terrestrial-aquatic linkage thereby reducing riparian influence on the stream channel. Until riparian vegetation can establish after dewatering, there will be reduced vegetation adjacent to the channel and thus decreased direct delivery of organic material to the channel. It has also been shown that impoundments can increase riparian vegetation downstream of the dam by augmenting floodplain groundwater. Consequently, it can be assumed that the removal of beaver dams which impound a large cross section of the floodplain, will affect downstream riparian functions by altering hyporheic flow. These effects will impose stressors through a number of impact submechanisms.

9.1.4.1 Altered Allochthonous Inputs

Fragmented connectivity between the active channel and the riparian zone and reduced riparian productivity in downstream habitats will lead to reduction in allochthonous inputs of insects, leaf litter, and LWD. This effect would be expected to reduce habitat suitability and food web productivity, thereby limiting the survival, growth, and fitness of species dependent on the affected environment. This equates to a moderate risk of take.

9.1.4.2 Altered Shading and Solar Input

Altered shading and solar input would be expected to alter water temperature conditions in the affected stream channel. The risk of take associated with this water quality submechanism is discussed in Section 9.1.6 (*Water Quality Modifications*).

9.1.4.3 Altered Stream Bank Stability

The effects of stressors related to altered bank stability caused by riparian vegetation modification are addressed in the discussion of hydraulic and geomorphic modification submechanisms in Section 9.1.2 (*Hydraulic and Geomorphic Modifications*).

9.1.4.4 Altered Buffering Capacity

The degradation of riparian vegetation downstream of beaver dam impoundments may decrease the buffering capacity of the riparian zone, creating the potential for increased exposure to pollutants and nutrients. In general, this effect would be expected to be relatively minor in comparison to the significant water quality effects that result from draining of the impoundment. Risk of take resulting from nutrient and pollutant loading and other water quality effects due to altered buffering capacity are discussed in Section 9.1.6 (*Water Quality Modifications*).

9.1.5 Aquatic Vegetation Modifications

Draining of beaver dam impoundments converts slack water habitats into flowing water, reducing the amount of habitat suitable for aquatic vegetation. This will result in the loss of emergent and other aquatic vegetation in the impoundment, and the loss of suitable habitat area capable of supporting these communities. This will result in the loss of autochthonous production and habitat structure within the affected reach. While these are unique stressors, they are considered to be a component of the broader effects of conversion from slack water to flowing water habitats, and the resulting ecological fragmentation. Therefore, they impose a similar moderate risk of take.

9.1.6 Water Quality Modifications

Beaver dam removal or alteration imposes a number of water quality related impact mechanisms on the aquatic environment. These effects are wide ranging, from acute pulses and chronic loading of fine sediments, alteration of water temperature regime, increased nutrient and pollutant loading, and acute dissolved oxygen depletion due to nutrient induced eutrophication.

9.1.6.1 Altered Temperature Regime

The literature on beaver dams and their removal is equivocal with regard to the potential effects on stream temperatures. Beaver dam impoundments are typically shallow, open water habitats that expose greater surface area to solar radiation, and therefore conceivably would be characterized by higher ambient temperatures on average than open stream channels. Removal of beaver dams may in turn result in reduced stream temperatures which could benefit certain species such as native char that are cold water dependent. However, beaver dam impoundments may also serve moderate water temperatures within optimal ranges for aquatic species that co-evolved with beavers in riverine environments. Applying a worst-case scenario perspective, the removal of or modification of beaver dams is expected to modify stream temperatures unfavorably for the HCP species occurring in these environments. Exposure to temperatures outside of optimal growth ranges would in turn be expected to cause avoidance behavior, and otherwise limit the survival, growth, and fitness of exposed species. This equates to a moderate risk of take.

9.1.6.2 Altered Suspended Solids

Beaver dam removal or modification will unavoidably cause mobilization of fine sediments deposited in the impoundment. This will increase suspended sediment levels within the affected area immediately upon dam removal, and for an extended period afterwards as the channel within the former impoundment erodes to a stable configuration. Bank erosion within the impoundment will continue to contribute fine sediment loading during high flow events until riparian vegetation growth provides sufficient root cohesion for bank stability. Short-term increases in suspended sediment loading following beaver dam removal could potentially reach concentrations high enough to cause injury or mortality to sensitive species and life-history stages in downstream environments, which equates to a high risk of take. Chronic sediment loading over time would be expected to alter habitat suitability, affecting foraging opportunities and behavior. These effects are potentially limiting to survival, growth, and fitness, which equates to a moderate risk of take.

9.1.6.3 Altered Pollutant Loading

Beaver dam impoundments capture sediments and slow the movement of water, effectively sequestering a variety of pollutants. Research has demonstrated that the biogeochemical processes that are active in beaver dam impoundments can trap nutrients and pollutants and render them less toxic. Draining of the impoundment removes some portion of this capacity and has been shown to result in the relatively rapid release and transport of stored pollutants and nutrients to downstream environments. Acute exposure to a range of pollutants have the potential to cause injury or mortality, which represents a high risk of take.

9.1.6.4 Altered Dissolved Oxygen

As discussed in the previous section, beaver dam removal or modification can result in the release of a pulse of sequestered nutrients when sediments in the impoundment bed are scoured. A large pulse of nutrients could cause temporary eutrophication that, depending on the nature of the downstream environment, could cause a relatively rapid decrease in dissolved oxygen levels. This stressor has the potential to cause direct mortality or injury to non-motile species or life-history stages, or organisms unable to escape the effect. This equates to a high risk of take.

9.2 Large Woody Debris Placement/Removal/Modifications

This subactivity type includes two widely divergent types of projects: (1) the placement or repositioning of LWD to improve habitat conditions and the functioning of ecological processes, and (2) the removal of LWD from the aquatic environment to facilitate human uses. This latter type of project occurs most often riverine environments. However, LWD removal from manmade structures in the marine environment (e.g., jetties and breakwaters) may interfere with the eventual deposition of this material in the littoral environment.

Presuming LWD placement projects are properly designed for their ecological context and function as intended, the impact mechanisms associated with the project would not be expected to impose stressors on aquatic species once construction is complete. In contrast, LWD removal projects have been shown to detrimentally affect ecological conditions through a number of impact mechanisms, meaning that this type of project has the potential to impose a number of ecological stressors resulting in an ongoing risk of take. For the purpose of this assessment, the risk of take associated with this subactivity type is based on the worst-case scenario for each type of impact mechanism. Because the construction requirements for LWD placement projects are more extensive than those for removal, risk of take from construction activities is based on the stressors imposed by this type of project. For the remaining impact mechanisms, risk of take is rated based on the effects of LWD removal on the aquatic environment.

Species-specific risk of take ratings for LWD placement and removal projects are presented by impact mechanism category in Table 9-2.

9.2.1 Construction Activities

Construction of LWD projects involve a diverse array of activities, including driving pilings, heavy equipment operation and materials placement, and work area dewatering. The majority of these activities are temporary in nature, lasting from a few days to several weeks, depending on the size of the project in question. The risk of take associated with construction activity varies by impact mechanism and is dependent on the project-specific magnitude of that impact mechanism. As discussed below, some mechanisms may produce a high risk of individual take due to their intensity, while others may result in a low risk of take due to their limited magnitude and duration.

The risk of take resulting from these impact mechanisms also varies by the type of environment in which it is implemented, the life-history stages exposed, and the intent of the project. For example, an engineered logjam in a riverine setting may have significant construction-related impacts but will produce an array of beneficial changes in habitat conditions. Accordingly, the risk of take associated with the project would be limited to those species and individual life-history stages that occur in this environment type during construction, while the impact mechanisms associated with beneficial changes in habitat conditions are presumed not to impose stressors leading to risk of take. In contrast, the removal of LWD from a stream system (e.g., to protect infrastructure) would involve impact mechanisms that impose stressors during construction, as well as from adverse changes in habitat characteristics.

The species-specific risk of take ratings for construction impacts for LWD projects reflects the above perspective. These ratings are presented at the end of this narrative in Table 9-2. The risk of take resulting from each associated submechanism of impact is described in further detail below.

9.2.1.1 Equipment Operation and Materials Placement

The operation of heavy construction equipment and the physical placement or removal of LWD and other related materials imposes stressors in the form of increased underwater noise, as well as physical and visual disturbance. The magnitude of these stressors will vary widely, depending on the scale of the project in question and the specific construction measures used. Applying a "worst-case-scenario" perspective, the magnitude of these stressors can be significant. For example, many engineered logjam designs include placement of timber or in some cases steel piles using either impact or vibratory hammers. As detailed in Section 7.10 (*Discussion of Common Stressors*) sound pressure from pile driving has the potential to cause injury and mortality of aquatic receptors, particularly fish. The potential for injury or mortality varies depending on piling size and composition, pile driving methods, and site-specific environmental characteristics such as bathymetry, intervening land masses, and substrate composition.

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

> ***SEL:*** *A fish receiving an accumulated Sound Exposure Level (SEL) at or above 187 dB re: one micropascal squared-second during the driving of piles likely results in the onset of physical injury; a simple accumulation method shall be used to sum the energy produced during multiple hammer strikes.*
>
> ***Peak SPL:*** *A fish receiving a peak sound pressure level (SPL) at or above 208 dB re: one micropascal from a single hammer strike likely results in the onset of physical injury.*

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

The literature on underwater noise levels produced by heavy equipment use and materials placement is quite limited, and this subject is considered a data gap. In general however, noise produced by these sources is anticipated to be of far lesser magnitude than that produced by pile driving and therefore unlikely to exceed established injury thresholds. Therefore, projects that do not involve pile driving are expected to result in a lesser (moderate) risk of take in the form of temporary disturbance and displacement. Visual disturbance during construction would have similar effects. Physical disturbance is similarly expected to produce only a moderate risk of take due to temporary disturbance and displacement for most species exposed to this stressor. Sessile or otherwise non-motile species or life-history stages are an exception, as they will be unable to escape or avoid physical disturbance. Therefore, they are at increased risk of mechanical injury from crushing or burial during construction, which constitutes a high risk of take.

9.2.1.2 Bank/Channel and Shoreline Disturbance

Construction-related bank, channel, and shoreline disturbance could result in decreased stream bank and shoreline stability, as well as increased erosion and turbidity. These effects are localized and would occur during construction and possibly again during seasonal high-flow conditions. The risk of take associated with this stressor varies depending on species-specific sensitivity to increased turbidity. In general, more motile fish species experience only temporary behavioral alteration and a low risk of take. In contrast, less motile fish life-history stages or sessile invertebrates could experience a high risk of take from decreased survival due to mortality from substrate sedimentation and smothering, as well as decreased growth and fitness due to the effects of high turbidity on foraging success.

9.2.1.3 Temporary Dewatering and Fish Handling

This construction activity poses a relatively high risk of take. Well-designed protocols and trained personnel are necessary to avoid high levels of mortality. Even with appropriate protocols and experienced field crews, high levels of mortality can result. For example, NOAA Fisheries evaluated take associated with dewatering and fish handling in a recent biological opinion and estimated that salmonid mortality rates in the range of 8 to as high as 20 percent may occur even when trained personnel are used (NMFS 2006).

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

In addition to these effects, the act of dewatering the stream and redirecting flow may pose a barrier to fish migration. Delays in migration can lead to adverse effects on spawning fitness, can increase exposure to predation and poaching, and can deny juvenile fish access to rearing habitats during critical periods. These effects also constitute a moderate risk of take of those HCP species with migratory life-history stages.

9.2.2 Hydraulic and Geomorphic Modifications

LWD placement or removal projects can be implemented in riverine, marine, and lacustrine environments. While the role LWD plays in regulating hydrologic and geomorphic processes differs between these environment types, for the purpose of this assessment it is assumed that LWD placement projects are properly designed for the ecosystem context, and that the impact mechanisms imposed will result in beneficial changes in habitat conditions. Therefore, regardless of environment type, these impact mechanisms will produce no stressors and no resulting risk of take.

In contrast, hydraulic and geomorphic modification caused by LWD removal is expected to impose an array of impact mechanisms and related stressors. Because the nature of these impact mechanisms varies between riverine, marine, and lacustrine habitats, the resulting risk of take is discussed by the environment type. The combined risk of take ratings for this subactivity type are presented in Table 9-2 (at the end of this narrative). These ratings represent the highest potential risk of take associated with the hydraulic and geomorphic modification category of impact mechanisms, and they apply only to LWD removal projects. As noted above, LWD placement projects are expected to result in no risk of take due to hydraulic and geomorphic modification.

9.2.2.1 Riverine Environments

LWD projects are most commonly implemented in riverine environments, and vary from the removal or repositioning of wood to permit navigation, protect infrastructure, and/or improve public safety, to the placement of LWD structures to improve the functioning of physical and biological processes and provide for fish habitat. As noted above, the hydraulic and geomorphic modifications produced by properly implemented LWD placement projects are not expected to produce stressors, and therefore there will be no related risk of take. In contrast, LWD removal projects often extensively modify the riverine environment, imposing a number of stressors on those species that use these habitats. Risk of take associated with the resulting impact mechanisms is determined by the size and scale of the project in question, and species-specific dependence on the riverine environment where the stressors associated with these impact mechanisms are manifest. Risk of take resulting from hydraulic and geomorphic modification effects of LWD removal in riverine environments is presented in Table 9-2.

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

Channel geometry, flow conditions, and substrate composition are dominant factors determining aquatic habitat structure in riverine environments. Alteration of any of these habitat components can change the suitability of the habitat for various life-history stages of HCP species. These habitat alterations are essentially permanent and continuous, and can lead to changes in the productivity of the habitat for spawning, forage, rearing, and refuge. In a worst-case scenario, these effects are in turn likely to lead to reduced spawning success as well as reduced survival, growth, and fitness for species and life-history stages dependent on the affected habitat.

9.2.2.2 Marine Environments

LWD placement and removal projects could potentially be implemented in the marine environment, specifically in littoral habitats. While specific research data are lacking, anecdotal assessments suggest that LWD can modify local scale hydraulic and geomorphic conditions in the nearshore marine environment, affecting habitat structure and the quality and distribution of habitat patches. It follows, therefore, that the removal of LWD can result in the imposition of several impact mechanisms and related stressors. The risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment.

9.2.2.2.1 Altered Wave Energy

Wave energy is an important determinant governing nearshore marine habitat characteristics that determine the suitability of these habitats for a number of species-specific life-history processes. For example, wave energy conditions have a strong influence on nearshore water temperatures and on the sorting and transport of sediments. For example, forage fish spawning and juvenile fish rearing in nearshore environments often occurs in environments selectively chosen on the basis of suitable wave energy conditions. Localized alterations in wave energy conditions can fundamentally alter habitat suitability for these uses, leading to decreased habitat availability, and decreased survival, growth, and fitness. This equates to a moderate risk of take for species that are dependent on these habitats during some phase of their life history.

9.2.2.2.2 Altered Substrate Composition and Stability

Sediment supply and substrate composition are fundamental components of the nearshore ecosystem structure. Anecdotal observations from shoreline surveys suggest that LWD affects the transport, distribution, and composition of shoreline substrates. Therefore, the removal of LWD can lead to localized alterations in substrate composition and stability through the interruption or alteration of longshore sediment transport. In conjunction with altered wave energy, this can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the nearshore environment, these habitat changes can fundamentally alter community structure and habitat suitability for species dependent on the original habitat condition. This equates to a moderate risk of take for species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed life-history stages.

9.2.2.3 Lacustrine Environments

LWD removal projects implemented in the lacustrine environment unavoidably modify hydraulic and geomorphic conditions, resulting in the imposition of several impact mechanisms and related stressors. Risk of take associated with the resulting impact mechanisms is determined by the size and scale of the project in question, and species-specific dependence on the nearshore lacustrine environment where the stressors associated with these impact mechanisms are manifest. Risk of take resulting from hydraulic and geomorphic modification effects of LWD removal in lacustrine environments is presented in Table 9-2.

9.2.2.3.1 Altered Wave Energy, Altered Current Velocities

Wave energy and current velocities are important determinants governing nearshore lacustrine habitat characteristics. These processes strongly influence nearshore water temperatures and other water quality parameters, shoreline stability, and the accumulation of allochthonous and autochthonous materials. Removal of LWD can lead to an alteration of these parameters, fundamentally altering the suitability of nearshore habitats for those species dependent on these habitats, leading to decreased survival, growth, and fitness. This equates to a moderate risk of take for species that are dependent on these habitats during some phase of their life history.

9.2.2.3.2 Altered Sediment Supply and Altered Substrate Composition

Sediment supply and substrate composition are also fundamental components of the nearshore ecosystem structure. Removal of LWD can change the depositional environment by altering nearshore current and wave energy regimes, and by altering longshore sediment transport. This can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the lacustrine environment, these habitat changes can fundamentally alter community structure and habitat suitability for those species dependent on the original habitat condition. This equates to a moderate risk of take for species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed life-history stages).

9.2.3 Ecosystem Fragmentation

Ecosystem fragmentation is an impact mechanism that incorporates the collective effects caused by the removal of LWD from the habitat in question, the resulting effects on the migration and dispersal of organisms, the transport, distribution, and biogeochemical processing of LWD, other organic material, nutrients, and pollutants, and the impact mechanisms imposed by hydraulic and geomorphic modification. This impact mechanism operates differently in riverine, marine, and lacustrine environments due to the differences in characteristic physical and biological processes. The species-specific risk of take associated with ecosystem fragmentation caused by LWD removal projects is presented by environment type in Table 9-2.

9.2.3.1 Riverine Environments

LWD plays a dominant role in structuring riverine ecosystems and regulating physical and biological processes. Therefore, LWD projects have the potential for significant effects on ecological connectivity in the riverine environment. Because LWD placement projects are typically intended to restore ecological functions, they would be expected to beneficially affect this impact mechanism. In contrast, LWD removal projects are intended to modify the riverine environment to support human uses and, when applying a worst-case scenario perspective, can only be viewed as negatively affecting ecological connectivity.

9.2.3.1.1 Altered Terrestrial/River-Floodplain Connectivity, Habitat Complexity and Longitudinal Connectivity

LWD removal can result in channel degradation and other forms of hydraulic and geomorphic modification leading to the disconnection of floodplain and off-channel habitats in riverine systems. This form of ecosystem fragmentation limits the extent to which river flows interact with the floodplain and terrestrial riparian ecosystem, disconnecting the stream channel from important sources and sinks of organic matter, nutrients, and pollutants. This in turn may limit food web productivity, affecting the survival, growth, and fitness of any species dependent on the riverine environment for rearing. In addition, this loss of connectivity may limit the availability of important habitat types for HCP species. For example, side channel habitats are preferentially selected by various species of salmonids (e.g., sockeye salmon) for spawning. These habitats also provide key winter rearing and storm refuge habitats for coho salmon, steelhead, spring Chinook, native char (bull trout and Dolly Varden), and other species. The reduction in suitable refuge and foraging habitat area caused by ecosystem fragmentation increases competition for remaining habitat, predation risk, and risk of displacement to habitats unfavorable for rearing. Collectively, these factors pose a moderate risk of take for HCP species that occur in the affected riverine environment.

In addition to the effects on lateral (i.e., floodplain) connectivity described above, the removal of LWD from riverine environments reduces the structural complexity of instream habitat itself. LWD, whether in individual units or complex jams, provides three dimensional structure that encourages the formation of pools and other hydraulically complex features. This hydraulic complexity in turn encourages the sorting and deposition of sediments and organic material in diverse patches, supporting food web productivity and providing spawning and rearing habitat for a diverse array of species. This diversity of habitat patches supports a biologically diverse community. LWD removal promotes simplification of the riverine environment, reducing the density and longitudinal distribution of these habitat patches across the riverine landscape. This reduction in habitat complexity leads to reduced food web productivity and the reduced availability of habitats suitable for those HCP species that occur in these environments. Therefore, this impact mechanism equates to a moderate risk of take for the HCP species.

9.2.3.1.2 Altered Groundwater-Surface Water Interactions

The hydraulic and geomorphic modifications caused by the removal of LWD from a stream channel can influence and alter groundwater and surface water exchange in the vicinity. This hyporheic exchange is an important component of ecosystem function (including water quality moderation) in riverine environments. Therefore, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. This mechanism is generally equated with a moderate to low risk of take for species exposed to this stressor, depending on species-specific, life-history characteristics. Species with a moderate risk of take include those with life-history stages that are dependent on hyporheic exchange for its beneficial effects on water temperature and dissolved oxygen levels. For example, most salmonids preferentially spawn in areas with groundwater-induced upwelling which promotes the oxygenation of spawning gravels.

Alteration of hyporheic exchange in environments suitable for spawning could potentially affect egg survival and reduce the availability of suitable spawning habitat, resulting in reduced spawning success. Similarly, groundwater inflow can provide important thermal refugia for migrating adult and rearing juvenile salmonids during periods with high water temperatures. A reduction in the amount of thermal refugia may negatively affect survival during these life-history stages. Similar effects would be expected for other coldwater fish species with low thermal tolerance thresholds, such as pygmy whitefish. More generally, hyporheic exchange also plays a key role in nutrient cycling and food web productivity in alluvial bed rivers. Projects resulting in significant alteration of hyporheic exchange could adversely affect food web productivity, thereby limiting foraging opportunities for fish and invertebrate species dependent on these types of environments.

9.2.3.2 Marine and Lacustrine Environments

The available literature on the effects of LWD removal and placement projects in lacustrine and marine environments is more limited than for riverine systems. While the role of wood in the operation of physical and biological processes is different in marine and lacustrine environments, the same basic factors regarding the benefits of LWD placement versus the detrimental effects of LWD removal in riverine environments apply.

9.2.3.2.1 Altered Habitat Complexity/Connectivity

Because marine and lacustrine environments are not as dominated as riverine environments by the longitudinal transport of water, sediment, and other materials, the influence of LWD on ecological connectivity is less pronounced. While the literature on this subject is limited, LWD certainly provides cover and organic substrate and has been shown to influence wave energy and sediment deposition in the surrounding environment, and to influence the stability of the boundary between the riparian and littoral zone. Therefore, LWD arguably influences the diversity and distribution of habitat patches in the longshore environment and along the gradient between littoral and riparian systems. Therefore, the removal of LWD may lead to simplification of the nearshore environment and reduced longshore connectivity of suitable habitat patches, and may alter connectivity along the gradient between the littoral and riparian environment. Reduced longshore connectivity of suitable habitats may lead to increased stress, increased predation risk, and reduced foraging opportunities for juvenile Chinook, chum, and pink salmon, and other species that utilize the nearshore environment during early life-history stages. Exposure to these stressors may in turn be limiting to survival, growth, and fitness, which would equate to a moderate risk of take. Fragmentation of riparian and littoral connectivity may equate to a similar level of risk. For example, LWD accumulations have been shown to promote littoral vegetation growth, and riparian vegetation has been demonstrated to influence incubation success in forage fishes. Alteration of the connectivity between the littoral and riparian zone could affect the suitability of habitats for species such as forage fish and Newcomb's littorine snail that are dependent on these fringing environments.

9.2.4 Riparian Vegetation Modifications

The extent to which riparian vegetation is modified by an LWD placement or removal project is determined predominantly by the nature of the project itself. In many cases, LWD removal projects take place from existing infrastructure, such as roadways and bridges, with the intent of providing protection of that infrastructure. However, in some cases, LWD removal may require the disturbance of intact riparian vegetation to create a construction access point. Many LWD placement projects may present similar or even more extensive riparian impacts if excavation of the bank is necessary to anchor the foundation of an engineered LWD structure. The resulting impact mechanism is the modification of a sufficient extent of the riparian zone to support the project. As restoration of the affected area is typically required as a condition of the HPA permit process, these effects are usually intermediate-term in their duration with riparian function returning as the replanted vegetation becomes established. In total, the extent of riparian impacts associated with this project type is likely to be limited, and the duration over which the impact mechanism imposes stressors will depend on the time required for the riparian function to recover. Therefore, while the full suite of impact mechanisms will occur and these impact mechanisms will produce stressors resulting in some risk of take, the extent of take will be relatively limited in terms of the number of individuals likely to be affected from HCP species that occur in environments affected by this subactivity type.

In contrast, LWD removal projects have the potential for longer-lasting effects. Hydraulic and geomorphic effects caused by LWD removal may lead to fragmentation of riparian habitat from the aquatic environment, imposing a number of stressors on those HCP species that occur in the affected habitat. The longer term effects of removal projects are a primary consideration in the worst-case scenario based approach to assessing the risk of take. The risk of take resulting from this impact mechanism is described by environment type in the following sections. The species-specific risk of take ratings resulting from riparian modification imposed by LWD removal projects are presented in Table 9-2.

9.2.4.1 Riverine Environments

As discussed in Section 9.2.2 (*Hydraulic and Geomorphic Modifications*) and Section 9.2.3 (*Ecosystem Fragmentation*), LWD removal projects can demonstrably cause the fragmentation of riverine habitats from floodplain habitats. These impact mechanisms will in some cases lead to the fragmentation of riparian habitats from the stream channel. These effects will generally be more extensive than the limited area of riparian disturbance associated with project construction. Channel downcutting and realignment caused by LWD removal may lead to a loss of shading and allochthonous inputs if the stream channel becomes isolated from the riparian zone.

9.2.4.1.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

Loss of stream shading provided by riparian vegetation can demonstrably affect the temperature of streams and lower order river environments, producing a range of potential effects on fish and wildlife species. In higher order river environments, this effect is far less pronounced. Water temperatures in systems of this nature are less influenced by localized shading and ambient air temperature than by the combined effects of basin conditions in upstream areas of the watershed, hydromodification (e.g., dam and reservoir development), and other factors that affect the temperature of water flowing through the affected area. In contrast, in smaller rivers and streams, removal of riparian vegetation for a LWD project may have a measurable effect on stream temperature. These systems are also generally more sensitive to the effects of hydraulic and geomorphic modification on ecological connectivity when LWD is removed.

On this basis, the risk of take associated with this impact mechanism is viewed as variable depending on the nature of the project and the type of environment in which it is implemented. In larger river systems, the temperature effect may not be measurable and the resulting risk of take discountable. In smaller streams, stream temperature effects may influence local habitat suitability and by extension affect the survival, growth, and fitness of exposed species and life-history stages.

9.2.4.1.2 Altered Stream Bank Stability

Removal of riparian vegetation can affect shoreline stability through the reduction in root cohesion and the loss of LWD inputs that affect localized erosion and scour conditions. LWD placement projects are often intended to increase bank stability, so this effect would likely be minimized. In the worst-case scenario, however, riparian vegetation modification associated with a permitted LWD removal project could result in decreased stream bank and shoreline stability, as well as increased erosion and turbidity. These effects are localized and occur predominantly during seasonal high-flow conditions. The risk of take associated with this stressor varies depending on species-specific sensitivity to increased turbidity. In general, more motile fish species experience only temporary behavioral alterations and low risk of take. In contrast, less motile fish life-history stages or sessile invertebrates could experience a high risk of take from decreased survival due to substrate sedimentation or mortality from smothering, as well as decreased growth and fitness due to the effects of high turbidity on foraging success.

9.2.4.1.3 Altered Allochthonous Inputs

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

Therefore, the magnitude of this impact mechanism varies depending on the scale of the LWD project and the degree to which construction disturbs existing riparian vegetation. In lower order streams, allochthonous inputs are more important to food web productivity, while they provide a minor contribution in the lower reaches of large river systems. On this basis, the loss of allochthonous production from an LWD project near the mouth of a large river will produce related stressors of potentially far lower magnitude than a series of LWD projects in a small, higher elevation stream. In such cases, a localized reduction in food web productivity might result, leading to decreased foraging opportunities, decreased overall habitat suitability, and decreased growth and fitness. This equates to a moderate risk of take for a range of HCP species that are dependent on riverine rearing conditions.

9.2.4.1.4 Altered Habitat Complexity

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

9.2.4.2 Marine Environments

LWD projects in the marine littoral environment most often take place on exposed beaches. Because of this, the effects of construction activities during wood placement on riparian vegetation are typically limited. Usually only the construction access point is affected, and riparian disturbance may be further limited if an established access point is used. If existing access points are used, or the project is implemented from a barge or vessel, then the effects of the project on riparian vegetation from construction will be insignificant. Therefore, the overall risk of take from this impact mechanism is likely to be relatively limited in terms of the overall number of individuals affected from HCP species that occur in environments affected by this subactivity type.

LWD removal projects also have the potential to influence the interaction between the riparian and littoral zone. In certain circumstances, removal of LWD may expose the shoreline to increased wave action, leading to soil erosion and loss of riparian habitat.

These caveats must be taken into account when considering the effects of those stressors arising from marine riparian vegetation modification. The risk of take resulting from these impact mechanisms is strongly linked to scientific information on the specific dependence on the nearshore environment and, where supported by the available science, the demonstrated dependence on riparian functions of the species in question. For many species, the risk of take associated with marine riparian impact mechanisms is unknown because the scientific understanding of the related ecological processes is in its infancy, and the extent to which many marine or anadromous species rely on the nearshore environment during their life history is unclear.

9.2.4.2.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

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

9.2.4.2.2 Altered Shoreline and Bluff Stability

Depending on site-specific conditions, modifications of marine riparian vegetation can lead to physical alteration of the shoreline and to bluff instability. The effects of this stressor on receptors can be similarly variable. In general, however, this stressor would be expected to alter shoreline habitat conditions and habitat suitability for those species dependent on the nearshore environment during some portion of their life history. This equates to a moderate risk of take for those species with a demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness.

9.2.4.2.3 Altered Allochthonous Inputs

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

9.2.4.2.4 Altered Habitat Complexity

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

9.2.4.3 Lacustrine Environments

LWD projects in lacustrine environments have variable effects on riparian vegetation depending on the subactivity type and nature of the project. In general, LWD placement projects would not be expected to degrade riparian vegetation conditions outside of construction access points, and these effects would be expected to diminish over time as the site restoration matures. In contrast, LWD removal projects could expose the shoreline to increased wave energy, encouraging cyclical shoreline erosion that chronically degrades riparian functions over longer time periods.

These conditions must be taken into account when considering the effects of the stressors resulting from lacustrine riparian vegetation modification. The risk of take from these impact mechanisms is strongly linked to species-specific dependence on the nearshore lacustrine environment and, where supported by available science, the demonstrated dependence of the species in question on the affected riparian functions.

9.2.4.3.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

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

9.2.4.3.2 Altered Shoreline Stability

Depending on site-specific conditions, removal of LWD can lead to the alteration of shoreline stability conditions and the degradation of riparian vegetation due to cyclical patterns of erosion caused by increased wave or vessel wake exposure. Where this impact mechanism occurs, it would be expected to alter shoreline habitat conditions and habitat suitability for species dependent on the nearshore environment during some portion of their life history. This equates to a moderate risk of take for species with a demonstrable dependence on these habitats because the reduction in suitable habitat area caused by these impact mechanisms will lead to reduced survival, growth, and fitness.

9.2.4.3.3 Altered Allochthonous Inputs

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

9.2.4.3.4 Altered Habitat Complexity

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

9.2.5 Aquatic Vegetation Modifications

LWD projects can result in aquatic vegetation modification through the alteration or elimination of vegetation in the construction footprint as well as the subsequent effects of the project, either through wood removal or wood placement, on hydraulic and geomorphic conditions. During construction, vegetation in the footprint of LWD structures can be eradicated or buried by the placement of fill or structural material. After construction of a LWD structure, or the removal or repositioning of LWD, changes in wave energy, circulation patterns, flow and/or current velocities, and substrate composition can lead to adverse or beneficial alterations in vegetation community structure.

Alteration of aquatic vegetation imposes impact mechanisms on the nearshore environment in the form of changes in autochthonous production and altered habitat complexity. The nature of these mechanisms and related stressors varies slightly between riverine and lacustrine habitats versus marine habitats, primarily because the role of aquatic vegetation differs between these systems. Therefore, the risk of take in these different environments is discussed separately. Species-specific risk of take ratings for the impact mechanisms resulting from aquatic vegetation modification are presented by subactivity and environment in Table 9-2.

As with the other categories of impact mechanisms addressed in this white paper, the nature and scale of aquatic vegetation modification are dependent on the size and design of the individual project in combination with site-specific conditions.

9.2.5.1 Riverine and Lacustrine Environments

Aquatic vegetation is a relatively minor component of the ecological structure of riverine and lacustrine systems in Washington State. Aside from native emergent vegetation confined to a relatively narrow range of depths, many of the aquatic vegetation species in rivers and lakes and are invasive species (WDFW 2001b). Thus, the risk of take resulting from this impact mechanism is relatively minor in comparison to that occurring in the marine environment. In riverine systems, protected slow-water areas created LWD projects may increase suitable habitat for emergent vegetation. The removal of LWD would be expected to limit this habitat area, resulting in the loss of aquatic vegetation functions.

9.2.5.1.1 Altered Autochthonous Production

Modification of the submerged aquatic vegetation community in lakes and rivers can lead to decreased primary and secondary productivity, which in turn may affect overall food web productivity in the nearshore environment. In systems where the aquatic vegetation community is an important component of food web productivity, this can lead to a moderate risk of take through indirect effects on foraging success, growth, and fitness of species and life-history stages that depend on forage in the nearshore environment.

9.2.5.1.2 Altered Habitat Complexity

Submerged aquatic vegetation provides habitat structure in nearshore environments, creating vertical dimension and overhead cover. Alteration of habitat complexity can decrease the availability of suitable rearing habitat for those species and life-history stages dependent on the nearshore environment, leading to increased predation risk and increased competition for suitable space, further leading to effects on survival, growth, and fitness. This equates to a moderate risk of take for species dependent on aquatic vegetation functions in these environments.

9.2.5.2 Marine Littoral Environments

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

9.2.5.2.1 Altered Autochthonous Production

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

9.2.5.2.2 Altered Habitat Complexity

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

9.2.6 Water Quality Modifications

Water quality modification is a broad category covering several impact mechanisms and related stressors. LWD placement and removal projects have the potential to introduce a limited number of pollutant stressors to the aquatic environment, specifically suspended solids and toxic substances from accidental spills during the project construction phase, and increased suspended solids loading from bank and channel bed instability caused by channel adjustment following LWD removal projects. The severity of individual stressor exposure will vary depending on the nature of the effect, its magnitude and duration, and the sensitivity of the species and life-history stage exposed. The effects of these submechanisms are described in more detail in the following subsections. Species-specific risk of take ratings for the water quality modification impact mechanism are presented in Table 9-2.

9.2.6.1 Altered Suspended Solids

LWD related projects would be expected to result in temporary increases in suspended sediment loading during delivery and implementation. Channel, bed, or bank disturbance during construction and materials placement/removal will unavoidably result in the release of suspended sediments, with the potential in some cases to cause mortality or injury (e.g., if salmonid eggs incubating in gravel redds are smothered by settling fines) or behavioral modification. LWD removal projects may also have longer term effects. Channel and bank instability induced by the hydraulic and geomorphic effects of wood removal may lead to increased erosion and more chronic suspended sediment loading problems. These stressors would similarly induce a moderate risk of take, but these effects would manifest over a longer period until channel instability reaches equilibrium.

9.2.6.2 Altered Pollutant Loading

LWD projects present primarily a single pathway for the introduction of toxic substances to the aquatic environment, via accidental spills during project construction. Depending on the nature and concentration of the contaminant, toxic substance exposure can cause a range of adverse effects in exposed species. In extreme cases, these effects can include direct mortality (e.g., exposure of immobile rockfish larvae in the demersal microlayer). More commonly, chronic, low-level exposure to a variety of contaminants is likely to cause physiological injury and/or contaminant bioaccumulation, leading to decreased survival, growth, and fitness. This presents a moderate risk of take to species potentially exposed to this stressor.

9.2.6.3 Altered Dissolved Oxygen

Additions of large wood debris are generally expected to have limited effects on dissolved oxygen conditions. As noted in Section 7.2.1.6.3 (*Altered Dissolved Oxygen*), decreased nutrient retention associated with LWD removal from riverine environments could theoretically impose some eutrophication-related effects on downstream habitats. In reality, the scale of these effects is expected to be insignificant in all but the most extreme cases (e.g., LWD removal projects that cause dewatering of impounded or backwatered areas). LWD placement projects would be expected to increase sequestration of organic material, distributing nutrient cycling more broadly across the riverine landscape. On this basis, the risk of take associated with this submechanism in riverine environments is expected to be insignificant.

LWD placement or removal projects would not be expected to affect DO levels in marine or lacustrine environments, as DO levels in these environments are driven by import of nutrients from other sources, stratification, and a host of other factors not affected by LWD density. Therefore, risk of take is similarly insignificant.

9.3 Spawning Substrate Augmentation

Spawning substrate augmentation projects involve the placement of gravel sized substrates into the stream channel, either through direct placement or passive placement using stream energy to distribute the material. These projects are usually designed to mitigate the loss of spawning suitable substrate caused by hydromodification or other sources of environmental degradation. Under the presumption that these projects are designed properly for the surrounding ecological context and are implemented as intended, this subactivity type would be expected to improve the functioning of ecological processes resulting in improved habitat conditions. Therefore, with the exception of construction activities and subsequent channel adjustments, the impact mechanisms associated with this type of project would not be expected to impose ecological stressors beyond a short-term period. Thus, the related risk of take is limited.

Species-specific risk of take ratings for this subactivity type are presented in Table 9-3. Because this subactivity type, by definition, occurs in riverine environments only, the associated risk of take from construction applies only to those species that occur within this environment type.

9.3.1 Construction Activities

Substrate augmentation projects require the use of heavy machinery to place gravel sized material either directly into the stream channel or along the channel bank to allow for passive distribution during flood conditions. Primary impact mechanisms associated with project construction include the in-water operation of heavy equipment and related noise, visual, and physical disturbance, and bank and channel disturbance from equipment use and materials placement.

9.3.1.1 Equipment Operation

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.2.1 (*Construction Activities*) for LWD placement. This construction methodology equates to a moderate risk of take for this subactivity type.

9.3.1.2 Bank and Channel Disturbance

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.2.1 (*Construction Activities*) for LWD placement. This construction methodology equates to a moderate risk of take for this subactivity type.

9.3.2 Hydraulic and Geomorphic Modifications

Spawning gravel augmentation involves the imposition of new bedload upon the stream channel that forces the channel to undergo hydraulic and geomorphic adjustment. Under the presumption that the project has been appropriately designed for ecological context, these impact mechanisms would not be expected to impose ecological stressors. Therefore, no related risk of take will result for species exposed to these effects. Species-specific risk of take ratings for this impact mechanism are presented in Table 9-3, with additional and justification for the ratings provided by component submechanisms of impact in the following sections.

9.3.2.1 Altered Channel Geometry

The expected effects of gravel augmentation on channel geometry include particle sorting that creates diverse substrate patches, creation of exposed bars, increased hydraulic complexity and shear zones, and creation of backwaters and other complex alluvial features. These morphologic changes have been observed to increase the quality, quantity, and diversity of both aquatic habitats and associated terrestrial habitats associated with the stream channel. Gravel augmentation can also have the undesirable effect of filling pools, decreasing the amount of pool habitat available. Assuming that the project has been properly conceived for the ecosystem context, these effects would be temporary in nature, and, on balance with the other beneficial geomorphic effects of the project, would not be expected to impose stressors on HCP species. Therefore, there is no anticipated risk of take resulting from this impact mechanism.

9.3.2.2 Altered Bank and Shoreline Stability

Gravel augmentation projects can have variable effects on bank stability depending on the nature of the project. Passive gravel augmentation projects may cause temporary armoring of stream banks while substrate piled on bars or banks is gradually eroded into the channel. The transitory nature of this effect on bank stability would not be expected to produce stressors that would cause a risk of take. However, some risk of take may result from related effects on ecosystem connectivity, which are addressed in Section 9.3.3 (*Ecosystem Fragmentation*).

Gravel augmentation can also temporarily reduce bank instability as the channel adjusts to the presence of the new bed material and as the bed elevation rises. Once the substrate has been distributed, the augmentation will at least temporarily arrest channel incision which is a primary source of bank instability. Therefore, it can be presumed that in the majority of cases the channel aggradation provided by spawning gravel augmentation will help to stabilize banks. Increased bank stability will reduce sediment import into the channel and subsequent spawning gravel and organism burial. Consequently, an increase in bank stability would not be expected to impose stressors on HCP species and there would be no related risk of take. This conclusion is contingent on the presumption that the augmentation project is designed appropriately for the ecosystem context and functions as intended following implementation.

9.3.2.3 Altered Substrate Composition/Stability

Spawning gravel augmentation projects are specifically intended to improve the composition and stability of spawning substrates. Assuming that the project in question is designed appropriately for the ecosystem context and functions as intended, this impact mechanism would not be expected to impose stressors on the aquatic community. Therefore, there is no associated risk of take resulting from this impact mechanism.

9.3.3 Ecosystem Fragmentation

Spawning gravel augmentation projects have some potential to affect ecosystem connectivity in the vicinity of the project. Depending on how the specific project is configured, these effects may be positive, resulting in no risk of take, or negative. Negative effects would primarily be associated with temporary fragmentation of habitat caused by the presence of substrate material as it is naturally distributed by hydraulic forces. These effects, and the related risk of take, would be expected to diminish over time as the substrates assume a positive and productive role in the environment. The risk of take assessment presented for the following ecosystem fragmentation submechanisms applies this worst-case scenario perspective. Species-specific risk of take ratings for this impact mechanism are presented in Table 9-3.

9.3.3.1 Altered Terrestrial and River-Floodplain/Open Water Connectivity

Spawning gravel augmentation has the potential to raise the channel bed, affecting surface water elevations and, in turn, the frequency at which side channel, off-channel, and floodplain habitats are activated over a range of flow conditions. Assuming that these projects are properly designed and implemented, this hydraulic and geomorphic impact mechanism could lead to increased floodplain and side-channel connectivity in riverine environments. This beneficial result would not lead to a risk of take.

Passive augmentation projects often involve the piling of introduced substrate on bars or other channel features, allowing high flows to recruit the introduced material into the channel. Once sediments are entrained into the channel, temporary low flow barriers may occur under certain circumstances before they are fully distributed. In marine and lacustrine environments, substrate piles may be left for recruitment by wave action and longshore sediment transport. Depending on placement, these substrate piles may locally affect the availability of shallow water habitat until the pile has been fully dispersed and distributed. Therefore, this impact mechanism may result in a temporary reduction in the availability and/or accessibility of suitable habitats. This equates to a moderate risk of take for certain types of gravel augmentation projects.

9.3.3.2 Altered Groundwater-Surface Water Interactions

Spawning gravel augmentation has the potential to raise the channel bed, affecting surface water elevation and, in turn, may alter surface water and groundwater exchange. Assuming that these projects are properly designed and implemented, this effect is expected to be beneficial, imposing no ecological stressors and resulting in no risk of take.

9.3.4 Aquatic Vegetation Modifications

Spawning gravel augmentation potentially involves the introduction of large amounts of substrate to the stream channel over a short period of time. Depending on the methods of distribution, this substrate has the potential to result in burial or other physical damage to aquatic vegetation. This would impose a temporary reduction in autochthonous production and alteration of the habitat complexity associated with the vegetation itself. These effects may be short-term or long-term in nature, depending on the degree to which the augmentation project changes the existing substrate characteristics and the sensitivity of the local plant community to this change. From a worst-case scenario perspective, these impact mechanisms could limit the availability of foraging habitat, refuge, and cover, and limit foodweb productivity by reducing autochthonous production. These stressors would equate to a moderate risk of take for those species and life-history stages dependent on aquatic vegetation in the affected environment type.

9.3.5 Water Quality Modifications

Substrate augmentation projects will cause a temporary modification of water quality conditions during the initial delivery and dispersal of the new material, primarily in the form of suspended sediment loading. Once the project has stabilized, this subactivity type would be expected to have either a neutral or a potentially beneficial effect on water quality conditions.

9.3.5.1 Altered Suspended Solids

Substrate augmentation projects would be expected to result in temporary increases in suspended sediment loading during delivery and implementation. Fine sediments mixed with the augmentation material would be released when the sediments are dumped or passively dispersed by high flows or wave action. This temporary increase in suspended sediment levels is equated with a moderate risk of take.

9.3.5.2 Altered Pollutant Loading

The increased hyporheic exchange promoted by substrate augmentation promotes the biogeochemical transformation of nutrients, metals, and other pollutants. Therefore, gravel augmentation projects in riverine environments can promote reductions in pollutant loading. On this basis, stressors related to pollutant exposure would remain unchanged or would be reduced by gravel augmentation projects; therefore, there is no associated risk of take.

9.3.5.3 Altered Dissolved Oxygen

The available research tends to indicate that spawning gravel augmentation increases intergravel DO levels resulting in an improvement in habitat conditions. Therefore, this submechanism would not impose stressors on species using these habitats. Consequently, there is no risk of take associated with this submechanism in any environment type.

9.4 In-Channel/Off-Channel Habitat Creation/Modifications

In-channel and off-channel habitat creation or modification projects are, for the purpose of this white paper, fundamentally considered efforts intended to enhance or restore degraded habitat conditions. Channel modification projects designed for other purposes are addressed in the Channel Modifications white paper (Herrera 2007b). Under the presumption that these projects are designed properly for the surrounding ecological context and are implemented as intended, this subactivity type would be expected to improve the functioning of ecological processes resulting in improved habitat conditions. With the exception of the short-term effects associated with construction activities, the impact mechanisms associated with this type of project would not be expected to impose ecological stressors. Therefore, there will be no associated risk of take once project construction is complete.

Species-specific risk of take ratings for this subactivity type are presented in Table 9-4. Because this subactivity type, by definition, occurs in riverine environments only, the associated risk of take from construction applies only to those species that occur within this environment type.

9.4.1 Construction Activities

Depending on scale, the construction of in-channel and off-channel habitat enhancement projects typically involves the use of heavy machinery, the placement of LWD or rock to modify hydraulic and geomorphic conditions in the affected stream reach, and in some cases the breaching of existing manmade or natural barriers to floodplain connectivity, or the excavation of new off-channel habitat features. These activities can impose a number of stressors on the aquatic environment.

9.4.1.1 Equipment Operation

The operation of heavy construction equipment to create or modify in-channel and off-channel habitats and connect these habitats to mainstem channels imposes stressors in the form of physical and visual disturbance and, potentially, increased underwater noise. The magnitude of these stressors will vary widely depending on the scale of the project in question and the specific construction measures used. Applying a "worst-case-scenario" perspective, the magnitude of these stressors can be significant.

The literature on underwater noise levels produced by heavy equipment use is quite limited, and this subject is considered a data gap. In general, however, noise produced by heavy equipment during the in-water operation of heavy equipment is unlikely to exceed established injury thresholds but may well exceed disturbance thresholds. Therefore, projects involving some element of in-water work are expected to result in a moderate risk of take from underwater noise. Visual disturbance during construction would have similar effects. Physical disturbance is similarly expected to produce only a moderate risk of take due to temporary disturbance and displacement for most species exposed to this stressor. Sessile or otherwise non-motile species or life-history stages are an exception, as they will be unable to escape or avoid physical disturbance. Therefore, they are at increased risk of mechanical injury from crushing or burial during construction, which constitutes a high risk of take.

9.4.1.2 Bank and Channel Disturbance

Bank, channel, and/or shoreline disturbance during the construction of in-channel and off-channel habitat projects can potentially be significant, resulting in the short-term modification of habitats that are potentially suitable for HCP species of concern. On balance, it is expected that properly designed projects would compensate for adverse effects caused by bank and channel disturbance as the project matures. However, the short-term effects may limit the availability and suitability of habitats for sensitive life-history stages during critical periods. For example, a channel enhancement project may require the alteration or removal of complex bank habitat and overhead cover from a pool during construction. Equivalent habitat function may not return until geomorphic forces act on the project and riparian replanting matures. In the interim, habitat suitability in the affected pool could be reduced, limiting the number of juvenile salmonids (e.g., coho salmon and steelhead) or other species (e.g., mountain sucker, cutthroat and redband trout) that the pool can support with adequate cover to avoid predation. In such cases, this impact mechanism could result in a moderate risk of take for species utilizing these habitats until equivalent or superior habitat function is achieved.

9.4.1.3 Temporary Dewatering and Fish Handling

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.2.1 (*Construction Activities*) for LWD placement. This construction methodology equates to a moderate risk of take for this subactivity type.

9.4.2 Hydraulic and Geomorphic Modifications

Hydraulic and geomorphic modifications caused by off-channel and side-channel habitat creation are anticipated to improve habitat complexity and increase habitat suitability. Therefore, this impact mechanism category is not expected to impose any stressors on HCP species and there is no related risk of take.

9.4.3 Ecosystem Fragmentation

Off-channel and side-channel habitat creation will result in increased ecological connectivity and complexity, which will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.4.4 Riparian Vegetation Modifications

Off-channel and side-channel habitat creation will effectively increase the amount of functional riparian habitat in connection with the active channel, thereby increasing allochthonous inputs, reducing solar radiation exposure and related effects on water temperature, and increasing the buffering capacity. This will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.4.5 Aquatic Vegetation Modifications

Off-channel and side-channel habitat creation will effectively increase the amount of habitat available for aquatic vegetation growth, thereby increasing autochthonous production, habitat complexity and community structure. This will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.4.6 Water Quality Modifications

Forms of water quality modification associated with in-channel and off-channel habitat creation that have the potential to impose stressors on HCP species will occur principally during project construction. The primary water quality related impact mechanism is increased suspended sediments caused by bank and channel disturbance, and the “first flush” effect when the dewatered project areas are first exposed to stream flows. Pollutant loading may also occur as a result of accidental spills from heavy equipment during construction. The related risk of take associated with these impact mechanisms (moderate) is similar to that described for LWD projects in Section 9.2.6 (*Water Quality Modifications*). Altered thermal regime is also mentioned in Section 7.4.1.6 (*Water Quality Modifications*) as an effect of this type of habitat modification. Because this type of project is expected to improve temperature conditions, however, the effects of altered thermal regime are expected to be beneficial. Therefore, there is no related risk of take.

As this type of project becomes functional, increased hyporheic exchange and storage of flood waters in off-channel habitats is likely to provide additional biogeochemical processing capacity that will aid in the sequestration and detoxification of certain forms of pollutants. This effect would be expected to provide beneficial improvements in water quality.

9.5 Riparian Planting/Restoration/Enhancement

Riparian planting, restoration, and enhancement projects (hereafter referred to as riparian enhancement) are commonly implemented in conjunction with habitat restoration initiatives or as mitigation for a separate human induced source of habitat degradation. This subactivity type is employed in riverine, marine, and lacustrine environments and is most typically implemented using manual labor or, in specific circumstances, light machinery. As such, this type of project usually requires only limited disturbance of the bank or shoreline and little or no disturbance of the aquatic environment itself. Once implemented, riparian enhancement projects will generally result in improved riparian function and the related impact mechanisms would not be expected to impose stressors on HCP species. Therefore, the overall risk of take associated with this subactivity type is low and is primarily associated with construction for almost all of the HCP species. An exception to this rule includes the Newcomb's littorine snail because this species is actually dependent on littoral vegetation and is therefore potentially subject to direct disturbance or injury. Species-specific risk of take resulting from this project type is presented in Table 9-5.

9.5.1 Construction Activities

Riparian enhancement projects typically involve the planting of native vegetation using manual labor often with some prior site preparation and soil amendment. In some cases, specialized machinery may be used to facilitate planting. In riverine and lacustrine environments, this equipment would typically not enter the water. In the marine environment, the beach may be used to access the work site in specific circumstances.

Riparian planting may produce construction-related impacts in the form of visual and noise-related disturbance, as well as the disturbance of the stream bank or shoreline. The magnitude of this disturbance is minor in comparison to that produced by the construction of other habitat modification subactivity types. Because this work takes place primarily out of the water and is short-term in duration, the extent of stressor exposure is limited to short-term behavioral alteration. This equates to a low risk of take for species present in the affected habitat when the activity takes place.

9.5.2 Hydraulic and Geomorphic Modifications

Once established, riparian enhancement projects will produce multiple benefits. While the immediate effect of such projects on hydraulic and geomorphic conditions is limited, over time vegetation growth will consolidate the stream bank or shoreline through root cohesion, thereby increasing stability. As vegetation matures, it will eventually provide a source of LWD recruitment that will have a broad beneficial influence on aquatic habitat. Therefore, riparian vegetation modification impact mechanisms are not expected to impose stressors on the HCP species and there is no related risk of take.

9.5.3 Ecosystem Fragmentation

Once established, riparian enhancement projects will produce multiple benefits. While the immediate effect of such projects on ecosystem connectivity will be limited, over time vegetation growth will consolidate the stream bank or shoreline through root cohesion, thereby increasing stability. As the vegetation matures it will eventually provide a source of LWD recruitment that will have a broad beneficial influence on aquatic habitat complexity, enhancing connectivity by expanding the frequency and distribution of desirable habitat patches. Therefore, riparian vegetation modification impact mechanisms are not expected to impose stressors on HCP species, and there is no related risk of take in any environment type.

9.5.4 Riparian Vegetation Modifications

Riparian enhancement projects are specifically intended to modify the riparian environment for the purpose of providing habitat benefits. Thus, these projects directly address stressors imposed by riparian vegetation modification impact mechanisms. Therefore, these projects are expected to lessen the magnitude of stressors imposed by degraded riparian conditions and will result in no related risk of take in any environment type.

9.5.5 Aquatic Vegetation Modifications

Riparian enhancement projects are not expected to cause adverse aquatic vegetation modification. Thus, impact mechanisms related to this subactivity type are not expected to impose any stressors on HCP species. Therefore, there is no associated risk of take in any environment type.

9.5.6 Water Quality Modifications

Riparian enhancement projects may cause minor short-term changes in water quality during implementation, primarily in the form of increased suspended solids from reworking of bank or shoreline substrates for soil preparation and amendment purposes. As the project matures, beneficial improvements in water quality should be realized. The effects of this subactivity type on water quality related submechanisms are discussed below.

9.5.6.1 Altered Temperature Regime

Once established, riparian enhancement projects will be expected to alter temperature conditions for the benefit of native aquatic species. These temperature effects are realized through increased shading (i.e., reduced insulation) and through buffering of ambient air temperatures. In riverine environments, these effects will primarily take the form of moderated water temperature conditions. In both marine and lacustrine environments, increased shading will moderate water temperatures primarily in isolated nearshore shallow water environments. Altered ambient air temperatures and increased shading on marine shorelines will provide additional benefits for sand lance and surf smelt, HCP species that spawn in the upper intertidal zone. Collectively, this submechanism is expected to moderate temperature conditions, improving habitat suitability in all environment types. Therefore, it will not impose stressors on HCP species and there will be no resulting risk of take.

9.5.6.2 Altered Suspended Solids

Riparian enhancement projects have some limited potential to increase sediment loading to the aquatic environment during and immediately following the construction phase. This may occur during manual reworking of the bank or shoreline environment for planting and soil amendment, and exposure to the first high-water or runoff events that follow project completion. In practice, the amount of sediment loading likely to result from riparian enhancement is low relative to that produced by other types of habitat projects because the extent of ground disturbance is generally more limited. With proper project design and BMP implementation, the short-term increase in sediment loading produced by riparian enhancement is not expected to exceed levels sufficient to adversely affect survival, growth, or fitness of HCP species. Therefore, this impact mechanism is equated with a low risk of take.

9.5.6.3 Altered Pollutant Loading

Once established, riparian enhancement projects are expected to slow the overland flow of stormwater, encouraging infiltration and vegetative filtering. The improved buffering and filtering capacity provided by this subactivity type would be expected to reduce the delivery of pollutants to aquatic ecosystems, and decrease shoreline erosion that contributes to sediment loading. As such, this type of project will not directly produce any pollutant-related stressors, and will reduce the incidence and severity of pollutant loading from other sources. Therefore, no risk of take is anticipated from this submechanism.

9.6 Wetland Creation/Restoration/Enhancement

Wetland creation, restoration, and enhancement projects are, for the purpose of this white paper, fundamentally considered efforts to enhance or restore degraded habitat conditions. Under the presumption that these projects are designed properly for the surrounding ecological context and are implemented as intended, this subactivity type would be expected to improve the functioning of ecological processes and to result in improved habitat conditions. Therefore, ecological stressors would only be expected to occur during the short-term period required for construction and the intermediate-term period required for vegetation and site hydrology to mature. Therefore, the related risk of take resulting from this type of project would be expected to diminish over time.

Wetland creation and enhancement projects vary widely in scale, from the enhancement of existing wetlands by restoring water supply, removing invasive species, and/or replanting invasive vegetation, to full-scale wetland creation or enhancement projects. The latter form of project typically involves the use of heavy machinery for clearing and grading to contour the project area for the desired hydrologic conditions, the placement of LWD, rock, or other materials as habitat structure or components in water level control structures, and extensive revegetation. Breaching of existing hydromodifications or other barriers may be required to establish connectivity between the wetland and surface waters.

The magnitude of impact mechanisms, the related stressors, and the resulting risk of take associated with wetland creation and enhancement projects must be considered in this context. Smaller scale projects constructed in seasonally dry wetlands will have effectively no potential for construction-related or longer term impacts, and no related risk of take. In contrast, larger scale projects in existing wetlands or in habitats in close association with existing aquatic habitats will impose impact mechanisms of greater magnitude and present more potential for stressor exposure. The latter type of project represents the worst-case scenario perspective used for the purpose of this risk of take assessment. Species-specific risk of take ratings for this subactivity type are presented in Table 9-6.

9.6.1 Construction Activities

For the purpose of this assessment, a worst-case scenario perspective is taken toward the potential construction-related impacts associated with wetland creation and enhancement projects. The construction effects from large-scale projects involving the following elements are used to evaluate the potential risk of take: the project occurs within existing aquatic habitat, requiring fish exclusion and dewatering; use of heavy machinery for clearing and grading to contour the project area for the desired hydrologic conditions; placement of LWD, rock, or other materials as habitat structure or components in water level control structures; breaching of existing hydromodifications to establish connectivity with surface waters; and extensive revegetation.

9.6.1.1 Equipment Operation

Heavy equipment operation in and around riparian areas during wetland construction and the breaching of hydromodifications or other barriers to connect wetlands to surface waters have the potential to impose a number of stressors on the aquatic environment. The stressors and related risk of take associated with this submechanism are similar to those described in Sections 9.2.1 (*Construction Activities*) and 9.4.1 (*Construction Activities*) for LWD placement and in-channel and off-channel habitat creation and enhancement projects, respectively.

9.6.1.2 Bank/Channel and Shoreline Disturbance

The stressors and related risk of take associated with this submechanism are similar to those described in Sections 9.2.1 (*Construction Activities*) and 9.4.1 (*Construction Activities*) for LWD placement and in-channel and off-channel habitat creation and enhancement projects, respectively. This construction methodology equates to a moderate risk of take for this subactivity type.

9.6.1.3 Temporary Dewatering and Fish Handling

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.2.1 (*Construction Activities*) for LWD placement. This construction methodology equates to a moderate risk of take for this subactivity type.

9.6.2 Hydraulic and Geomorphic Modifications

Wetland creation and enhancement projects are typically designed specifically for local hydraulic and geomorphic conditions, often through the reconnection of fragmented floodplain, off-channel habitat, and estuarine habitats. These measures would be expected to improve habitat complexity and increase habitat suitability for a wide range of aquatic and terrestrial species. Therefore, this impact mechanism category is not expected to impose any stressors on HCP species and there is no related risk of take.

9.6.3 Ecosystem Fragmentation

Wetland creation and enhancement projects will, by design, result in increased ecological connectivity and complexity that will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.6.4 Riparian Vegetation Modifications

Wetland creation and enhancement projects typically incorporate the preservation and restoration of riparian buffer vegetation. This will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.6.5 Aquatic Vegetation Modifications

Wetland creation and enhancement projects will, in most cases, increase the amount of habitat available for aquatic vegetation growth, thereby increasing autochthonous production, habitat complexity and community structure. This will increase the availability and suitability of habitats for HCP species. Therefore, this impact mechanism category is not expected to impose any stressors and there is no related risk of take.

9.6.6 Water Quality Modifications

Water quality modification impact mechanisms, stressors, and the related risk of take resulting from wetland creation and enhancement are similar to those described in Sections 9.2.1 (*Construction Activities*) and 9.4.1 (*Construction Activities*) for LWD placement and in-channel and off-channel habitat creation and enhancement, respectively.

9.7 Beach Nourishment/Contouring

Beach nourishment and contouring projects involve the placement of new sand to gravel or cobble-sized substrates in the littoral zone, or the reconfiguration of existing beach substrates to provide a more desirable beach contour. These projects are typically intended to address degraded beach conditions that are most often caused by shoreline modification or overwater structures. Under the presumption that these projects are designed properly for the surrounding ecological context and are implemented as intended, this subactivity type would be expected to improve the functioning of ecological processes and result in improved habitat conditions. Therefore, with the exception of construction activities and subsequent channel adjustments, the impact mechanisms associated with this type of project would not be expected to impose ecological stressors beyond a short-term period. Thus, the related risk of take is limited. Species-specific risk of take ratings for this subactivity type are presented in Table 9-7. Because this subactivity type, by definition, occurs in marine and lacustrine environments, the associated risk of take from construction applies only to those species that occur within these environment types. Projects of this type in the riverine environment are considered substrate augmentation, which is addressed in Section 9.3 (*Spawning Substrate Augmentation*).

9.7.1 Construction Activities

Beach nourishment projects typically involve the operation of heavy equipment on the shoreline to deposit and/or distribute substrate. The quantity of substrate involved is typically substantial, changing the depth profile of the affected area from approximately 3 to 8 ft (1 to 2.5 m). Beach contouring projects typically involve the redistribution and contouring of existing substrates and may or may not involve the placement of new material. This activity will result in the immediate burial of benthic organisms and aquatic vegetation and, if present, forage fish eggs and the non-motile larvae of certain fish species that are prevalent in the nearshore environment. Impacts on benthic organism diversity and abundance are typically temporary as these communities tend to recover from disturbance quickly. However, this impact mechanism could result in a short-term, localized reduction in foraging opportunities for those species dependent on these prey resources, potentially affecting growth and fitness. This equates to a moderate risk of take. In the case of non-motile HCP species or species life-history stages exposed to this stressor, there is a high likelihood of direct mortality or injury, which equates to a high risk of take.

9.7.2 Hydraulic and Geomorphic Modifications

Beach nourishment projects directly alter the hydraulic and geomorphic characteristics of the affected shoreline environment. Because they are typically intended to address beach degradation most often caused by shoreline modification projects, properly designed beach nourishment projects either directly or indirectly result in improved hydraulic and geomorphic conditions from a habitat perspective. On this basis, this impact mechanism would generally not be expected to impose stressors on aquatic organisms and there would be no related risk of take. In practice, however, current understanding of marine and lacustrine geomorphology is sufficiently limited to create design uncertainty in site-specific circumstances. On this basis, some risk of take may occur that is difficult to quantify. On this basis, an uncertain risk of take is assigned to specific submechanisms in this section and to this impact mechanism as a whole in Table 9-7. Additional discussion regarding the specific effects of beach nourishment on hydraulic and geomorphic conditions and the related potential to produce stressors is provided below.

9.7.2.1 Altered Wave Energy and Nearshore Circulation Patterns

Properly designed beach nourishment and beach contouring projects are typically intended to restore a pre-development wave energy and nearshore circulation environment. These beneficial impact mechanisms would not be expected to impose stressors on HCP species. Therefore, there will be no related risk of take.

9.7.2.2 Altered Shoreline Stability

By reducing incident wave energy and expanding the foreshore, properly designed beach nourishment and beach contouring projects reduce ecologically damaging shoreline instability. Therefore, this impact mechanism would not be expected to impose stressors on HCP species and there would be no related risk of take.

9.7.2.3 Altered Substrate Composition/Stability

Improperly designed beach nourishment projects have, in the past, unintentionally induced environmental stressors by altering the composition and stability of substrates in and downdrift of the project area. Introduction of substrates of dissimilar size, particularly larger substrates to reduce erosion and dissipate wave energy, has had the undesirable effect of limiting habitat suitability for specific uses, such as forage fish spawning. These effects can be translated downdrift of the project area through longshore sediment transport, extending the ecological stressor beyond the project boundary. These practices are now discouraged and issuance of an HPA typically requires that the introduced substrates are consistent with the surrounding environment. Presuming that beach nourishment projects are properly designed for their ecosystem context, the resulting alterations in substrate composition and stability are expected to be beneficial in nature and would not impose stressors on HCP species occurring in the project area.

Currently, however, the ability to match substrates and site conditions for the best ecological outcome is constrained by uncertainty. The size distribution, composition, and arrangement of substrates in a beach nourishment project are all important factors determining the ecological benefits of a project. An inappropriate choice may result in broad changes in ecological conditions with a range of direct indirect effects on species that use the nearshore environment. However, the nature and extent of these effects are difficult to quantify. Therefore, this submechanism is associated with an uncertain risk of take.

9.7.3 Ecosystem Fragmentation

The ability of beach nourishment to reconnect or disconnect pre-existing shoreline communities depends on the nature of the shorelines adjacent to the activity site. If the substrate is significantly different than the shorelines adjacent to it, or if added sediment buries aquatic vegetation, the activity may fragment the alongshore transit of HCP species. Under the basic presumption that the project is properly designed and implemented, these forms of ecosystem fragmentation should not occur. In contrast, beach contouring can moderate the ecological gradient between the littoral and riparian zones, thereby improving ecological connectivity. Properly designed beach nourishment projects should not further degrade or may even improve this impact mechanism and would therefore not impose any related stressors. Accordingly, there will be no related risk of take from this impact mechanism.

9.7.4 Riparian Vegetation Modifications

Beach nourishment projects do not involve direct modification of the riparian environment, except where necessary to provide access for equipment and materials. Once established, beach nourishment projects are expected to produce beneficial changes in hydraulic and geomorphic conditions along the shoreline, thereby contributing to preservation and improvement of riparian conditions.

Beach nourishment projects would be expected to avoid impacts on riparian vegetation to the greatest extent possible as a condition of permitting. However, in a worst-case scenario, limited riparian disturbance necessary for equipment and materials access may occur. For HCP species with limited dependence on marine or lacustrine riparian vegetation, the resultant effects of this limited disturbance are expected to be insignificant. Some HCP species (e.g., sand lance, surf smelt, Chinook salmon) inhabit littoral fringe areas during life-history stages that are more sensitive to stressor exposure. These species face a moderate risk from the limited and minor resultant effects. Newcomb's littorine snail is considered an exception. Because this species has a limited distribution and is entirely dependent on shoreline vegetation, any alteration of its habitat would be associated with a high risk of take.

9.7.5 Aquatic Vegetation Modifications

Beach nourishment projects can modify the aquatic vegetation community directly through the burial of established vegetation, by changing substrate conditions, and by altering the hydraulic and geomorphic conditions adjacent to and downdrift of the project area. Depending on the nature of the effect, the fragmentation and loss of aquatic vegetation functions could impose a variety of stressors on HCP species in the affected habitat. This translates to a potential risk of take. The species-specific risk of take ratings for this impact mechanism are presented in Table 9-7. The nature of the submechanisms and related stressors that constitute this risk are described in the following subsections.

9.7.5.1 Altered Autochthonous Production

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

9.7.5.2 Altered Habitat Complexity/Community Structure

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

9.7.6 Water Quality Modifications

Water quality modification is a broad category covering several impact mechanisms and related stressors. Beach nourishment projects have the potential to introduce a limited number of pollutant stressors to the aquatic environment, including suspended solids and toxic substances from accidental spills, with exposure occurring only during the project construction phase. The severity of individual stressor exposure will vary depending on the nature of the effect, its magnitude and duration, and the sensitivity of the species and life-history stage exposed. The effects of these submechanisms are described in more detail in the following subsections. Species-specific risk of take ratings for the water quality modification impact mechanism are presented in Table 9-7.

9.7.6.1 Altered Suspended Solids

Increased suspended solids can result from several different impact mechanisms. The severity of this stressor varies depending on its magnitude, duration, and frequency, as well as the sensitivity of the species and life-history stage exposed. In general, motile species and life-history stages exposed to temporary sediment impacts at low occurrence frequency experience only temporary disturbance, behavioral alteration, and low risk of take. In contrast, sessile invertebrates or relatively immobile life-history stages exposed to the same stressor may experience decreased survival and reduced foraging opportunities leading to a moderate to high risk of take. For example, increased fine sediment levels in spawning gravels demonstrably affect the survival of salmonid eggs. In the marine environment, larval rockfish, cod, pollock, and lingcod reside in microlayer habitat. Increased suspended solids in the microlayer habitat can cause direct mortality of exposed larvae that are relatively immobile and thereby incapable of escaping acute water quality degradation. Sublethal levels of suspended sediments may affect the foraging success of planktonic herring larvae, leading to decreased foraging success and decreased survival, growth, and fitness. More frequent or longer duration sediment impacts have more pronounced effects on even motile species. Such exposure can cause behavioral alteration for longer periods, potentially increasing stress, exertion, and predation exposure; thereby decreasing foraging opportunities or even causing injury in extreme events.

9.7.6.2 Altered Pollutant Loading

Beach nourishment projects present few pathways for the introduction of toxic substances to the aquatic environment, but this could occur through accidental spills from construction equipment. Depending on the nature and concentration of the contaminant, toxic substance exposure can cause a range of adverse effects in exposed species. In extreme cases, these effects can include direct mortality (e.g., exposure of immobile rockfish larvae in the demersal microlayer). More commonly, chronic, low-level exposure to a variety of contaminants is likely to cause physiological injury and/or contaminant bioaccumulation leading to decreased survival, growth, and fitness. This presents a moderate to high risk of take to species potentially exposed to this stressor, depending on life-history specific sensitivity.

9.8 Reef Creation/Restoration/Enhancement

Reef creation, restoration, or enhancement projects (hereafter referred to as reef creation or artificial reef projects, are commonly implemented in marine waters but may also occur in lakes and reservoirs. These projects involve the placement of rock, wood, concrete, metal (e.g., sunken vessel hulls), or other materials on the bottom, creating three dimensional structure that attracts or encourages the settlement of fish, invertebrates, and aquatic vegetation. Ideally, these structures are intended to increase the availability of suitable habitat for fish and invertebrates, leading to increased abundance and productivity. However, the degree to which reefs provide this function versus merely concentrating existing populations without increasing abundance or productivity remains uncertain.

Artificial reefs will impose a number of stressors on the environment during construction. Depending on the configuration and location of the reef, the structure may also have long-term effects on habitat suitability through modification of hydraulic and geomorphic characteristics and ecosystem fragmentation. The risk of take from artificial reef development has been assessed using a worst-case scenario perspective with regard to these impact mechanisms. Species-specific risk of take ratings for impact mechanisms caused by this subactivity type are presented in Table 9-8.

9.8.1 Construction Activities

The construction of artificial reef projects is typically a straightforward process, involving the placement of materials from a deck, a barge, or other floating or stationary platform. In some cases, decommissioned ships are sunk to serve as reefs. Reef construction is a short-term activity, lasting from a few days to weeks, depending on the size and location of the structure in question. The risk of take associated with construction activity varies by impact mechanism and is dependent on the project-specific magnitude of that impact mechanism. As discussed below, some mechanisms may produce a high risk of individual take due to their intensity, while others may result in a low risk of take due to their limited magnitude and duration. Species-specific risk of take ratings for construction-related submechanisms are presented by subactivity and environment in Table 9-8.

9.8.1.1 Equipment Operation and Materials Placement

Development of artificial reefs involves the placement of materials by dumping from the surface, typically from a barge or other type of construction vessel. The following stressors are anticipated to occur as a result of construction:

- Visual, physical, and noise related disturbance and displacement from vessel operation and placement of materials

- Potential injury or mortality from burial or mechanical injury by materials sinking into place

- Water quality effects, including: introduction of toxic substances from accidental spills during construction vessels; increased suspended sediments liberated from the reef material or substrate disturbance during materials placement; and the potential resuspension of contaminated sediments during construction.

The potential for take associated with benthic disturbance during materials placement varies depending on the nature of the stressor and the species and life-history stage exposed. Temporary disturbance and displacement and a decreased ability to sense predators and prey due to auditory masking effects equate to a moderate risk of take. Limited or non-motile species or life-history stages occurring in the project area during materials placement face a high risk of take from physical injury or mortality (e.g., from burial and mechanical injury). Generally, many juvenile and most adult fish are sufficiently motile to avoid injury or mortality. In combination with timing restrictions, this will limit exposure so that only a moderate risk of take will result from activity-related disturbance and temporary or permanent displacement. In contrast, eggs and demersal larvae are not motile and therefore are vulnerable to these effects. Therefore, timing restrictions may not provide protection for all HCP species in all environments. Thus, artificial reef development is likely to result in varying degrees of take.

In addition to the potential for take from disturbance and direct physical impacts, dredging may produce water quality related stressors that create the potential for take. Specifically, increased suspended solids (turbidity) are likely to occur during construction. If the reef is constructed where contaminated sediments are present, these contaminants may be introduced into the water column when the bottom is physically disturbed. Construction vessel operation is also a potential vector for the introduction of toxic substances through accidental spills. The risk of take associated with these water quality effects is described in Section 9.8.5 (*Water Quality Modifications).*

9.8.2 Hydraulic and Geomorphic Modifications

Artificial reefs are a subactivity type that is predominantly implemented in the marine environment but can occur in the lacustrine environment. This project type can, under specific conditions, modify hydraulic and geomorphic conditions in the nearshore environment, resulting in the imposition of several impact mechanisms and related stressors. These effects occur when the top of the reef extends above the wave closure depth (see Section 7.8.1.2 [*Geomorphic and Hydraulic Modifications]*). The resulting risk of take from these impact mechanisms is strongly linked to species-specific dependence on the nearshore environment.

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

Artificial reefs that extend above the wave closure depth can significantly affect nearshore wave energy, current velocities, and circulation patterns. These physical processes are all important determinants governing nearshore marine as well as lacustrine habitat characteristics. These factors determine habitat suitability for a number of species-specific life-history processes. For example, wave energy conditions, currents, and circulation patterns have a strong influence on nearshore water temperatures and on the sorting and transport of sediments. Many fish species selectively spawn in locations where current and circulation patterns promote the settling of planktonic larvae in favorable environments for rearing. Alteration of these patterns can cause larvae to be transported to unfavorable environments. Similarly, juvenile fish rearing in nearshore environments selectively choose environments with suitable wave energy and current conditions. These impact mechanisms can fundamentally alter habitat suitability for these uses, leading to decreased habitat availability, and decreased survival, growth, and fitness. This equates to a moderate risk of take for species that are dependent on these habitats during some phase of their life history (see Tables 9-2, 9-3, and 9-4, presented following this narrative).

9.8.2.1.2 Altered Sediment Supply and Altered Substrate Composition

Sediment supply and substrate composition are fundamental components of the nearshore ecosystem structure. The physical alterations of the shoreline environment that accompany certain reef creation projects can cause alterations in sediment supply and substrate conditions through alteration of longshore sediment transport. In conjunction with altered wave energy, this can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the nearshore environment, these habitat changes can fundamentally alter community structure and habitat suitability for species dependent on the original habitat condition. This equates to a moderate risk of take for species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed life-history stages (see Tables 9-2, 9-3, and 9-4, presented following this narrative).

9.8.3 Ecosystem Fragmentation

Depending on the nature and configuration of the structure, artificial reefs present some potential for habitat fragmentation. It is certain that existing habitats in the physical footprint of the structure will be permanently modified as a result of construction. If the new reef creates an expanse of unsuitable habitat that fragments existing habitat patches, its presence could be detrimental to those species dependent on the ecological connectivity that has been compromised.

As discussed in Section 9.8.2 (*Hydraulic and Geomorphic Modifications*), artificial reefs can, under certain circumstances, alter wave energy, current, and circulation patterns in the nearshore and offshore environment. Alteration of these habitat characteristics may render productive habitats less suitable for a given species or, in the case of organisms with a planktonic life-history stage (e.g., rockfish, herring, forage fish, Pacific cod, lingcod, hake, pollock), may hinder the dispersal and retention of eggs and larvae in areas suitable for rearing. Juvenile salmon species, such as Chinook, pink, and chum salmon are dependent on migratory rearing habitats in the nearshore environment during their early ocean phase. Reefs created in nearshore habitats may fundamentally alter habitat characteristics. Changes in foraging opportunities and increased predation risk due to increased cover and habitat for predatory fish species may lead to decreased survival, growth, and fitness. Collectively, this can result in take through effects on survival, growth, and fitness of affected populations, which equates to a moderate risk of take for exposed species. Again, the risk of take will vary depending on the nature of the project. Reefs constructed offshore and below the wave closure depth would be expected to have limited effects on the nearshore environment and would provide beneficial habitat conditions for a variety of HCP species including rockfish, lingcod, and northern abalone. These structures may present little or no risk of take from ecosystem fragmentation.

9.8.4 Aquatic Vegetation Modifications

Reef creation projects can result in aquatic vegetation modification through the alteration or elimination of vegetation in the construction footprint, as well as the subsequent effects of the structure on hydraulic and geomorphic conditions. During construction, vegetation in the structural footprint of the project can be eradicated or buried by the placement of fill or structural material. After construction, changes in wave energy, circulation patterns, flow and/or current velocities, and substrate composition can also alter the vegetation community.

Alteration of aquatic vegetation imposes impact mechanisms on the nearshore environment in the form of changes in autochthonous production and altered habitat complexity. The nature of these mechanisms and related stressors varies slightly between riverine and lacustrine habitats versus marine habitats, primarily because the role of aquatic vegetation differs between these systems. Therefore, the risk of take in these different environments is discussed separately. Species-specific risk of take ratings for the impact mechanisms resulting from aquatic vegetation modification are presented by subactivity and environment in Table 9-8.

As with the other categories of impact mechanisms addressed in this white paper, the nature and scale of aquatic vegetation modification are dependent on the size and design of the individual project in combination with site-specific conditions.

9.8.4.1 Altered Autochthonous Production

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.7.5 (*Aquatic Vegetation Modifications*) for beach nourishment/contouring. This construction methodology equates to a moderate risk of take for this subactivity type.

9.8.4.2 Altered Habitat Complexity/Community Structure

The stressors and related risk of take associated with this submechanism are similar to those described in Section 9.7.5 (*Aquatic Vegetation Modifications*) for beach nourishment/contouring. This construction methodology equates to a moderate risk of take for this subactivity type.

9.8.5 Water Quality Modifications

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

The size of the structure, the materials used, and its construction requirements will determine stressor intensity. Again, to assess the risk of take associated with reefs, a “worst-case scenario” approach is taken in this white paper. Species-specific risk of take ratings by impact mechanism are presented in Table 9-8.

9.8.5.1 Altered Suspended Solids

Increased suspended solids can result from several different impact mechanisms. The severity of this stressor varies depending on its magnitude, duration, and frequency, as well as the sensitivity of the species and life-history stage exposed. In general, motile species and life-history stages exposed to temporary sediment impacts at low occurrence frequency experience only temporary disturbance, behavioral alteration, and low risk of take. In contrast, sessile invertebrates or relatively immobile life-history stages exposed to the same stressor may experience decreased survival and reduced foraging opportunities leading to a moderate risk of take. For example, increased fine sediment levels in spawning gravels demonstrably affect the survival of salmonid eggs. In the marine environment, larval rockfish, cod, pollock, and lingcod reside in microlayer habitat. Increased suspended solids in the microlayer can cause direct mortality of exposed larvae that are relatively immobile and thereby incapable of escaping acute water quality degradation. Sublethal levels of suspended sediments may affect the foraging success of planktonic herring larvae leading to decreased foraging success and decreased survival, growth, and fitness. More frequent or longer duration sediment impacts have more pronounced effects on even motile species. Such exposure can cause behavioral alteration for longer periods, potentially increasing stress, exertion, and predation exposure, thereby decreasing foraging opportunities or even causing injury in extreme events.

9.8.5.2 Altered Pollutant Loading

Reef creation projects present multiple pathways for the introduction of a range of toxic substances to the aquatic environment primarily through construction activities and, in some cases, the presence of toxic substances in materials used to create the structure (e.g., sinking of decommissioned ships). Materials placement can also result in the resuspension of contaminated sediments during construction if these substances are present in the project area. This effect may continue for some time if the hydraulic effects of the structure induce scouring. Depending on the nature and concentration of the contaminant, toxic substance exposure can cause a range of adverse effects in exposed species. In extreme cases these effects can include direct mortality (e.g., exposure of immobile rockfish larvae in the demersal microlayer). More commonly, chronic, low-level exposure to a variety of contaminants is likely to cause physiological injury and/or contaminant bioaccumulation leading to decreased survival, growth, and fitness. This presents a moderate risk of take to species potentially exposed to this stressor.

9.9 Eelgrass and Other Aquatic Vegetation Creation/Enhancement/Restoration

In comparison to other nearshore restoration techniques, the restoration and enhancement of eelgrass and other types of aquatic vegetation can provide a variety of habitat benefits while imposing little potential for take during project construction. This type of project has the least potential for take of any habitat modification subactivity type considered in this white paper. The species-specific risk of take ratings for this subactivity type are presented in Table 9-9.

9.9.1 Construction Activities

Eelgrass and aquatic vegetation enhancement most often have low intensity construction requirements. These project types are typically implemented by hand or by using nonpowered equipment. Therefore, the construction-related effects would occur in the form of low intensity physical and visual disturbance. Because planting success requires careful placement, sessile or non-motile organisms would be at relatively low risk of physical injury when carefully trained staff are used. Therefore, the stressors imposed by construction-related submechanisms would be expected to result only in short-term disturbance and behavioral modification, which equates to a low risk of take.

9.9.2 Hydraulic and Geomorphic Modifications

Assuming that the project has been conceived and designed properly for the ecosystem context, augmentation of eelgrass and other types of aquatic vegetation are expected to provide beneficial improvements in hydraulic and geomorphic conditions. On this basis, this impact mechanism would not be expected to impose stressors on the aquatic environment, and there is no associated risk of take.

9.9.3 Ecosystem Fragmentation

Assuming that the project has been conceived and designed properly for the ecosystem context, augmentation of eelgrass and other types of aquatic vegetation would be expected to improve ecological connectivity by increasing the diversity of habitat patches and improving their distribution. On this basis, this impact mechanism would not be expected to impose stressors on the aquatic environment, and therefore there is no associated risk of take.

9.9.4 Aquatic Vegetation Modifications

This project type is specifically intended to improve the abundance and distribution of aquatic vegetation in the project environment. In turn, it is anticipated that the ecological functions provided by aquatic vegetation would also be enhanced. On this basis, this impact mechanism would not be expected to impose stressors on HCP species and there is no associated risk of take.

9.9.5 Water Quality Modifications

Enhancement of eelgrass and other aquatic vegetation has essentially no potential for adverse effects on water quality, with the exception of minor effects during project construction. In the case of eelgrass enhancement, there are often effectively no discernable construction-related effects on water quality. Taking a worst-case scenario perspective, short-term increases in suspended sediment levels may occur during construction-related disturbance from vessel operation and manual or diver labor. The magnitude of suspended sediment levels caused by construction is expected to be relatively limited however, as this subactivity type is typically implemented using diver or manual labor rather than heavy equipment. Therefore, this submechanism would be expected to result in a low risk of take, predominantly in the form of temporary behavioral effects, for a short-term period. Once vegetation has been established, chronic levels of suspended sediment should decrease as vegetation encourages the settling of fines. Increased dissolved oxygen levels and other beneficial water quality effects would be expected to develop once a successfully implemented eelgrass or aquatic vegetation enhancement project matures. Following project completion, no risk of take would be expected from this submechanism.

Table 9-1. Species- and habitat-specific risk of take for mechanisms of impacts associated with beaver dam removal.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Chinook salmon are known to occur in environments where beaver dam removal or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Coho salmon	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Coho salmon are known to occur in environments where beaver dam removal or modification may occur, and preferentially select beaver impoundments for juvenile rearing habitat. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Chum salmon	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Chum salmon are known to spawn in environments where beaver dam removal or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Pink salmon	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Pink salmon are known to spawn in environments where beaver dam removal or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Sockeye salmon	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Sockeye salmon are known to spawn in environments where beaver dam removal or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Steelhead	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Steelhead are known to occur in environments where beaver dam removal or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Coastal cutthroat trout	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Coastal cutthroat trout are known to occur in environments where beaver dam removal or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Westslope cutthroat trout	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Westslope cutthroat and redband trout are known to occur in environments where beaver dam removal or modification may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Redband trout	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	
Bull trout	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Native char occur in rivers and streams where beaver are often abundant, indicating the potential for these species to be exposed to the effects of beaver dam removal or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Dolly Varden	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	
Pygmy whitefish	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	This species spawns in small, cold water tributary streams to rearing lakes. These habitats are potentially within the range of beaver distribution, indicating the potential for exposure to beaver dam removal projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Olympic mudminnow	H	N	N	H	N	N	M	N	N	H	N	N	M	N	N	H	N	N	Primary habitats are wetlands and small, slow-flowing streams, presumably including beaver pond habitats. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Margined sculpin	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages where beaver dam removal or modification has the potential to occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Mountain sucker	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	This species spawns in tributary habitats potentially suitable for beaver dam removal or modification projects. Therefore this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Lake chub	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are potentially subject to beaver dam removal or modification projects. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Leopard dace	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. Therefore, this species occurs in habitats potentially subject to beaver dam removal or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with beaver dam removal.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Umatilla dace	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in habitats potentially subject to beaver dam removal or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Western brook lamprey	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Western brook lamprey spend their entire life history in habitats potentially affected by beaver dam removal. Due to its limited motility and dependence on small streams and similar habitats where beaver dams are prevalent, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
River lamprey	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	Pacific and river lamprey are anadromous species that spawn in habitats potentially affected by beaver dam removal. Ammocoetes burrow into riverine sediments to rear for extended periods and are similarly vulnerable. Freshwater life-history stages of both species are potentially exposed to a range of impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Pacific lamprey	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	
Green sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Green sturgeon distribution in Washington State is restricted to marine waters; therefore, there is no potential for exposure to beaver dam modification and no related risk of take.
White sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The freshwater distribution of White sturgeon in Washington State is restricted to large river environments that are insensitive to the effects of beaver dam removal projects. Therefore there is no related risk of take.
Longfin smelt	H	N	N	H	N	N	H	N	N	N	N	N	H	N	N	N	N	N	The freshwater distribution of longfin smelt is limited to larger river environments that are insensitive to the effects of beaver dam removal, with the possible exception of the Lake Washington population. Spawning habitats for this population may be in river systems where beaver dam removal or modification could occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Eulachon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The freshwater distribution of this species in Washington State is limited to larger river environments that are insensitive to the effects of beaver dam removal. Therefore there is no related risk of take.
Pacific sand lance	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Surf smelt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Pacific herring	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Lingcod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Pacific hake	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Pacific cod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Walleye pollock	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with beaver dam removal.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Brown rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Copper rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Greenstriped rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Widow rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yellowtail rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Quillback rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Black rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
China rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Tiger rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Bocaccio rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Canary rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Redstripe rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yelloweye rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where beaver dam removal or modification take place; therefore, there is no related risk of take from this subactivity type.
Giant Columbia River limpet	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to beaver dam removal projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Great Columbia River spire snail	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. This species is unlikely to be exposed to the effects of beaver dam removal projects and no effects are expected. In contrast, the great Columbia River spire snail inhabits smaller tributary streams to the Columbia River where exposure to the effects of beaver dam removal is likely. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
California floater (mussel)	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates the potential for exposure to beaver dam projects. These non-motile species are particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beaver dam removal.
Western ridged mussel	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	H	N	N	

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

Table 9-2. Species- and habitat-specific risk of take for mechanisms of impacts associated with large woody debris placement/removal/modification.

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			
Species	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Comments
Chinook salmon	H	H	H	H	M	M	N	N	N	M	M	M	M	M	M	M	M	M	Chinook salmon occur in riverine, lacustrine, and nearshore marine habitats. Individuals occurring in spawning, incubation, rearing, and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Coho salmon	H	H	H	H	M	M	N	N	N	M	M	M	M	M	M	M	M	M	Coho salmon occur in riverine, lacustrine, and nearshore marine habitats. Individuals occurring in spawning, incubation, rearing, and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Chum salmon	H	H	I	H	M	I	N	N	I	L	M	I	M	M	I	L	M	I	Chum salmon in Washington State do not use lacustrine habitats and occur in this environment type infrequently. Therefore, the effects of stressor exposure in lacustrine environments are expected to be insignificant. Individuals occurring in spawning, incubation and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Pink salmon	H	H	I	H	M	I	N	N	I	L	M	I	M	M	I	L	M	I	Pink salmon in Washington State do not use lacustrine habitats and occur in this environment type infrequently. Therefore, the effects of stressor exposure in lacustrine environments are expected to be insignificant. Individuals occurring in spawning, incubation and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Sockeye salmon	H	H	H	H	M	M	N	N	N	M	M	M	M	M	M	L	M	M	Sockeye salmon occur in riverine, lacustrine, and nearshore marine habitats, and are particularly dependent on the latter two environment types. Individuals occurring in spawning, incubation, rearing and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Steelhead	H	?	H	H	?	M	M	M	M	M	?	M	M	?	M	M	?	M	Steelhead occur in riverine, lacustrine, and nearshore marine habitats and are particularly dependent on the latter two environment types. As juvenile steelhead are more typically found far from shore in the marine environment, the effects of shading are less clear; therefore, the risk of take in the marine environment is uncertain. Individuals occurring in spawning, incubation, rearing, and migratory habitats in fresh water, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Coastal cutthroat trout	H	H	H	H	M	M	M	M	M	M	M	M	M	M	M	M	M	M	This species is prevalent in rivers, estuaries, and nearshore marine habitats, and also occurs at lesser frequencies in lacustrine habitats (e.g., Lake Washington). It is highly dependent on nearshore marine areas for foraging. Individuals occurring in spawning, incubation, rearing, and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Westslope cutthroat trout	H	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	N	M	These species occur primarily in coldwater streams, small to medium-sized rivers, and lakes. Individuals occurring in spawning, incubation, rearing, and migratory habitats in freshwater, and foraging and rearing habitats in lacustrine waters may be exposed to stressors resulting from LWD placement and removal projects.
Redband trout	H	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	N	M	
Bull trout	H	H	H	H	M	M	N	N	N	L	M	M	M	M	M	L	M	M	Native char occur in riverine, lacustrine, and nearshore marine habitats. Individuals occurring in spawning, incubation, rearing and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Dolly Varden	H	H	H	H	M	M	N	N	N	L	M	M	M	M	M	L	M	M	
Pygmy whitefish	H	N	H	H	N	M	M	N	M	N	N	M	M	N	M	M	N	M	Lakes and smaller lake tributaries are primary habitats used by pygmy whitefish. Individuals occurring in spawning, incubation, rearing and migratory habitats in freshwater, and juvenile migratory habitats in marine waters may be exposed to stressors resulting from LWD placement and removal projects.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are wetlands and small, slow-flowing streams. These habitats are not typically suited for LWD placement and removal projects, except in the context of wetland enhancement projects (which are addressed in Table 9-8). Outside of this context this species would not likely be exposed to this type of project and there would be no related risk of take.
Margined sculpin	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages. Individuals occurring in spawning, incubation, rearing, and migratory habitats may be exposed to stressors resulting from LWD placement and removal projects.
Mountain sucker	H	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	N	M	This species is commonly found in moderate to large rivers and lakes suitable for LWD placement and removal projects. Individuals occurring in spawning, incubation, rearing, and migratory habitats may be exposed to stressors resulting from LWD placement and removal projects.

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with large woody debris placement/removal/modification.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Lake chub	H	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	N	M	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. Individuals occurring in spawning, incubation, rearing, and migratory habitats may be exposed to stressors resulting from LWD placement and removal projects.
Leopard dace	H	N	H	H	N	M	N	N	N	M	N	M	M	N	M	M	N	M	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. Therefore, this species occurs in habitats potentially suitable for LWD placement and removal projects at sensitive life-history stages, including egg incubation. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Umatilla dace	H	N	H	H	N	M	N	N	N	M	N	M	M	N	M	M	N	M	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers (including reservoirs within the Columbia and Snake River systems). Therefore, this species occurs in habitats potentially suitable for LWD placement and removal projects at sensitive life-history stages, including egg incubation. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Western brook lamprey	H	N	H	H	N	M	N	N	N	N	N	N	N	N	N	M	N	M	This species is characterized by isolated breeding populations favoring small streams and brooks. Therefore, this species occurs in habitats potentially suitable for LWD placement and removal projects at sensitive life-history stages, including egg incubation. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
River lamprey	H	H	H	H	M	M	M	?	M	?	?	?	M	M	M	M	M	M	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of rivers to rear for extended periods, potentially years. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance. In their saltwater phase, river lamprey remain close to shore for periods of 10–16 weeks from spring through fall, increasing exposure to stressors in the nearshore environment. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take. Impact mechanisms affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults, which in turn equates to a moderate risk of take.
Pacific lamprey	H	L	H	H	L	M	M	N	M	?	N	?	M	L	M	M	L	M	Pacific lamprey are anadromous, with migratory corridors extending from marine waters to small tributary streams. Ammocoetes burrow into riverine sediments to rear for extended periods. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance. Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6–40 months and are therefore less likely to be exposed to project-related stressors in the nearshore marine environment. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take. Impact mechanisms affecting abundance of host fish may lead to indirect effects on growth and fitness of transforming adults and adults. This in turn equates to a moderate risk of take.
Green sturgeon	N	?	N	N	?	N	N	?	N	N	?	N	N	?	N	N	?	N	Green sturgeon distribution in Washington State is restricted to marine waters; therefore, there is no potential for exposure to LWD placement/removal projects in freshwater and marine environments and no related risk of take. Sensitivity to impact mechanisms resulting from this project type in marine environments are uncertain.
White sturgeon	H	?	H	H	?	M	M	?	M	M	?	M	M	?	M	M	?	M	The freshwater distribution of White sturgeon in Washington State is restricted to large river environments that are insensitive to the effects of LWD placement and removal projects. However, side channel and margin habitats in the Columbia River and lacustrine impoundments used for juvenile rearing may be suitable environments for this project type. Therefore some potential for stressor exposure exists. Sensitivity to impact mechanisms resulting from this project type in marine environments are uncertain.
Longfin smelt	H	I	M	H	I	M	M	I	M	N	I	M	M	I	M	M	I	M	Eulachon and longfin smelt spawn in the lower reaches of moderate to large river systems potentially suitable for LWD placement or removal projects. Longfin smelt are also located in Lake Washington. Demersal adhesive eggs are vulnerable to acute transient water quality impacts and direct physical effects. Planktonic larvae and juveniles of these species may also

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with large woody debris placement/removal/modification.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Eulachon	H	I	N	H	I	N	M	I	N	N	I	N	M	I	N	M	I	N	be vulnerable to stressor exposure in the nearshore marine environment during early rearing. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take. Mature juveniles and adults occupy offshore environments and are therefore at less risk of take from these stressors.
Pacific sand lance	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	Surf smelt and sand lance populations are widespread and ubiquitous in Puget Sound, the Strait of Juan de Fuca, and the coastal estuaries of Washington. They are dependent on shoreline habitats for spawning and are prevalent in the nearshore environment, meaning that the likelihood of stressor exposure from marine LWD projects is high. Larvae of both species disperse in nearshore waters for early rearing. These beach-spawning species depend on a narrow range of substrate conditions for suitable spawning habitat, increasing sensitivity to hydraulic and geomorphic effects. Planktonic larvae are also dependent on nearshore current and circulation patterns for rearing survival. Planktonic life-history stages are also incapable of escaping acute water quality impacts. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Surf smelt	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	
Pacific herring	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	Pacific herring are common throughout the inland marine waters of Washington, particularly in protected bays and shorelines used for spawning. This species is dependent on nearshore habitats for spawning, egg incubation, and larval rearing, meaning that the likelihood of stressor exposure from hydraulic/geomorphic and aquatic vegetation modifications are high. Planktonic larvae disperse in nearshore waters for early rearing and are dependent on current and circulation patterns for survival, growth, and fitness. Planktonic life-history stages are also incapable of escaping acute water quality impacts. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Lingcod	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	Larval lingcod settle in nearshore habitats for juvenile rearing, favoring habitats with freshwater inflow and reduced salinities, and are potentially exposed to water quality related impact mechanisms from LWD placement and removal projects. Adults may occur anywhere from the intertidal zone to depths of approximately 1,560 ft (475 m), but are most prominent between 330 and 500 ft (100 and 150 m) and, therefore, have low exposure potential. Larvae disperse and settle in nearshore waters for early rearing. Because they are demersal and relatively immobile, larvae are vulnerable to short-term construction and water quality related impacts. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Pacific hake	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	Hake, cod, and pollock spawn in nearshore areas and estuaries, and their planktonic larvae settle in nearshore areas for rearing. Larval Pacific cod settle in nearshore areas associated with eelgrass. Larval pollock settle in nearshore areas at depths as shallow as 33 ft (10 m) for juvenile rearing and are commonly associated with eelgrass algae. Therefore, spawning adults, eggs, larvae, and juveniles may experience stressor exposure. Larvae disperse and settle in nearshore waters for early rearing, and are dependent on current, wave, and circulation patterns to ensure dispersal to environments favorable for rearing. Because they are demersal and relatively immobile, larvae are vulnerable to short-term construction and water quality related impacts. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Pacific cod	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Walleye pollock	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Brown rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	Rockfish are ovoviviparous species that release their planktonic larvae in open water, depending on favorable currents and circulation patterns to carry them into nearshore habitats where they settle for rearing as demersal juveniles. Many species remain in the vicinity of the nearshore environment as they grow into adulthood. Therefore, rockfish can experience stressor exposure across all life-history stages. Juveniles disperse and settle in nearshore waters for early rearing, and are dependent on current, wave, and circulation patterns to ensure dispersal to environments favorable for rearing. Because they are demersal and relatively immobile once they have settled, juveniles are vulnerable to short-term construction and water quality related impacts. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Copper rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Greenstriped rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Widow rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Yellowtail rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Quillback rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Black rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
China rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Tiger rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Bocaccio rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	

Table 9-2 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with large woody debris placement/removal/modification.**

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Comments**
Canary rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Redstripe rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Yelloweye rockfish	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	
Olympia oyster	N	H	N	N	M	N	N	N	N	N	M	N	N	M	N	N	M	N	This species occurs commonly in shallow water nearshore habitats. This distribution increases risk of stressor exposure and potential for take resulting from water quality modification in the nearshore environment. Because this species is sessile during much of its life-history, it is vulnerable to both short-term construction and water quality related impacts, as well as modification of hydraulic and geomorphic conditions in the nearshore environment. Modification of current, wave, and circulation patterns may also affect larval settlement, influencing survival during this life-history stage. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take.
Northern abalone	N	I	N	N	I	N	N	I	N	N	I	N	N	I	N	N	I	N	While increasingly rare due to depressed population status, this species occurs commonly in nearshore habitats less than 33 ft (10 m) in depth, but is not found in shallow water habitats where the construction and water quality-related effects of LWD projects are most pronounced.
Newcomb's littorine snail	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	M	N	The Newcomb's littorine snail inhabits *Salicornia* marshes on the littoral fringe. It is intolerant of extended submergence in both fresh and marine water; therefore, it not a true aquatic species. This species will be particularly vulnerable to LWD placement and removal projects in saltmarsh environments, particularly removal projects.
Giant Columbia River limpet	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to spawning gravel augmentation projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from LWD placement and removal projects.
Great Columbia River spire snail	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Exposure to the effects of spawning gravel augmentation is likely to occur in smaller river systems and streams in habitat by this species. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from LWD placement and removal projects.
California floater (mussel)	H	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	N	M	The western ridged mussel is predominantly found in the larger tributaries of the Columbia and Snake rivers and the mainstems of these systems. The California floater occurs in shallow muddy or sandy habitats in larger rivers, reservoirs, and lakes. Therefore, both species may occur in habitats potentially suitable for LWD placement and removal projects. Life-history stages exposed to construction activities face a high risk of take, while the effects of the structure on the environment are likely to result in a moderate risk of take. Habitat accessibility modifications will not directly affect this species; however, indirect effects could occur through direct effects on host-fish.
Western ridged mussel	H	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	N	

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

Table 9-3. Species- and habitat-specific risk of take for mechanisms of impacts associated with spawning substrate augmentation.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Chinook salmon are known to occur in environments where spawning gravel augmentation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Coho salmon	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Coho salmon are known to occur in environments where spawning gravel augmentation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Chum salmon	H	N	N	N	N	N	I	N	N	M	N	N	M	N	N	Chum salmon are known to spawn in environments where spawning gravel augmentation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Pink salmon	H	N	N	N	N	N	I	N	N	M	N	N	M	N	N	Pink salmon are known to spawn in environments where spawning gravel augmentation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Sockeye salmon	H	N	N	N	N	N	I	N	N	M	N	N	M	N	N	Sockeye salmon are known to spawn in environments where spawning gravel augmentation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Steelhead	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Steelhead are known to occur in environments where spawning gravel augmentation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Coastal cutthroat trout	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Coastal cutthroat trout are known to occur in environments where spawning gravel augmentation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Westslope cutthroat trout	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Westslope cutthroat and redband trout are known to occur in environments where spawning gravel augmentation or modification may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Redband trout	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	
Bull trout	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Native char occur in rivers and streams, indicating the potential for these species to be exposed to the effects of spawning gravel augmentation or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Dolly Varden	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	
Pygmy whitefish	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	This species spawns in small, cold water tributary streams to rearing lakes, indicating the potential for exposure to spawning gravel augmentation projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats used by this species include wetlands and small, slow-flowing streams, environments unsuitable for spawning gravel augmentation. Therefore there is no related risk of take.
Margined sculpin	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages where spawning gravel augmentation or modification has the potential to occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Mountain sucker	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	This species spawns in tributary habitats potentially suitable for spawning gravel augmentation projects. Therefore this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Lake chub	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are potentially subject to spawning gravel augmentation or modification projects. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Leopard dace	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. Therefore, this species occurs in habitats potentially subject to spawning gravel augmentation or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Umatilla dace	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in habitats potentially subject to spawning gravel augmentation. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with spawning substrate augmentation.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Western brook lamprey	H	N	N	N	N	N	?	N	N	M	N	N	M	N	N	Western brook lamprey spend their entire life history in habitats potentially affected by spawning gravel augmentation. Due to its limited motility and dependence on small streams and similar habitats this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
River lamprey	H	N	N	N	N	N	?	N	N	M	N	N	M	N	N	Pacific and river lamprey are anadromous species that spawn in habitats potentially affected by spawning gravel augmentation. Ammocoetes burrow into riverine sediments to rear for extended periods and are similarly vulnerable. Freshwater life-history stages of both species are potentially exposed to a range of impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Pacific lamprey	H	N	N	N	N	N	?	N	N	M	N	N	M	N	N	
Green sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Green sturgeon distribution in Washington State is restricted to marine waters; therefore, there is no potential for exposure to spawning gravel augmentation and no related risk of take.
White sturgeon	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	The freshwater distribution of white sturgeon in Washington State is restricted to large river environments that are potentially suitable for spawning gravel augmentation. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Longfin smelt	H	N	N	N	N	N	N	N	N	M	N	N	M	N	N	The freshwater distribution of longfin smelt may include river environments where spawning gravel augmentation may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Eulachon	H	N	N	N	N	N	N	N	N	M	N	N	M	N	N	The freshwater distribution of eulachon may include river environments where spawning gravel augmentation may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Pacific sand lance	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Surf smelt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Pacific herring	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Lingcod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Pacific hake	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Pacific cod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Walleye pollock	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Brown rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Copper rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Greenstriped rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Widow rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yellowtail rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Quillback rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Black rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
China rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Tiger rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Bocaccio rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Canary rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Redstripe rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yelloweye rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with spawning substrate augmentation.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where spawning gravel augmentation take place; therefore, there is no related risk of take from this subactivity type.
Giant Columbia River limpet	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to spawning gravel augmentation projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Great Columbia River spire snail	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Exposure to the effects of spawning gravel augmentation is likely to occur in smaller river systems and streams in habitat by this species. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
California floater (mussel)	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates the potential for exposure to spawning gravel augmentation projects. These non-motile species are particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from spawning gravel augmentation.
Western ridged mussel	H	N	N	N	N	N	M	N	N	M	N	N	M	N	N	

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

Table 9-4. Species- and habitat-specific risk of take for mechanisms of impacts associated with in-channel and off-channel habitat creation/modification.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Chinook salmon are known to occur in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coho salmon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Coho salmon are known to occur in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Chum salmon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Chum salmon are known to spawn in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pink salmon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Pink salmon are known to spawn in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Sockeye salmon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Sockeye salmon are known to spawn in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from in-channel/off-channel habitat creation.
Steelhead	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Steelhead are known to occur in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coastal cutthroat trout	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Coastal cutthroat trout are known to occur in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Westslope cutthroat trout	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Westslope cutthroat and redband trout are known to occur in environments where in-channel/off-channel habitat creation or modification may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Redband trout	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	
Bull trout	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Native char occur in rivers and streams, indicating the potential for these species to be exposed to the effects of in-channel/off-channel habitat creation or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Dolly Varden	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	
Pygmy whitefish	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	This species spawns in small, cold water tributary streams to rearing lakes, indicating the potential for exposure to in-channel/off-channel habitat creation projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats used by this species include wetlands and small, slow-flowing streams, environments unsuitable for in-channel/off-channel habitat creation. Therefore there is no related risk of take.

Table 9-4 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with in-channel and off-channel habitat creation/modification.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Margined sculpin	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages where in-channel/off-channel habitat creation or modification has the potential to occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Mountain sucker	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	This species spawns in tributary habitats potentially suitable for in-channel/off-channel habitat creation projects. Therefore this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Lake chub	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are potentially subject to in-channel/off-channel habitat creation or modification projects. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Leopard dace	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. Therefore, this species occurs in habitats potentially subject to in-channel/off-channel habitat creation or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Umatilla dace	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in habitats potentially subject to in-channel/off-channel habitat creation. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western brook lamprey	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Western brook lamprey spend their entire life history in habitats potentially affected by in-channel/off-channel habitat creation. Due to its limited motility and dependence on small streams and similar habitats this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
River lamprey	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	Pacific and river lamprey are anadromous species that spawn in habitats potentially affected by in-channel/off-channel habitat creation. Ammocoetes burrow into riverine sediments to rear for extended periods and are similarly vulnerable. Freshwater life-history stages of both species are potentially exposed to a range of impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific lamprey	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	
Green sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Green sturgeon distribution in Washington State is restricted to marine waters; therefore, there is no potential for exposure to in-channel and off-channel habitat creation projects and no related risk of take.
White sturgeon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The freshwater distribution of white sturgeon in Washington State is restricted to large river environments that are potentially suitable for in-channel/off-channel habitat creation. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-4 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with in-channel and off-channel habitat creation/modification.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Longfin smelt	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The freshwater distribution of longfin smelt may include river environments where in-channel/off-channel habitat creation may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Eulachon	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The freshwater distribution of eulachon may include river environments where in-channel/off-channel habitat creation may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific sand lance	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Surf smelt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Pacific herring	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Lingcod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Pacific hake	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Pacific cod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Walleye pollock	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Brown rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	These marine species do not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Copper rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Greenstriped rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Widow rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yellowtail rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Quillback rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Black rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
China rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Tiger rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Bocaccio rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Canary rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Redstripe rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Yelloweye rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.
Newcomb’s littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where in-channel/off-channel habitat creation take place; therefore, there is no related risk of take from this subactivity type.

Table 9-4 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with in-channel and off-channel habitat creation/modification.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Giant Columbia River limpet	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to in-channel/off-channel habitat creation projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Great Columbia River spire snail	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Exposure to the effects of in-channel/off-channel habitat creation is likely to occur in smaller river systems and streams inhabited by this species. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
California floater (mussel)	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates the potential for exposure to this project type. These non-motile species are particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with in-channel/off-channel habitat creation. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western ridged mussel	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	

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

Table 9-5. Species- and habitat-specific risk of take for mechanisms of impacts associated with riparian planting/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Chinook salmon are known to occur in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coho salmon	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Coho salmon are known to occur in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Chum salmon	L	L	I	N	N	I	N	N	I	N	N	I	L	L	I	N	N	I	Chum salmon are known to spawn in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pink salmon	L	L	I	N	N	I	N	N	I	N	N	I	L	L	I	N	N	I	Pink salmon are known to spawn in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Sockeye salmon	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Sockeye salmon are known to spawn in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from riparian planting/restoration/enhancement.
Steelhead	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Steelhead are known to occur in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coastal cutthroat trout	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Coastal cutthroat trout are known to occur in environments where riparian planting/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Westslope cutthroat trout	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	Westslope cutthroat and redband trout are known to occur in environments where riparian planting/restoration/enhancement may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Redband trout	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	
Bull trout	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Native char occur in rivers and streams, indicating the potential for these species to be exposed to the effects of riparian planting/restoration/enhancement or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Dolly Varden	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	
Pygmy whitefish	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	This species spawns in small, cold water tributary streams to rearing lakes, indicating the potential for exposure to riparian planting/restoration/enhancement projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Olympic mudminnow	N	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	Primary habitats used by this species include ponds, wetlands and small, slow-flowing streams. For the purpose of this assessment, these habitats are considered lacustrine, and are potentially suitable for riparian planting/restoration/enhancement projects. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-5 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with riparian planting/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Margined sculpin	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages where riparian planting/restoration/enhancement has the potential to occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Mountain sucker	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	This species spawns in tributary habitats potentially suitable for riparian planting/restoration/enhancement projects. Therefore this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Lake chub	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are potentially subject to riparian planting/restoration/enhancement projects. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Leopard dace	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. Therefore, this species occurs in habitats potentially subject to riparian planting/restoration/enhancement or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Umatilla dace	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in habitats potentially subject to riparian planting/restoration/enhancement. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western brook lamprey	L	N	L	N	N	N	N	N	N	N	N	N	L	N	L	N	N	N	Western brook lamprey spend their entire life history in habitats potentially affected by riparian planting/restoration/enhancement. Due to its limited motility and dependence on small streams and similar habitats this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
River lamprey	L	L	L	N	N	N	N	N	N	N	N	N	L	L	L	N	N	N	Pacific and river lamprey are anadromous species that spawn in habitats potentially affected by riparian planting/restoration/enhancement. Ammocoetes burrow into riverine sediments to rear for extended periods and are similarly vulnerable. Freshwater life-history stages of both species are potentially exposed to a range of impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific lamprey	L	I	L	N	N	N	N	N	N	N	N	N	L	I	L	N	N	N	
Green sturgeon	N	L	N	N	?	N	N	?	N	N	?	N	N	?	N	N	?	N	Green sturgeon distribution in Washington State is restricted to marine waters, typically in offshore environments. Therefore this species has limited potential for stressor exposure to and related risk of take.
White sturgeon	L	L	L	N	?	N	N	?	N	N	?	N	L	?	L	N	?	N	The freshwater distribution of white sturgeon in Washington State is restricted to large river environments that are potentially suitable for riparian planting/restoration/enhancement. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-5 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with riparian planting/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Longfin smelt	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The freshwater distribution of longfin smelt may include river environments where riparian planting/restoration/enhancement may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Eulachon	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The freshwater distribution of eulachon may include river environments where riparian planting/restoration/enhancement may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific sand lance	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species use upper intertidal habitats subject to the effects of marine riparian planting/restoration/enhancement projects. Therefore, some exposure to short-term stressors may occur, resulting in risk of take.
Surf smelt	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Pacific herring	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species uses lower intertidal habitats subject to the effects of marine riparian planting/restoration/enhancement projects. Therefore, some exposure to short-term stressors may occur, resulting in risk of take.
Lingcod	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species uses nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from marine riparian planting/restoration/enhancement projects.
Pacific hake	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species use nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from marine riparian planting/restoration/enhancement projects.
Pacific cod	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Walleye pollock	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Brown rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species use nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from marine riparian planting/restoration/enhancement projects.
Copper rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Greenstriped rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Widow rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Yellowtail rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Quillback rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Black rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
China rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Tiger rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Bocaccio rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Canary rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Redstripe rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Yelloweye rockfish	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	
Olympia oyster	N	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species uses nearshore habitats and may experience exposure to minor stressors resulting from marine riparian planting/restoration/enhancement projects.
Northern abalone	N	I	N	N	N	N	N	N	N	N	N	N	N	I	N	N	N	N	This marine species may occur in nearshore habitats and may experience exposure to minor stressors resulting from marine riparian planting/restoration/enhancement projects. However, distribution in deeper waters away from the shoreline limits the severity of stressor exposure to insignificant levels.
Newcomb's littorine snail	N	H	N	N	N	N	N	N	N	N	N	N	N	N	N	N	L	N	This marine species uses a specific type of littoral vegetation (*Salicornia* spp.) as its sole habitat and is limited in distribution to a few discrete locations in Washington State. Therefore, this species will be highly sensitive to adverse effects from riparian vegetation projects that affect its habitat.

Table 9-5 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with riparian planting/restoration/enhancement.**

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Comments**
Giant Columbia River limpet	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to riparian planting/restoration/enhancement projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Great Columbia River spire snail	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Exposure to the effects of riparian planting/restoration/enhancement is likely to occur in smaller river systems and streams inhabited by this species. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
California floater (mussel)	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates the potential for exposure to this project type. These non-motile species are particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with riparian planting/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western ridged mussel	L	N	N	N	N	N	N	N	N	N	N	N	L	N	N	N	N	N	

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

Table 9-6. Species- and habitat-specific risk of take for mechanisms of impacts associated with wetland creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Chinook salmon are known to occur in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coho salmon	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Coho salmon are known to occur in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Chum salmon	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Chum salmon are known to spawn in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pink salmon	H	H	I	N	N	N	N	N	N	N	N	N	M	M	I	N	N	N	Pink salmon are known to spawn in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Sockeye salmon	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Sockeye salmon are known to spawn in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from wetland creation/restoration/enhancement.
Steelhead	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Steelhead are known to occur in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coastal cutthroat trout	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Coastal cutthroat trout are known to occur in environments where wetland creation/restoration/enhancement may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Westslope cutthroat trout	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	Westslope cutthroat and redband trout are known to occur in environments where wetland creation/restoration/enhancement may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Redband trout	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	
Bull trout	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	Native char occur in rivers and streams, indicating the potential for these species to be exposed to the effects of wetland creation/restoration/enhancement or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Dolly Varden	H	H	H	N	N	N	N	N	N	N	N	N	M	M	M	N	N	N	
Pygmy whitefish	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	This species spawns in small, cold water tributary streams to rearing lakes, indicating the potential for exposure to wetland creation/restoration/enhancement projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Olympic mudminnow	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	Primary habitats used by this species include ponds, wetlands and small, slow-flowing streams. For the purpose of this assessment, these habitats are considered lacustrine, and are potentially suitable for wetland creation/restoration/enhancement projects. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with wetland creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Margined sculpin	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages where wetland creation/restoration/enhancement has the potential to occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Mountain sucker	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	This species spawns in tributary habitats potentially suitable for wetland creation/restoration/enhancement projects. Therefore this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Lake chub	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are potentially subject to wetland creation/restoration/enhancement projects. Therefore, this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Leopard dace	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. Therefore, this species occurs in habitats potentially subject to wetland creation/restoration/enhancement or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Umatilla dace	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in habitats potentially subject to wetland creation/restoration/enhancement. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western brook lamprey	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	Western brook lamprey spend their entire life history in habitats potentially affected by wetland creation/restoration/enhancement. Due to its limited motility and dependence on small streams and similar habitats this species is particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
River lamprey	H	L	H	N	N	N	N	N	N	N	N	N	M	L	M	N	N	N	Pacific and river lamprey are anadromous species that spawn in habitats potentially affected by wetland creation/restoration/enhancement. Ammocoetes burrow into riverine sediments to rear for extended periods and are similarly vulnerable. Freshwater life-history stages of both species are potentially exposed to a range of impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific lamprey	H	I	H	N	N	N	N	N	N	N	N	N	M	I	M	N	N	N	
Green sturgeon	N	?	N	N	?	N	N	?	N	N	?	N	N	L	N	N	?	N	Green sturgeon distribution in Washington State is restricted to marine waters, typically in offshore environments. Therefore this species has limited potential for exposure to wetland enhancement projects in coastal environments, and similarly limited risk of take.
White sturgeon	H	?	H	N	?	N	N	?	N	N	?	N	M	L	M	N	?	N	The freshwater distribution of white sturgeon in Washington State is restricted to large river environments that are potentially suitable for wetland creation/restoration/enhancement. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with wetland creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Longfin smelt	H	N	N	N	N	N	N	N	N	N	N	N	M	L	N	N	N	N	The freshwater distribution of longfin smelt may include river environments where wetland creation/restoration/enhancement may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Eulachon	H	N	N	N	N	N	N	N	N	N	N	N	M	L	N	N	N	N	The freshwater distribution of eulachon may include river environments where wetland creation/restoration/enhancement may be appropriate. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific sand lance	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	These marine species use upper intertidal habitats subject to the effects of estuarine and coastal marine wetland restoration/enhancement projects. Therefore, some exposure to short-term stressors may occur, resulting in risk of take.
Surf smelt	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Pacific herring	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	This marine species uses lower intertidal habitats subject to the effects of estuarine and coastal marine wetland restoration/enhancement projects. Therefore, some exposure to short-term stressors may occur, resulting in risk of take.
Lingcod	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	This marine species uses nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from estuarine and coastal marine wetland restoration/enhancement projects.
Pacific hake	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	These marine species use nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from estuarine and coastal marine wetland restoration/enhancement projects.
Pacific cod	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Walleye pollock	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Brown rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	These marine species use nearshore habitats during larval rearing and may experience exposure to minor stressors resulting from estuarine and coastal marine wetland restoration/enhancement projects.
Copper rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Greenstriped rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Widow rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Yellowtail rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Quillback rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Black rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
China rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Tiger rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Bocaccio rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Canary rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Redstripe rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Yelloweye rockfish	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	
Olympia oyster	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	This marine species uses nearshore habitats and may experience exposure to minor stressors resulting from estuarine and coastal marine wetland restoration/enhancement projects.
Northern abalone	N	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	This marine species may occur in nearshore habitats and may experience exposure to minor stressors resulting from estuarine and coastal marine wetland restoration/enhancement projects. However, distribution in deeper waters away from the shoreline limits the severity of stressor exposure to insignificant levels.

Table 9-6 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with wetland creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Newcomb's littorine snail	N	H	N	N	N	N	N	H	N	N	N	N	N	N	N	N	N	N	This marine species uses a specific type of littoral vegetation (*Salicornia* spp.) as its sole habitat and is limited in distribution to a few discrete locations in Washington State. Therefore, this species will be highly sensitive to adverse effects from estuarine and coastal marine wetland restoration/enhancement projects that affect its habitat.
Giant Columbia River limpet	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating the potential for exposure to wetland creation/restoration/enhancement projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Great Columbia River spire snail	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. Exposure to the effects of wetland creation/restoration/enhancement is likely to occur in smaller river systems and streams inhabited by this species. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
California floater (mussel)	H	N	H	N	N	N	N	N	N	N	N	N	M	N	M	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates the potential for exposure to this project type. These non-motile species are particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with wetland creation/restoration/enhancement. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western ridged mussel	H	N	N	N	N	N	N	N	N	N	N	N	M	N	N	N	N	N	

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

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Table 9-7. Species- and habitat-specific risk of take for mechanisms of impacts associated with beach nourishment/contouring.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	N	H	H	N	?	?	N	M	M	N	N	N	N	M	M	N	N	N	Chinook salmon are known to occur in lacustrine and marine environments where beach nourishment/contouring may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coho salmon	N	H	H	N	?	?	N	M	M	N	N	N	N	M	M	N	N	N	Coho salmon are known to occur in lacustrine and marine environments where beach nourishment/contouring may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Chum salmon	N	H	I	N	?	I	N	M	I	N	N	N	N	M	I	N	N	N	Chum salmon are known to occur in marine environments where beach nourishment/contouring may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pink salmon	N	H	I	N	?	I	N	M	I	N	N	N	N	M	I	N	N	N	Pink salmon are known to occur in marine environments where beach nourishment/contouring may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Sockeye salmon	N	H	H	N	?	?	N	I	M	N	N	N	N	M	M	N	N	N	Sockeye salmon are known to occur in lacustrine and marine environments where beach nourishment/contouring may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from beach nourishment/contouring.
Steelhead	N	H	H	N	?	?	N	I	M	N	N	N	N	M	M	N	N	N	Steelhead are known to occur in lacustrine and marine environments where beach nourishment/contouring may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Coastal cutthroat trout	N	H	H	N	?	?	N	M	M	N	N	N	N	M	M	N	N	N	Coastal cutthroat trout are known to occur in lacustrine and marine environments where beach nourishment/contouring may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Westslope cutthroat trout	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	Westslope cutthroat and redband trout are known to occur in lacustrine environments where beach nourishment/contouring may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Redband trout	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	
Bull trout	N	H	H	N	?	?	N	M	M	N	N	N	N	M	M	N	N	N	Native char occur in lacustrine and marine environments, indicating the potential for these species to be exposed to the effects of beach nourishment/contouring or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Dolly Varden	N	H	H	N	?	?	N	M	M	N	N	N	N	M	M	N	N	N	
Pygmy whitefish	N	N	H	N	N	?	N	N	I	N	N	N	N	N	M	N	N	N	This species rears in lakes, indicating the potential for exposure to lacustrine beach nourishment/contouring projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats used by this species include ponds, wetlands and small, slow-flowing streams. These habitats are unsuitable for beach nourishment/contouring projects. Therefore there will be no risk of take from this project type.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages. Therefore there is no potential for exposure to this type of project and no related risk of take.
Mountain sucker	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	This species rears in lacustrine habitats potentially suitable for beach nourishment/contouring projects. Therefore this species is

Table 9-7 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with beach nourishment/contouring.**

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Comments**
																			vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Lake chub	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. While unlikely, the lacustrine habitats used by this species could potentially be subject to beach nourishment/contouring projects. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Leopard dace	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east, including smaller rivers and stream systems. While exposure is generally unlikely, this species may occur in lacustrine impoundments potentially subject to beach nourishment/contouring or modification. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Umatilla dace	N	N	H	N	N	?	N	N	M	N	N	N	N	N	M	N	N	N	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in lacustrine impoundments potentially subject to beach nourishment/contouring projects. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Western brook lamprey spend their entire life history in small streams and rivers unsuitable for beach nourishment/contouring. Therefore there is no risk of stressor exposure and no related risk of take.
River lamprey	N	H	H	N	?	?	N	I	M	N	N	N	N	L	M	N	N	N	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of rivers to rear for extended periods, potentially years. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance. In their saltwater phase, river lamprey remain close to shore for periods of 10–16 weeks from spring through fall, meaning there is some potential for exposure to beach nourishment/contouring related stressors in the nearshore environment. Life-history stages exposed to lacustrine beach nourishment/contouring projects face a high risk of take during project construction, while exposure to marine projects produce lesser risk of take because the effects are avoidable. Once established, these projects should result in no risk of take.
Pacific lamprey	N	I	H	N	N	?	N	N	M	N	N	N	N	I	M	N	N	N	Pacific lamprey are anadromous, with migratory corridors extending from marine waters to small tributary streams. Ammocoetes burrow into riverine sediments to rear for extended periods. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance during construction of lacustrine beach nourishment/contouring projects and face high risk of take. In marine waters, Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6–40 months and are therefore face an insignificant potential for exposure to stressors from marine beach nourishment projects. Once established, these projects should result in no risk of take.
Green sturgeon	N	?	N	N	?	N	N	?	N	N	N	N	N	?	N	N	N	N	Green sturgeon distribution in Washington State is restricted to offshore marine waters. The potential for exposure to stressors resulting from beach nourishment/contouring is limited to avoidable disturbance and water quality effects. Risk of take is similarly low.
White sturgeon	N	L	H	N	I	?	N	I	M	N	N	N	N	L	M	N	N	N	The freshwater distribution of white sturgeon in Washington State includes lacustrine impoundments that are potentially suitable for beach nourishment/contouring. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.

Table 9-7 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with beach nourishment/contouring.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Longfin smelt	N	H	H	N	I	?	N	I	M	N	N	N	N	M	M	N	N	N	The freshwater distribution of longfin smelt includes lacustrine environments where beach nourishment/contouring may be appropriate. The marine distribution of this species is primarily limited to offshore habitats so the risk of stressor exposure in these environments is insignificant. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting construction and temporary water quality impacts associated with beach nourishment/contouring in lacustrine environments. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Eulachon	N	H	N	N	I	N	N	I	N	N	N	N	N	M	N	N	N	N	Eulachon distribution in freshwater is limited to river environments unsuitable for beach nourishment/contouring projects. The marine distribution of this species is primarily limited to offshore habitats so the risk of stressor exposure in these environments is insignificant.
Pacific sand lance	N	H	N	N	?	N	N	M	N	N	N	N	N	H	N	N	N	N	These marine species are dependent on littoral beach habitats for spawning, which are directly affected by beach nourishment/contouring are highly likely to occur; therefore, the likelihood of stressor exposure and related risk of take during project construction is high. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Surf smelt	N	H	N	N	?	N	N	M	N	N	N	N	N	H	N	N	N	N	
Pacific herring	N	H	N	N	?	N	N	M	N	N	N	N	N	H	N	N	N	N	This marine species is dependent on littoral beach habitats for spawning which are directly affected by beach nourishment/contouring are likely to occur; therefore, the likelihood of stressor exposure and related risk of take during project construction is high. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Lingcod	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	This marine species occurs in nearshore habitats as rearing larvae and juveniles with limited motility. Therefore, these vulnerable life-history stages may be exposed to stressors from beach nourishment/contouring projects associated with construction and water quality impacts. Exposure to these short-term stressors presents risk of take. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific hake	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	These marine species occur in nearshore habitats as rearing larvae and juveniles with limited motility. Therefore, these vulnerable life-history stages may be exposed to stressors from beach nourishment/contouring projects associated with construction and water quality impacts. Exposure to these short-term stressors presents risk of take. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Pacific cod	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Walleye pollock	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Brown rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	These marine species occur in nearshore habitats as rearing juveniles with limited motility. Therefore, this vulnerable life history-stage may be exposed to stressors from beach nourishment/contouring projects associated with construction and water quality impacts. Exposure to these short-term stressors presents risk of take. Once established, these projects will improve habitat conditions and would not be expected to impose ecological stressors; therefore, there will be no related risk of take.
Copper rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Greenstriped rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Widow rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Yellowtail rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Quillback rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Black rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
China rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Tiger rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Bocaccio rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Canary rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Redstripe rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Yelloweye rockfish	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	
Olympia oyster	N	H	N	N	?	N	N	I	N	N	N	N	N	H	N	N	N	N	This marine species occurs in the shallow nearshore marine environments and is non-motile once settled. Therefore, this species could potentially be exposed to impact mechanisms and stressors from beach nourishment projects in the nearshore environment. Limited mobility increases sensitivity to construction and water quality related stressors. Once established, these projects should result in improved habitat conditions and will have no ongoing risk of take.

Table 9-7 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with beach nourishment/contouring.

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Comments**
Northern abalone	N	H	N	N	?	N	N	I	N	N	N	N	N	M	N	N	N	N	This marine species occupies nearshore marine habitats covering a range of depths and is effectively non-motile. Therefore, this species could potentially be exposed to impact mechanisms and stressors from beach nourishment projects. Limited mobility increases sensitivity to construction and water quality related stressors. Once established, these projects should result in improved habitat conditions and will have no ongoing risk of take, with the exception of potential water quality impacts if reef materials include toxic substances with leaching potential.
Newcomb's littorine snail	N	N	N	N	?	N	N	H	N	N	N	N	N	N	N	N	N	N	Newcomb's littorine snail occurs solely in saltmarsh environments unsuitable for beach nourishment. Therefore, there is no potential for stressor exposure and no related risk of take.
Giant Columbia River limpet	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, environments unsuitable for beach nourishment projects. Therefore there is no potential for stressor exposure and no related risk of take
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. These environments are unsuitable for beach nourishment projects. Therefore there is no risk of stressor exposure and no related risk of take.
California floater (mussel)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). The distribution of both species in small to moderate sized rivers and streams indicates no potential for exposure to beach nourishment projects. Therefore there is no risk of stressor exposure and no related risk of take.
Western ridged mussel	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	

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

1 **Table 9-8. Species- and habitat-specific risk of take for mechanisms of impacts associated with reef creation.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Chinook salmon are known to occur in lacustrine and marine environments where reef creation may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Coho salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Coho salmon are known to occur in lacustrine and marine environments where reef creation or modification may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Chum salmon	N	H	I	N	M	I	N	M	I	N	M	I	N	M	I	Chum salmon are known to occur in marine environments where reef creation may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Pink salmon	N	H	I	N	M	I	N	M	I	N	M	I	N	M	I	Pink salmon are known to occur in marine environments where reef creation may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Sockeye salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Sockeye salmon are known to occur in lacustrine and marine environments where reef creation may occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Steelhead	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Steelhead are known to occur in lacustrine and marine environments where reef creation may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Coastal cutthroat trout	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Coastal cutthroat trout are known to occur in lacustrine and marine environments where reef creation may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Westslope cutthroat trout	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	Westslope cutthroat and redband trout are known to occur in lacustrine environments where reef creation may occur. Therefore, these species are vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Redband trout	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	
Bull trout	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	Native char occur in lacustrine and marine habitats where reef creation projects may occur. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Dolly Varden	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	
Pygmy whitefish	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species rears throughout their juvenile and adult life history in lakes, indicating the potential for exposure to reef creation projects in lacustrine environments. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats used by this species include wetlands and small, slow-flowing streams, environments unsuitable for reef creation. Therefore there is no related risk of take.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for reef creation; therefore, there is no risk of stressor exposure and no related risk of take.
Mountain sucker	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species occurs in lacustrine habitats potentially suitable for reef creation projects. Therefore there is some potential for stressor exposure and related risk of take.
Lake chub	N	N	H	N	N	N	N	N	N	N	N	N	N	N	N	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. These habitats are unsuitable for reef creation projects; therefore, there is no potential for stressor exposure and no related risk of take.
Leopard dace	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. Therefore, this species occurs in habitats potentially subject to reef creation or modification. Therefore, this species is vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Umatilla dace	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in lacustrine impoundments potentially subject to reef creation. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.

Table 9-8 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with reef creation.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Western brook lamprey spend their entire life history in habitats potentially unsuitable for reef creation. Therefore there is no risk of stressor exposure and no related risk of take.
River lamprey	N	H	H	N	M	M	N	?	?	N	M	M	N	M	M	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of rivers to rear for extended periods, potentially years. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance. In their saltwater phase, river lamprey remain close to shore for periods of 10–16 weeks from spring through fall, meaning there is some potential for exposure to beach nourishment/contouring related stressors in the nearshore environment. Life-history stages exposed to lacustrine reef creation projects face a high risk of take during project construction, while exposure to marine projects produce lesser risk of take because the exposed life-history stages have higher motility. Once established, these projects should result in no risk of take.
Pacific lamprey	N	H	H	N	M	M	N	?	?	N	M	M	N	M	M	Pacific lamprey are anadromous, with migratory corridors extending from marine waters to small tributary streams. Ammocoetes burrow into riverine sediments to rear for extended periods. The non-motile ammocoete life-history stage is more susceptible to acute transient water quality impacts and direct physical disturbance during construction of lacustrine beach nourishment/contouring projects and face high risk of take. In marine waters, Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6–40 months and are therefore face reduced potential for exposure to stressors from marine reef creation projects. Once established, these projects should result in no risk of take.
Green sturgeon	N	L	N	N	?	N	N	?	N	N	L	N	N	?	N	Green sturgeon distribution in Washington State is restricted to marine waters as foraging adults. Therefore, the potential for stressor exposure is limited to this large, mobile life-history stage.
White sturgeon	N	L	H	N	?	M	N	?	M	N	L	M	N	?	M	The freshwater distribution of white sturgeon in Washington State includes lacustrine environments that are potentially suitable for reef creation, as well as marine habitats where reef creation is likely to occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type. However, sensitivity to stressor exposure in the marine environment is lower because only large motile adults occur in this environment type.
Longfin smelt	M	H	H	N	M	M	N	N	N	N	M	M	N	?	M	The freshwater distribution of longfin smelt includes lacustrine environments (Lake Washington) where reef creation may be appropriate, and marine habitats where reef creation is likely to occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type.
Eulachon	N	H	N	N	M	N	N	N	N	N	M	N	N	?	N	Eulachon occur in marine environments where reef creation is likely to occur. Therefore, this species is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Pacific sand lance	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	These marine species occur in marine environments where reef creation is likely to occur. Therefore, they are potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Surf smelt	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Pacific herring	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	This marine species occurs in marine environments where reef creation is likely to occur. Therefore, it is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Lingcod	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	This marine species occurs in marine environments where reef creation is likely to occur. Therefore, it is potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Pacific hake	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	These marine species occur in marine environments where reef creation is likely to occur. Therefore, they are potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Pacific cod	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Walleye pollock	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	

Table 9-8 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with reef creation.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	
Brown rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	These marine species occur in marine environments where reef creation is likely to occur. Therefore, they are potentially vulnerable to the impact mechanisms, stressors, and related risk of take resulting from this subactivity type in the marine environment.
Copper rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Greenstriped rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Widow rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Yellowtail rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Quillback rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Black rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
China rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Tiger rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Bocaccio rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Canary rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Redstripe rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Yelloweye rockfish	N	H	N	N	M	N	N	M	N	N	M	N	N	M	N	
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where reef creation take place; therefore, there is no related risk of take from this subactivity type.
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where reef creation take place; therefore, there is no related risk of take from this subactivity type.
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species does not occur in environments where reef creation take place; therefore, there is no related risk of take from this subactivity type.
Giant Columbia River limpet	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep, indicating no potential for exposure to reef creation projects. Therefore, this species is not vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. These environments are unsuitable for reef creation projects; therefore, there is no potential for stressor exposure and no related risk of take.
California floater (mussel)	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	The California floater mussel is known to occur in the Okanogan River basin (as well as fringing ponds of the Columbia River). While unlikely, the distribution of this species in lacustrine impoundments presents the potential for exposure to reef creation projects. This non-motile species would be particularly vulnerable to the impact mechanisms, stressors, and related risk of take resulting from reef creation.
Western ridged mussel	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. These environments are unsuitable for reef creation; therefore, there is no risk of stressor exposure and no related risk of take.

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

Table 9-9. Species- and habitat-specific risk of take for mechanisms of impacts associated with eelgrass and other aquatic vegetation creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Chinook salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	This species occurs in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Coho salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	This species occurs in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Chum salmon	N	H	I	N	M	I	N	M	I	N	M	I	N	M	I	This species occurs in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Pink salmon	N	H	I	N	M	I	N	M	I	N	M	I	N	M	I	This species occurs in marine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Sockeye salmon	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	This species occurs in marine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Steelhead	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	This species occurs in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Coastal cutthroat trout	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	This species occurs in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Westslope cutthroat trout	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	These species occur in lacustrine habitats where aquatic vegetation restoration/enhancement projects may occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Redband trout	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	
Bull trout	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	These species occur in marine and lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Dolly Varden	N	H	H	N	M	M	N	M	M	N	M	M	N	M	M	
Pygmy whitefish	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species occurs in lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats used by this species include wetlands and small, slow-flowing streams, environments potentially suitable for emergent vegetation enhancement projects. Therefore some potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Margined sculpin	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Primary habitats are located in smaller tributary streams of the Walla Walla and Tucannon River drainages unsuitable for aquatic vegetation enhancement projects; therefore, there is no risk of stressor exposure and no related risk of take.
Mountain sucker	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species occurs in lacustrine habitats where aquatic vegetation restoration/enhancement projects are likely to occur. Therefore the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Lake chub	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	The known distribution of this species in Washington State is limited to small streams and lakes in Okanogan and Stevens counties. Occurrence in lacustrine habitats potentially suitable for aquatic vegetation restoration/enhancement projects are likely to occur suggests the potential for stressor exposure exists. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.

Table 9-9 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with eelgrass and other aquatic vegetation creation/restoration/enhancement.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Leopard dace	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species has been reported to occur in the Columbia and Cowlitz River systems west of the Cascade Range, and in the Columbia River mainstem to the east. Lacustrine and riverine habitats in the Columbia River could be suitable environments for aquatic vegetation enhancement.
Umatilla dace	N	N	H	N	N	M	N	N	M	N	N	M	N	N	M	This species has been reported to occur in the Columbia, Yakima, Okanogan, Similkameen, Kettle, Colville, and Snake rivers. Therefore, this species occurs in lacustrine impoundments potentially subject to reef creation. Lacustrine and riverine habitats in the Columbia and Snake rivers could be suitable environments for aquatic vegetation enhancement.
Western brook lamprey	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Western brook lamprey spend their entire life history in habitats potentially unsuitable for aquatic vegetation restoration and enhancement projects. Therefore there is no risk of stressor exposure and no related risk of take.
River lamprey	N	H	H	N	M	M	N	?	?	N	M	M	N	M	M	River lamprey are commonly found in nearshore areas of rivers and some lake systems. Lamprey ammocoetes burrow into sediments in quiet backwaters of lakes and nearshore areas of estuaries and lower reaches of rivers to rear for extended periods, potentially years, indicating the potential for exposure to aquatic vegetation enhancement and restoration projects in lakes and estuaries. In their saltwater phase, river lamprey remain close to shore for periods of 10–16 weeks from spring through fall, meaning there is some potential for exposure to aquatic vegetation restoration and enhancement projects in both environment types. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take.
Pacific lamprey	N	I	H	N	N	M	N	I	?	N	I	M	N	N	M	Pacific lamprey are anadromous, with migratory corridors extending from marine waters to small tributary streams. Ammocoetes burrow into riverine and lacustrine sediments to rear for extended periods, indicating the potential for exposure to aquatic vegetation enhancement and restoration projects in lakes. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established these projects would be expected to improve habitat conditions; therefore, there will be no ongoing risk of take. In marine waters, Pacific lamprey occupy epipelagic habitats away from the nearshore environment for periods ranging from 6–40 months and are therefore face little potential for exposure to this type of project in the marine environment.
Green sturgeon	N	I	N	N	N	N	N	N	N	N	I	N	N	N	N	Green sturgeon distribution in Washington State is restricted to marine waters as foraging adults. Given the tendency for distribution in offshore waters, the potential for exposure to stressors from this project type is insignificant. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
White sturgeon	N	I	L	N	N	N	N	N	N	N	I	L	N	N	N	The freshwater distribution of white sturgeon in Washington State includes lacustrine environments that are potentially suitable for aquatic vegetation restoration and enhancement projects, as well as marine habitats where this project type is likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Given the tendency for distribution in offshore waters, the potential for exposure to stressors from this project type is insignificant. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Longfin smelt	N	I	L	N	N	N	N	N	N	N	I	L	N	N	N	The freshwater distribution of longfin smelt includes lacustrine environments (Lake Washington) where aquatic vegetation restoration and enhancement may be appropriate. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Offshore distribution in marine waters suggests that the potential for stressor exposure and related risk of take from this project type are insignificant. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Eulachon	N	I	N	N	N	N	N	N	N	N	I	N	N	N	N	Eulachon occur in marine environments where reef creation is likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Offshore distribution in marine waters suggests that the potential for stressor exposure and related risk of take from this project type are insignificant. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Pacific sand lance	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species occur in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Surf smelt	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Pacific herring	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species occurs in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Lingcod	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species occurs in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.

Table 9-9 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with eelgrass and other aquatic vegetation creation/restoration/enhancement.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Aquatic Vegetation Modifications			Water Quality Modifications			Ecosystem Fragmentation			Comments
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	
Pacific hake	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species occur in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Pacific cod	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Walleye pollock	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Brown rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	These marine species occur in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Copper rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Greenstriped rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Widow rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Yellowtail rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Quillback rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Black rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
China rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Tiger rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Bocaccio rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Canary rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Redstripe rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Yelloweye rockfish	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	
Olympia oyster	N	L	N	N	N	N	N	N	N	N	L	N	N	N	N	This marine species occurs in marine environments where aquatic vegetation restoration and enhancement projects are likely to occur. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	This marine species occurs in nearshore marine environments, however it is typically distributed in habitats unsuitable for aquatic vegetation restoration and enhancement projects. Therefore there is no potential for stressor exposure and no related risk of take.
Newcomb's littorine snail	N	H	N	N	N	N	N	N	N	N	N	N	N	N	N	This species is dependent on saltmarsh vegetation as its sole habitat. Vegetation restoration and enhancement projects may occur in this environment type, suggesting the potential for direct physical injury or mortality during planting activities. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Giant Columbia River limpet	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The Columbia River spire snail is typically found in smaller streams in water less than 5 inches deep. These habitats are unsuitable for aquatic vegetation restoration and enhancement projects. Therefore there is no potential for stressor exposure and no related risk of take.
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The giant Columbia River limpet is known to occur in the Hanford Reach of the Columbia River and other moderate to large river environments in the state, typically in shallow, flowing water environments with cobble and boulder substrates. These habitats are unsuitable for aquatic vegetation restoration and enhancement projects. Therefore there is no potential for stressor exposure and no related risk of take.
California floater (mussel)	N	N	L	N	N	N	N	N	N	N	N	L	N	N	n	The California floater mussel is known to occur in the Okanogan River basin as well as fringing ponds of the Columbia River. The distribution of this species in lacustrine impoundments and fringing pond habitats presents the potential for exposure to aquatic vegetation restoration and enhancement projects. However, stressors associated with this subactivity type are limited in magnitude; therefore, the related risk of take is similarly limited. Once established, these projects will result in improved habitat conditions and will produce no ongoing risk of take.
Western ridged mussel	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	The western ridged mussel is commonly found in small, clear water tributaries and streams. These habitats are unsuitable for aquatic vegetation restoration and enhancement projects. Therefore there is no potential for stressor exposure and no related risk of take.

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

10.0 Data Gaps

This section identifies data gaps and the information needed to fill those gaps for the nine subactivity types defined as habitat modification projects. Several data gaps extend across all nine subactivities covered in this white paper and are addressed first, followed by a discussion of subactivity-specific data gaps.

10.1 Common Data Gaps

Several data gaps have been identified that are universal for all nine subactivity types addressed in this white paper: impacts from construction and maintenance activities, impacts from altered riparian vegetation in marine environments, habitat effects on fish species, and specific information on impacts for several HCP species, in particular information on invertebrates.

10.1.1 Construction and Maintenance Activities

In general, there is a lack of information or direct studies associated with construction-related impacts on HCP species for all subactivity types. It is expected that during the construction of most habitat modification projects, there will be increased noise from construction activities, and dewatering and fish handling will occur. While the potential for these impacts to occur is described in Section 7 (*Direct and Indirect Impacts*), no studies have examined these changes during the construction of habitat modification projects. These data gaps are described in more detail in the following sections.

10.1.1.1 Elevated Underwater Noise

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

10.1.1.2 Temporary Exclusion/Dewatering

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

10.1.2 Marine Riparian Vegetation Modifications

Although the functions of freshwater riparian vegetation have been identified for riverine systems, exploring and defining the functions of marine riparian vegetation is ongoing. There is reason to believe that marine riparian vegetation provides similar functions to riparian vegetation adjacent to freshwater habitats; however, the extent and nature of those functions are not fully understood (Desbonnet et al. 1995; NRC 2001; Brennan and Culverwell 2004). The following information needs are outstanding: (1) understanding the specific nature and function of riparian habitat elements along marine shorelines; (2) the dependence of HCP species on riparian marine and freshwater habitat functions; (3) the effects on HCP species from habitat modification projects; (4) the dependence of HCP species on marine allochthonous inputs; and (5) the cumulative and synergistic effects of riparian and shoreline removal.

Furthermore, no research has been conducted to study submarine and intertidal groundwater in Puget Sound. It is clear from work elsewhere that such flows are crucial in sustaining nearshore ecosystems (Gallardo and Marui 2006); however, their role on the nearshore environment throughout Puget Sound is virtually unknown (Finlayson 2006).

10.1.3 Habitat Effects on Species

One of the biggest gaps in the literature is information that directly relates habitat changes to fish productivity (Bolton and Shellberg 2001). This information is difficult to collect because multiple factors may simultaneously influence the overall productivity and survival of fish species. However, this type of information is crucial to minimize impacts on HCP species from habitat modification projects.

10.1.4 HCP Species-Specific Information

Besides the extensive research on salmonids, there is a general lack of information regarding the effects that habitat modification projects may have on other HCP fish species. In addition, during a detailed literature review for each subactivity type, little information on direct impacts on invertebrates was found. As with construction, impacts can be implied with a good deal of certainty (e.g., increased sedimentation will adversely affect invertebrates); however, more research is warranted, especially for Pacific Northwest species.

10.1.5 Lost-Opportunity Impacts

Although it is recognized that lost-opportunity impacts must be mitigated to achieve no loss of habitat (WDFW 2003), currently there are no tools for universal and consistent application of the concept. Tools are needed to assess the lost opportunities associated with habitat modification projects to ensure that appropriate mitigation is provided.

10.2 Beaver Dam Removal/Modifications

There has been considerable research regarding the use of beaver dam habitat and similar backwater habitat by fish and invertebrates. Thus, impacts associated with beaver dam removal and habitat loss are well documented. However, there are no studies which have specifically monitored fish and invertebrate populations both before and after a beaver dam removal. Consequently, impacts on these species must be inferred from studies which have monitored the impacts of man-made dam removal projects on aquatic species.

There is growing interest in man-made dam removals as a restoration strategy and there is continued research in this area. However, this research is focused on the removal of man-made dams and thus additional research on the impact of beaver dam removal is needed. The impact of nonlethal beaver management strategies on pond habitat and fish passage is even less well understood. It is assumed that these structures would have little impact on ecosystem dynamics while simultaneously controlling upstream flooding, but there have been no studies to support this assumption. Finally, there have been no studies on the impact of dam removal (beaver or otherwise) on any of the HCP invertebrate species.

10.3 Large Woody Debris Placement/Movement/Removal

The impact of LWD placement and removal is a thoroughly researched topic but there are several data gaps that still exist. There has been little research on the importance of wood in supporting beach structure and connectivity between estuarine environments. However, many shorelines in the Puget Sound area contain considerable wracked wood in the supertidal zone (Sobocinski 2003) which may serve to reduce shoreline erosion and protect the sediments which are the foundation for the shallow water habitat (Herrera 2005). Additional research is needed before the impact associated with wood modification on beaches can be assessed.

In marine ecosystems, the influence of LWD on primary productivity is somewhat unclear. Nonetheless, supratidal food web dynamics are likely driven by both terrestrial and marine processes including (but not limited to) marine deposition of large wood. LWD along with wrack material and other organic debris can be a source for the detritus-based nearshore food web. Colonization of wrack by scavengers, infauna, and ultimately bacteria and diatoms, is an important process in maintaining energy exchange between the terrestrial and marine systems (Sobocinski 2003).

In general, the largest data gap regarding LWD placement/movement/removal focuses on the fact that little research on LWD in marine environments has been conducted. Consequently, it is difficult to assess what impacts may be associated with LWD alteration in this environment.

10.4 Spawning Substrate Augmentation

The impact of augmented salmonid spawning gravels on channel geomorphology and ecosystem dynamics is poorly understood. Despite the fact that this subactivity type is widely practiced, there have been a limited number of studies regarding the ecological ramifications of spawning substrate augmentations. In particular, there is no information regarding the impact that added gravel may have on riparian flooding. Increased flooding of riparian areas could potentially benefit stream biota by providing increased habitat access and exporting additional food resources to the channel (see Section 7.6 [*Wetland Creation/Restoration/Enhancement*]). Conversely, increased flooding could endanger man-made structures within the floodplain and potentially import organic material which could degrade the permeability of the augmented gravels.

The goal of spawning substrate augmentation is to create quality salmonid spawning habitat which will result in an increase in redd density and fry productivity and survival. The research to date has reported conflicting results as to whether gravel augmentation actually increases redd density. Thus, additional research is needed to verify that augmented sites have a higher carrying capacity than unaltered sites. It should be noted that the research to date has indicated that benthic dissolved oxygen levels are higher in augmented gravels and that egg survivorship is elevated in augmented gravels (Merz and Setka 2004). Thus, even if redd density does not increase in a restored site, fry productivity and survival may still be improved.

Finally, the potential benefit of spawning substrate augmentation for invertebrates is unclear. It is evident that initially organisms with limited motility will be buried and will perish, and it is also clear that benthic organisms have the ability to rapidly recolonize augmented reaches (Merz and Chan 2005). What is less clear is what benefit, if any, the augmented gravels provide invertebrate organisms. Increased benthic dissolved oxygen will, in theory, benefit mollusks but there have been no studies that have identified a net benefit to invertebrate populations after gravel augmentation.

10.5 In-Channel/Off-Channel Habitat Creation/Modifications

There has been a wealth of studies on the ramifications of in-channel habitat modification. Yet, due to the wide array of projects which are built in highly variable fluvial environments, the research results to date regarding the efficacy of such projects is mixed. The science of river restoration is constantly evolving and more studies are needed to quantify the effectiveness of projects built to the most rigorous and up-to-date standards. If indeed, these projects fail as frequently as projects built in years past (see Frissell and Nawa 1992; Merz and Chan 2005; Roni et al. 2002; Roper et al. 1998), then it can be assumed that channel rehabilitation efforts should be focused elsewhere (e.g. volume control, riparian restoration, off-channel habitat rehabilitation).

The most significant data gap related to in-channel and off-channel habitat modification is regarding the effect of the restoration on fish populations. This is due to the fact that fish are mobile and are affected by impacts from outside the restored reach. Consequently, it is difficult to correlate alterations to a defined reach with fish population dynamics. Studies that monitor fish movement using different remote tracking technologies may be most useful in clarifying this issue. As tracking technologies improve, the question of habitat usage and restoration efficacy will be more definitively addressed.

Finally, for off-channel habitat creation data gaps, see Section 10.7 (*Wetland Creation/ Restoration/Enhancement*).

10.6 Riparian Planting/Restoration/Enhancement

The research findings regarding fish response to riparian restoration is mixed. Increased riparian shading will reduce water temperatures (LeBlanc and Brown 2000; Opperman and Merenlender 2004) and this may benefit fish in thermally impacted reaches, but fish response to riparian vegetation planting/restoration has not been clearly defined. For instance, Bjornn et al. (1991) found that age-0 coho did not respond to either riparian vegetation removal or artificial cover creation in an Alaskan stream. Despite this data gap, numerous researchers have monitored physical and macroinvertebrate response to riparian vegetation alteration (Fuchs et al. 2003; Sweeney et al. 2004; Teels et al. 2006; Wipfli 2005). These studies have found that partial riparian cover will promote the greatest macroinvertebrate abundance and it can be assumed that increased macroinvertebrate abundance will support a greater fish population. Regardless, more studies of fish response to riparian vegetation addition and removal are needed to definitively characterize the impact of this subactivity on fish.

There are no widely available studies regarding the impact of invasive vegetation removal on stream ecology. Vegetation removal can destabilize banks and increase stream temperatures. The removal of riparian invasives such as Himalayan blackberry is a common riparian restoration practice (Bennett 2007), and further studies are required to assess the impact of this and similar activities on both fish and invertebrates.

Finally, there is very limited information on marine riparian restoration efforts. Loss of riparian vegetation in marine environments has been identified as an important problem, but monitoring of marine riparian restoration efforts has not been done.

10.7 Wetland Creation/Restoration/Enhancement

The primary data gap regarding riparian wetland creation is the impact of wetland creation on invertebrate species. It can be assumed that there will be no impact because in these types of restorations, habitat is not being degraded or eliminated but rather is being connected and/or augmented. Regardless, there is no available research to quantify the impact of riparian wetland creation/restoration on the HCP invertebrate species.

There is also limited information as to what size riparian wetland would be most beneficial to the river-floodplain ecosystem. Most floodplain restorations are limited in scope and the resultant wetland is much less extensive then the natural historic wetland that once existed. Consequently, residence times are generally lower in restored versus natural riparian wetlands. There has been no research which has quantified how this lowered residence time may affect nutrient processing and carbon export from restored floodplains.

Finally, no studies have examined the impact of dike breaching on HCP fishes. In particular, tidal flow over modified landscapes can produce fish traps, but this effect has not been described in the literature. In addition, the effects of nutrient loading from the inundation of former nutrient-rich (fertilized) agricultural lands have not been investigated.

10.8 Beach Nourishment/Contouring

There is substantial information about beach nourishment projects in exposed, sandy settings (Speybroeck et al. 2006). However, there is no peer-reviewed literature describing the restorative characteristics of beach nourishment projects for HCP fishes in coarse-clastic environments that are typical in Puget Sound (Shipman 2001). While there have been several reports of nourishment projects in Puget Sound (Gerstel and Brown 2006; Shipman 2001; Zelo et al. 2000), these “grey literature” reports have only cataloged the physical response of the beach to nourishment activities. These studies are useful for design purpose, but they have not addressed the core issue of whether nourished shorelines are actually used by species targeted by this activity (i.e., forage fishes).

Despite the lack of peer-reviewed work there is substantial anecdotal evidence that forage fishes do use placed materials for spawning. For instance, a beach nourishment project in Silverdale Waterfront Park, Kitsap County, continues to be used by surf smelt. Shorelines cut into man-made fill in Commencement Bay have also been designated forage fish spawning areas (Penttila 2007). Developing this anecdotal evidence into a peer-reviewed articles should be the target of future research funding considering the novelty of the work and the large number of beach nourishment projects.

While there a number of peer-reviewed articles regarding the efficacy of beach nourishment in sandy settings (Speybroeck et al. 2006), none of these studies focus on the benefits or detriments to the HCP species. Many of the impacts that have been described in the literature relate to excess turbidity and deposition of fine sediments near nourishment project sites (Speybroeck et al. 2006; Wilber et al. 2003). It may be that these effects are less pronounced on the HCP species. The HCP species in the Pacific Northwest have adapted to environments where sediment concentrations are substantially higher than the tectonically benign east coast (Montgomery 2000).

Finally, there is essentially no information (peer-reviewed or otherwise) on the ecological impacts of beach nourishment on lakeshores. Only two peer-reviewed studies were found that examined the ecological impacts of freshwater beach nourishment. The results of these studies mirrored the work performed in the marine environment, with one study advocating nourishment for fish populations (Winfield 2004), while the other documented the loss of invertebrate species due to nourishment in the Great Lakes (Garza and Whitman 2004). Considering that numerous HPAs were authorized in 2006 alone for nourishment projects on lakshores, more work is urgently needed on both the design parameters and ecological impacts of lakeshore nourishment projects.

10.9 Reef Creation

Much of the information collected in the Environmental Design of Low Crested Coastal Defense Structures (DELOS) program sponsored by the European Community is useful for identifying the impacts of reefs and the subsequent effects on fish and invertebrates. However, the relative lack of salmonids on the European continent limits the applicability of that work to the nearshore ecology of the Pacific Northwest.

The loss of fish that serve as food (forage fish) for salmonids have been studied, but relating the construction of an artificial reef to salmonid loss has not. Also, identifying the role that invasive species infestations (associated with the deployment of offshore rocky structures) can have on native species needs to be investigated (e.g., the abundance of urchins or macroalgae at the expense of salmonids).

The only research literature on freshwater reefs comes from the Great Lakes (Marsden and Chotkowski 2001; Meadows et al. 2005). However, it would be helpful to have a study similar to Marsden and Chotkowski (2001) to identify the ability of Washington freshwater reefs to attract invasive species.

Finally, there has been no work on the attraction of the HCP invertebrate species to artificial reefs.

10.10 Eelgrass and other Aquatic Vegetation Enhancement

Although eelgrass planting programs have been undertaken for nearly twenty years (Thom 1990), successful programs have only existed for a few years (Thom et al. 2005). Techniques and procedures for successful programs have been established (Thom et al. 2005); however, no program has yet to document the net gain to HCP species. The lack of data regarding the return of higher trophic species remains a large data gap.

11.0 Habitat Protection, Conservation, Mitigation, and Management Strategies

Habitat modification projects, as defined within this white paper, are designed to protect, create, and/or restore habitat. Unfortunately, not every project is successful and some projects result in habitat degradation due to poor design or site constraints. This section presents suggested measures which should be followed during the construction and design phase for each of the nine subactivity types covered in this white paper. Because many recommendations are applicable to all subactivity types, widely applicable best management practices are presented first. Subsequently, specific recommendations are presented for each subactivity type.

11.1 Common Mitigation Strategies

Several common habitat protection, conservation, and mitigation strategies apply to each habitat modification project and include minimization of impacts from: construction and maintenance activities, riparian vegetation modifications, and aquatic vegetation modifications.

11.1.1 Construction Activities

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

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

Best management practices regarding underwater noise, dewatering, flow bypass, and fish handling are discussed in detail below.

11.1.1.1 Elevated Underwater Noise

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

- Use air bubble curtains to create a bubble screen that can reduce peak underwater sound pressure levels by at least 15 dB_{peak} (Reyff et al. 2003; Vagle 2003).
- Maintain the integrity of the air bubble curtain; no boat traffic or other structure or equipment should be allowed to penetrate the air curtain.
- In marine environments, installation of a geotube should occur during low tide to minimize the potential for entrapment and stranding of fish within the enclosed area.
- Use fabric barriers and/or cofferdams to create an additional interface to buffer sound transmission into the underwater environment (WSDOT 2006).

11.1.1.2 Temporary Exclusion/Dewatering

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

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

- Perform work during low-flow or dry conditions and/or during dry weather.
- Pump sediment-laden water (from the work area that has been isolated from surrounding water) to an infiltration treatment site.
- Dispose of debris or sediment outside of the floodplain.

- Stabilize disturbed areas at the work site with sediment corresponding to the ambient bed to prevent an influx of fine sediment once water is reintroduced to the site.

- Adopt science-based protocols for fish removal and exclusion activities, including tracking and reporting of number and species of fish captured, fish injured, and mortality.

- Define and require qualifications for personnel performing fish capture and handling; maintain a list of qualified personnel.

- Require slow dewatering and passive fish removal from the dewatered area before initiating active fish-removal protocols.

Electrofishing Guidelines:

- Require the use of NOAA Fisheries electrofishing guidelines.

- Use lowest power output for effective electrofishing.

- Use least damaging direct current (not alternating current).

- Watch for burns or brands or muscle spasms, as these indicate harm to the fish.

- Use spherical electrodes appropriate to the water conductivity and the desired size and intensity of the field (Snyder 2003).

- Minimize fish exposure to handling by netting rapidly.

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

- Avoid crowding of fish in holding areas.

11.1.2 Riparian Vegetation Modifications

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

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

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

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

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

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

SPTH = site potential tree height.

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

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

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

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

11.1.3 Revegetation Design

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

11.1.4 Monitoring Plan

Pursuant to WAC 220-110, revegetation should be monitored annually for 3 years to ensure 100 percent survival of all plantings at the end of 1 year and 80 percent survival by the end of the 3-year monitoring period. Monitoring data should be provided to permitting agencies in detailed annual monitoring reports. After 3 years, monitoring and reporting should be completed every other year or every third year. In addition, any specific conditions provided by the U.S. Army Corps of Engineers (for project permits) or NOAA Fisheries and USFWS (for ESA Section 7 compliance) must be implemented.

11.1.5 Insurance

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

11.1.6 Lost-Opportunity Impacts

The hydraulic and geomorphic modifications induced by many habitat modification projects, particularly beaver dam and LWD removal, can result in lost-opportunity impacts. Mitigation for lost opportunity requires mitigation for channel processes affected by a project. In some situations, off-site mitigation may be the only option (WDFW 2003). According to WDFW (2003), the concept of mitigation for lost opportunity should only be applied when consistent, acceptable assessment methods or site-specific information is available. More detailed information on mitigation for lost-opportunity is provided in WDFW (2003).

11.2 Beaver Dam Removal/Modifications

The habitat and species impacts of beaver dam removals can be decreased through a number of measures. Gradual drawdown of the beaver impoundment is important because it reduces the mobilization of sediments within the impoundment and provides motile organisms more time to evacuate the pond. This “notching” technique is frequently used in small dam removals (Doyle et al. 2003; Stanley et al. 2002). Other strategies to manage beaver include the application of flow devices which control the pond level so that flooding conditions are alleviated (Beaver Solutions 2007). This management strategy is ideal because the positive environmental benefit of the beaver pond is not lost while flooding issues are resolved simultaneously. Other strategies include the use of enlarged culverts. Beaver often use culverts as dam sites but research has shown that the application of enlarged culverts discourages dam building near the roadway (Jensen et al. 2001). It has been estimated that over the life of the enlarged culvert, the costs of installation will be less than those associated with beaver management activities (Jensen et al. 2001).

11.3 Large Woody Debris Placement/Movement/Removal

Historical forest clearing, river snagging, and splash damming has greatly reduced the quantity of woody debris in rivers and streams of the Pacific Northwest (Collins et al. 2002; Montgomery et al. 2003). Snagging records from the region suggest that wood loading in large Pacific Northwest rivers was 100 times greater than present-day wood loading and contained larger trees (Collins et al. 2002). Restoration efforts that increase wood loading must also consider the size and placement of wood pieces that will provide the stability necessary for habitat protection and function.

Logjams consisting of small pieces of wood are less stable than those jams anchored by large, key members (Braudrick and Grant 2000). Maclennan (2005) noted that overloading of loose wood in two Puget Sound estuaries resulted in reduced diversity and abundance of aquatic vegetation. Studies such as these suggest that stabilizing wood or adding wood that will not mobilize during flood events should be the goal of most LWD additions. If structural stability is a major goal of LWD additions, it is vital to either place large pieces of wood that will not move during the design flood event or provide stability using other means, such as piles. Observations from the undisturbed Queets watershed show that the size of key members capable of forming stable, natural logjams varies with channel depth and width (Abbe and Montgomery 2003). Other factors increasing stability include the ability of logjams to accrete additional wood delivered by floods and the root cohesion and added roughness provided by vegetation growing on accumulations of woody debris.

The structural failure of wood placed in aquatic environments can impose construction impacts on HCP species. The adverse ecological impacts on HCP species caused by the structural instability and failure of instream woody debris can be minimized or avoided by ensuring that wood placed in rivers is properly engineered according to accepted engineering guidelines. Such guidelines are currently under development by the Washington chapter of the American Council of Engineering Companies (ACEC). Project success depends on a thorough understanding of the site-specific geomorphic constraints, quantifiable habitat goals, and the development of performance-based criteria that account for the anticipated hydrodynamic forces and the desired factor of safety for stability (Miller and Skidmore 2003; Slate et al. 2007). In addition, WDFW has published a series of guidelines through the department's Aquatic Habitat Guidelines Program. These guidelines are available from WDFW and include the Stream Habitat Restoration Guidelines document (Saldi-Caromile 2004), which provides guidance for habitat assessment, the development of restoration goals, and implementation of habitat restoration techniques.

The desire to construct stable logjams often requires the harvesting of large conifer trees from the few remaining patches of old-growth forest in the region. Habitat-protection measures can include the use of wood from blow-down or the wholesale purchase of trees from commercial harvest projects. Alternative sources of wood, such as salvaging trees from reservoirs, should also be considered to provide habitat benefits that will outweigh the impacts associated with project construction. As mentioned above, the use of piles in engineered log structures can eliminate the need for large, key-member logs that would otherwise be required for stability.

11.4 Spawning Substrate Augmentation

With the realization that early gravel augmentation projects were failing due to a lack of consideration regarding stream hydraulics and site geomorphology (Kondolf et al. 1996), practitioners began adopting new techniques and management strategies. It is recommended that every gravel augmentation project be based upon information gathered from detailed monitoring of site conditions and a geomorphic analysis of the reach, including estimates of sediment transport rates. Given the stochastic nature of riverine systems, even with detailed hydrologic and geomorphic information, the outcome of the project may be uncertain. Consequently, an adaptive management approach is recommended whereby the project is designed as an experiment. Bunte (2004) recommends the following adaptive management steps when conducting a gravel augmentation project:

1) *Pre-project Analysis*: In this step information is collected to formulate a conceptual model that explains how the stream should ideally function with an active gravel bed. For sustainable geomorphological and biological functionality, a channel shape must be attained in which:

- The 1.5-year recurrence interval flow fills the channel to its morphological bankfull stage
- Gravel is partially mobile every 1-2 years
- The flow regime is seasonally variable
- The timing of high and low flows corresponds with the needs of the salmon population.

2) *Measuring and modeling*: In this step data are collected and used to model the reach to predict gravel mobility and channel form under different restoration and stream discharge scenarios. The information derived here is used to inform the next step.

3) *Monitoring, evaluation, adjustment*: In this post-project step the site is monitored and evaluated to quantify channel response to the gravel augmentation. This step is vital and frequently not included in most restoration efforts due to a lack of funding. It is in this step that information regarding where the project may have gone wrong and how it might be remedied is

collected. Without this step the project may fail and no lessons will have been learned. The ramifications of gravel augmentations are poorly understood (CALFED 2005), and it is only through projects which include monitoring programs that the science of gravel augmentation will progress.

11.5 In-Channel/Off-Channel Habitat Creation/Modifications

As with gravel augmentation, the prediction of the outcome of the majority of in-channel restoration work has some associated uncertainty. To reduce the risk associated with this uncertain outcome, a strategy must be in place to address the potential failure of the project. Project failure has been a common occurrence in past in-channel restoration efforts (Babcock 1986; Frissell and Nawa 1992) and every measure should be taken to prevent the failure of future projects. Suren and McMurtrie (2005) suggest that in-channel restoration efforts should focus on watersheds which have a natural hydrograph and minimal sediment loading. They argue that external drivers will dictate reach scale dynamics and that without a watershed based approach reach-scale restoration will be useless. In a separate study, Frissell and Nawa (1992) monitored 161 instream structures and found that 60 percent of the structures had the opposite of the intended effect on the stream. They attributed the high failure rate to the fact that structures were placed in both high velocity and sediment laden reaches. Other studies have found instream structures placed in Pacific Northwest streams to be more durable, with only a 20 percent failure rate after 5-year recurrence interval flood events (Roper et al. 1998). Regardless, most research indicates that instream structures are more likely to fail in large rivers (Roper et al. 1998), high energy environments (Frissell and Nawa 1992), and when sediment loading is elevated (Frissell and Nawa 1992; Suren and McMurtrie 2005).

These studies suggest a harsh reality which is that in-channel restoration is least likely to succeed in those reaches that need it the most. Streams with flashy hydrographs caused by watershed deforestation or urban development, streams with high sediment loads from anthropogenic disturbance in the watershed, these are the degraded systems that restoration practitioners focus on. These are also the systems where most restoration practitioners fail to achieve their goals. The recommendation which results from these studies is to focus in-channel rehabilitation efforts on those channels that have a natural hydrograph and average sediment loading. In more heavily impacted systems, a top-down approach whereby hydrology is addressed on the watershed scale may be more appropriate and effective (Roni et al. 2002).

Off-channel habitat modification has a higher success rate that in-channel work because the site does not receive the same flood induced shear stresses. The primary avenues of failure for off-channel habitat modification are infilling or isolation from the main channel, and improper hydrologic design. If off-channel habitat is too intimately connected with the channel, then the goal of increased habitat diversity will not be achieved. If the off-channel site is too disconnected from the channel, then entrapment may become an issue. This suggests that the most vital aspect of an off-channel habitat modification is the amount and duration of flows which flush the off-channel habitat. A recent study by Henning et al. (2006) indicated that floodplain habitat (i.e., enhanced wetlands) with flow control structures that provided an outlet for fish emigration and a longer hydroperiod for rearing, produced significantly higher age-1 coho abundance than unenhanced wetlands. Studies such as this suggest that off-channel restoration efforts should focus on the connectivity of the habitat with the main channel when designing the project.

11.6 Riparian Planting/Restoration/Enhancement

Some have argued that the maintenance of a healthy riparian system should be paramount in channel rehabilitation and should take precedence over in-channel work (Opperman and Merenlender 2004). Riparian restoration is indeed a powerful tool, but the project must be properly conducted in order for ecosystem benefits to be realized. As with most restoration efforts that do not attempt to remedy the processes driving ecosystem degradation, riparian planting will be best applied in watersheds that are either minimally or moderately impacted. If riparian planting is to be performed in highly degraded watersheds, the work needs to be conducted within the context of larger watershed restoration efforts. Riparian rehabilitation efforts which create a narrow corridor of improved habitat downstream of a degraded watershed may not improve stream conditions (Teels et al. 2006). In a study of forest fragments in agricultural areas of the South Island, New Zealand, Harding et al. (2006) found that forest fragments of 5-7 ha, located in the lower reaches of the study catchment did not mitigate the negative effects of upstream agriculture on stream functioning. They concluded that in order for a riparian buffer to be maximally effective the buffer should extend to all channels in the distributary network, even small first order tributaries.

A number of researchers have conducted literature reviews of the many riparian restoration research projects which have been performed since the practice became widespread in the 1970s (Hickey and Doran 2004). These synthesis papers have a number of recommendations regarding buffer width:

- Buffers should be between 33 and 165 ft (10 and 50 m) wide for effective nitrogen filtration (Mayer et al. 2005).
- Buffers should be greater than 98 ft (30 m) in width for effective nitrogen and phosphorus filtration (Hickey and Doran 2004).
- Forested buffer width should extend to the edge of the floodplain to reduce the impact of upslope silviculture practices on stream microclimate (Anderson et al. 2007).
- Buffer widths of 98 ft (30 m) or greater are required to protect the ecological integrity of the stream (Broadmeadow and Nisbet 2004).

The standard practice today is to create or maintain buffer widths that are approximately 3.2–33 ft (1–10 m) in width (Hickey and Doran 2004). The available research indicates that this range is too narrow to protect ecosystem functioning and that widths in excess of 98 ft (30 m) are preferable.

11.7 Wetland Creation/Restoration/Enhancement

Research has indicated that floodplain wetlands are most productive when hydraulic residence time on the floodplain is on the order of 2 to 10 days (Ahearn and Dahlgren 2005; Hein et al. 2004). Additionally, studies have indicated that when residence time on floodplains is below this threshold the floodplain becomes a net sink for algal biomass instead of a net source (Ahearn and Dahlgren 2005; Tockner et al. 1999). This suggests that small floodplain restorations may not increase food resources within the waterway and that restoration efforts should focus on large floodplains (or small floodplains which receive relatively low volumes of water). There is a delicate balance in the hydroperiod of restored wetlands; too much connectivity between the wetland and the main channel and the productivity of the wetland decreases; too little and the export of food resources to the channel is decreased while the probability of fish stranding on the floodplain increases. In a study located in the lower Chehalis River, Henning et al. (2006) collected juvenile Pacific salmon data in both natural wetlands and in wetlands that were enhanced with weirs designed to promote connectivity. They found that enhanced wetlands had significantly higher age-1 abundance than unenhanced wetlands that were a similar distance from the main-stem river. This study suggests that measures which promote connectivity between riparian wetlands and adjacent water bodies will benefit native fish species.

Several studies have examined the effectiveness of salt marsh restoration practices (French and Stoddart 1992; Williams and Orr 2002; Hood 2004; Konisky et al. 2006; Simenstad et al. 2006). These works lead to the following recommendations:

- Ensure that the marsh has not subsided below the elevation required for emergent marsh vegetation and, if so, provide sediment source such that this elevation will be reached shortly after the project has been constructed (Williams and Orr 2002).

- Consider the geomorphology of both the seaward and landward tide-channel network when designing the dimensions of tide channels (Hood 2004).

- Consider the project within the broader geomorphic context (Simenstad et al. 2006).

- Where possible, remove all dike structure so as not to compromise or constrict the tide channel network (Hood 2004).

11.8 Beach Nourishment/Contouring

Several decades of beach nourishment on the east coast and in Europe provide a track record of nourishment activities where nearshore organisms have been established (Speybroeck et al. 2006). Studies from these locales will be particularly germane to projects on the outer coast of Washington, and in similar high-energy, sandy environments. Based upon an exhaustive survey of this work, (Speybroeck et al. 2006) makes the following recommendations:

- Choose nourishment grain size commensurate to the wave energy environment. Where possible, an estimate of storm wave height should be made to make this determination.
- Avoid short-term compaction by plowing immediately after construction (applicable only to sandy nourishment projects).
- Execute the nourishment in a period of low beach use by fish, birds, and other motile organisms.
- Break large nourishment projects into a number of smaller projects and stagger them such that nourishment in one reach feeds adjacent reaches (USFWS 2002).
- Select the nourishment technique consistent with the natural mode of sediment delivery (e.g., longshore transport on the outer coast and in the Strait of Juan de Fuca; bluff landslides in Puget Sound).

Other work, some of which has been performed in settings more typical of western Washington, similar to that of Puget Sound, has put forward other recommendations:

- Completely remove former bulkhead materials where possible (Gerstel and Brown 2006).
- Avoid using dredged materials from nearby marine elevations above wave base (Demir et al. 2004).
- When large projects are undertaken, reduce the size of individual renourishment placements by subdividing the site and alternately nourishing different portions of the project site (Munoz-Perez et al. 2001).
- Avoid nourishing areas immediately adjacent to eelgrass beds. If nourishment is carried out near eelgrass, ensure that sedimentation rates in the affected meadows do not exceed the rate found by Mills and Fonseca (2003) to cause significant mortality (i.e., >25% of the average stem length).

11.9 Reef Creation

Thirty years of artificial reef research have led to a rich data set that has identified pitfalls in offshore hard-substrate deployment (Thompson et al. 2002). The following suggestions are taken directly from this work:

- Locate the reef to best connect the activity site to other areas of hard-rock habitat to reduce the probability of an invasive species infestation (Thompson et al. 2002).
- Use clean earthen materials where possible (i.e., no materials that would leech metals or other exotic organic compounds, e.g., creosote-treated wood).
- Avoid the use of vertical walls (Bulleri and Chapman 2004).
- Place reefs completely below wave and tidal influence to minimize hydrogeomorphic disturbance to adjacent shorelines.
- Avoid simple geometric designs. A complex landscape has been shown to be more productive for a wide variety of fishes than simple geometries (Moschella et al. 2005; West et al. 1994).
- Provide a rough, complex surface on which a variety of organisms can colonize. Gullies and small caves can be especially fruitful (Moschella et al. 2005), particularly if they are large enough to allow sand to accumulate (Fabi et al. 2006).
- Use stable materials only. Materials that decay or that can become mobile during storms can endanger the communities that inhabit the reef and ultimately reduce fish numbers (USA-Today 2007).
- Protect reef areas from fishing (Guidetti et al. 2005).

11.10 Eelgrass and other Aquatic Vegetation Enhancement

Eelgrass planting has been traditionally considered a difficult enterprise (Thom 1990). However, recent work has demonstrated that it is possible to restore eelgrass populations if an adaptive management strategy is undertaken from the beginning of the restorative work (Thom et al. 2005). Further, Thom et al. (2005) described the elements necessary for a successful eelgrass restoration program:

- Clear goal statement—drives what is done

- Conceptual model—organizes understanding
- Monitoring—provides information for management decisions
- Evaluation framework—provides a mechanism to evaluate information openly and objectively
- Adjustment strategy—ensures clear plans and mechanisms to implement actions when adjustment is necessary
- Dissemination of information—lets others learn regionally and nationally.

In terms of the planting method, there are several eelgrass planting techniques (Pickerell et al. 2005). The most common approach is simply to manually plant adult shoots in the restoration area (Fonseca et al. 1998). Mechanized approaches have been attempted with mixed results (Pickerell et al. 2005). As any direct method of planting initiates some disturbance of the seabed (ultimately causing resuspension of sediment that is potentially harmful to nearby existing plants), several methods have sought to more closely simulate natural reproduction. In particular, Pickerell et al. (2005) put forth a technique to use buoys to broadcast seed across a particular area. This was demonstrated to be effective in encouraging the colonization of eelgrass without the impacts associated with intrusive planting, although it has not yet been proven effective in Washington State waters.

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