APPENDIX A
TO THE
PACIFIC COAST SALMON
FISHERY MANAGEMENT PLAN

As Modified by Amendment 18 to
the Pacific Coast Salmon Plan

IDENTIFICATION AND DESCRIPTION OF ESSENTIAL FISH HABITAT, ADVERSE IMPACTS, AND RECOMMENDED CONSERVATION MEASURES FOR SALMON

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, OR 97221-1384
(503) 820-2280

http://www.pcouncil.org

September 2014

ACKNOWLEDGMENTS

The primary drafting of this document was accomplished by Dr. John Stadler, Kerry Griffin, and Eric Chavez. GIS mapping was contributed by Barbara Seekins and Charleen Gavette. Additional contributions were provided by (in alphabetical order) Scott Anderson, F. Dale Bambrick, Alice Berg, Stephanie Burchfield, Sean Callahan, Scott Carlon, Renee Coxen, Rebecca Dittmann, Brian Ellrott, Dr. Jeffrey Fisher, William Foster, Michael Grady, Mark Hampton, Dr. Peter Kiffney, Keith Kirkendall, Gayle Kreitman, Steven Landino, William Lind, Michael Lisitza, Jeffrey Lockwood, Matthew Longenbaugh, David Mabe, Robert Markel, Michael McDonald, Michelle McMullen, Ben Meyer, Kenneth Phippen, Dr. Phil Roni, Bonnie Shorin, Dr. Thomas Sibley, Jim Simondet, Dr. Brian Spence, Kenneth Troyer, Randy Tweten, Julie Weeder, and David White. Final compilation and editing were done by Kim Ambert and Chuck Tracy.

Partial funding for this effort was secured by Michael Tehan, Assistant Regional Administrator for Habitat Conservation Division, Northwest Region, National Marine Fisheries Service.

TABLE OF CONTENTS

List of abbreviations, acronyms, and initialisms

°C	degrees Celsius
µPa	micropascal
ATTF	Alaska Timber Task Force
BMP	best management practice
BTA	best technology available
CFR	Code of Federal Regulations
cm	centimeter
Cm/s	centimeters per second
Council	Pacific Fishery Management Council
CWT	coded wire tags
dB	decibels
EEZ	Exclusive Economic Zone
EFH	essential fish habitat
EMF	electromagnetic field
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FAD	fish aggregating device
FERC	Federal Energy Regulatory Commission
FHWG	Fisheries Hydroacoustic Working Group
FMP	fishery management plan
fps	feet per second
FRI	Fisheries Research Institute
HAPC	habitat areas of particular concern
HU	hydrologic unit
Hz	hertz
IAS	invasive alien species
JNCC	Joint Nature Conservation Committee
kg	kilogram
km	kilometer
kPa	kilopascal
LNG	liquefied natural gas
LTF	log transfer facility
LWD	large woody debris
m	meter
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSF	multi-stage flash
nm	nautical miles
NMDMP	National Marine Debris Monitoring Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPFMC	North Pacific Fishery Management Council
NRC	National Research Council
NWFSC	Northwest Fisheries Science Center
NWIFC	Northwest Indian Fisheries Commission
NWSI	Northwest Straits Initiative
ODFW	Oregon Department of Fish and Wildlife
OTC	once-through cooling
Pa	pascal
PFMC	Pacific Fishery Management Council

PNCCC	Pacific Northwest Pollution Control Council
Ppt	parts per thousand
PS	Puget Sound
RAC	Resource Agency of California
RO	reverse osmosis
SAFE	Stock Assessment and Fishery Evaluation
SAV	submerged aquatic vegetation
SCV	submerged combustion vaporization
sec	second
SEL	sound exposure level
SEL_{cum}	cumulative sound exposure level
TMDL	total maximum daily load
TNT	trinitrotoluene
U.S. DOE	U.S. Department of Energy
USDA	US Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WDF	Washington Department of Fisheries
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WFWC	Washington Fish and Wildlife Commission
WSCC	Washington State Conservation Commission
WWPI	Western Wood Preservers Institute

1. INTRODUCTION

Essential fish habitat means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.

MSA Section 3(10)

This document contains the identification and description of essential fish habitat (EFH) for salmon managed by the Pacific Fishery Management Council (Council) under the Pacific Coast Salmon Fishery Management Plan (salmon FMP). These managed salmon include most of the Chinook salmon (*Oncorhynchus tshawytscha*) stocks and all of the coho salmon (*O. kisutch*) stocks from Washington, Oregon, Idaho, and California as well as pink salmon (*O. gorbuscha*) stocks originating from watersheds within Puget Sound (PFMC 1997b).

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires all fishery management councils to amend their fishery management plans (FMPs) to describe and identify EFH for each managed fishery. As defined in the MSA, the term "essential fish habitat" means those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. For the purpose of interpreting this definition of EFH: ‘‘waters’’ include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; ‘‘substrate’’ includes sediment, hard bottom, structures underlying the waters, and associated biological communities; ‘‘necessary’’ means the habitat required to support a sustainable fishery and the managed species’ contribution to a healthy ecosystem; and ‘‘spawning, breeding, feeding, or growth to maturity’’ covers a species’ full life cycle (50 CFR 600.10).

The waters and substrate that comprise EFH designated in the FMPs managed by the Council are diverse and widely distributed. They are also closely interconnected with other aquatic and terrestrial environments. From a broad perspective, EFH is the geographic area where the species occurs at any time during its life. This area can be described in terms of ecological characteristics, location, and time. In ecological terms, EFH includes waters and substrate that focus distribution (e.g., migration corridors, spawning areas, rocky reefs, intertidal salt marshes, or submerged aquatic vegetation (SAV)) and other characteristics that are less distinct (e.g., turbidity zones, salinity gradients). Spatially, habitats and their use may shift over time due to natural habitat-forming processes, such as sediment transport or extreme weather events, and human activities, such as shoreline armoring or timber harvest. The type of habitat available, its attributes, and its functions are important to species productivity, diversity, health, and survival.

An FMP should minimize, to the extent practicable, adverse effects on EFH caused by fishing and identify other actions to encourage the conservation and enhancement of EFH. The MSA also require Federal agencies to consult with the National Marine Fisheries Service (NMFS) with respect to any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by such agency that may adversely affect any EFH identified under this Act.

The regulatory guidance that implements the EFH provisions of the MSA (50 CFR 600) defines an “adverse effect” as any impact that reduces quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality or quantity of EFH. Adverse effects on EFH may result from actions occurring within EFH or outside of EFH and may include site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions.

The regulatory guidance also requires FMCs and NMFS to periodically review the EFH provisions of FMPs and that those provisions should be revised or amended, as warranted, based on available information (50 CFR 600.815(a)(10)). The review should evaluate published scientific literature, unpublished scientific reports, information solicited from interested parties, and previously unavailable or inaccessible data. EFH for Pacific Coast salmon was first identified and described in Appendix A to the salmon FMP (PFMC 1999), and was reviewed by the PFMC and NMFS in 2011 (see Stadler et al. 2011). This revised appendix reflects the result of that review and subsequent Council action, and contains information required by the EFH regulatory guidance (50 CFR 600).

Chapter 2 of this document identifies EFH for the three species Pacific salmon managed under the salmon FMP and designates habitat areas of particular concern (HAPC). Chapter 3 describes the habitat requirements for each life history stage for each of the three species of salmon. Chapter 4 describes potential adverse effects on salmon EFH from both fishing and non-fishing activities as well as potential conservation and enhancement measures to avoid, minimize, mitigate, or otherwise offset those effects. Chapter 5 describes additional information and research needs for improving the identifications and descriptions of EFH for Pacific Coast salmon.

2. IDENTIFICATION OF ESSENTIAL FISH HABITAT FOR THE PACIFIC SALMON FISHERY

EFH for the Pacific Coast salmon fishery means those waters and substrate necessary for salmon production needed to support a long-term, sustainable salmon fishery and salmon contributions to a healthy ecosystem. To achieve that level of production, salmon EFH must include all freshwater, estuarine, and marine habitats in, and off of, Washington, Oregon, Idaho, and California and the marine waters off Alaska that are currently occupied by stocks of salmon managed under this FMP, as well as most of the habitats that were historically occupied by those same stocks. EFH cannot be designated for salmon stocks that are not managed under the FMP, and cannot be designated for stocks that are listed as Ecosystem Component Species in the FMP.

The geographic extent of freshwater EFH is identified as all water bodies currently or historically occupied by Council-managed salmon. In the estuarine and marine areas, salmon EFH extends from the extreme high tide line in nearshore and tidal submerged environments within state territorial waters out to the full extent of the Exclusive Economic Zone (EEZ) (200 nautical miles or 370.4 km) offshore of Washington, Oregon, and California north of Point Conception. Foreign waters off Canada, while still salmon habitat, are not included in salmon EFH, because they are outside United States jurisdiction. Pacific Coast salmon EFH also includes the marine areas off Alaska designated as salmon EFH by the North Pacific Fishery Management Council (NPFMC)[1]. If the NPFMC alters its designation of EFH for salmon in Alaskan marine waters, the marine EFH for Pacific Coast salmon under this FMP will change accordingly, without action by this Council. The coast-wide geographic range of EFH for Pacific Coast salmon, both freshwater and marine, is shown in Figure 1. This identification of EFH is based on the descriptions of habitat utilized by Chinook salmon, coho salmon, and Puget Sound pink salmon provided in Chapter 3 of this appendix. Areas above long-standing naturally impassable barriers (e.g., waterfalls) and above specific impassable dams are excluded from EFH, as are some areas that are the focus of reintroductions under Section 10(j) of the U.S. Endangered Species Act (ESA).

2.1 COMPREHENSIVE APPROACH TO IDENTIFICATION

The Council chose a comprehensive rather than a limiting approach to the identification of salmon EFH for several reasons. In the marine environment, Pacific salmon distribution can only be identified generally throughout the EEZ, because it is extensive, varies seasonally and inter-annually, and has not been extensively sampled in many ocean areas. In estuaries and freshwater, delimiting habitat to that which is essential is difficult, because of the diversity of habitats utilized by Pacific salmon coupled with (1) natural variability in habitat quality and use (e.g., some streams may have fish present only in years with plentiful rainfall; also, habitat of intermediate and low value may be important depending upon the health of the fish population and the ecosystem); (2) the current low abundance of Pacific salmon; (3) the lack of data on specific stream-by-stream historical distribution; and (4) the fact that salmon migrate through this entire continuum of habitats. Many of the current databases on salmon distribution were developed during recent periods of low salmon abundance and may not accurately reflect the complete distribution and habitats utilized by salmon. Furthermore, the current information on salmon freshwater distribution is useful at the regional level for determining which watersheds salmon inhabit, but not necessarily for identifying EFH down to specific stream reaches and habitats utilized by salmon.

After considering these factors, the Council adopted an inclusive, watershed-based approach, and designated EFH at the level of the U.S. Geological Survey (USGS) 4th field hydrologic units (HUs). Such an approach is appropriate, because it (1) recognizes the species' use of diverse habitats and underscores

1 Contact the North Pacific Fishery Management Council for information on salmon EFH in the marine waters off of Alaska. http://www.alaskafisheries.noaa.gov/npfmc/index.html

the need to account for all of the habitat types supporting the species' freshwater and estuarine life stages, from small headwater streams to migration corridors and estuarine rearing areas; (2) considers the variability of freshwater habitat as affected by environmental conditions (droughts, floods, etc.) that make precise mapping difficult; and (3) reinforces important linkages between aquatic and adjacent upslope areas. Habitat available and utilized by salmon changes frequently in response to floods, landslides, woody debris inputs, sediment delivery, and other natural events. To expect the distribution of salmon within a stream, watershed, province, or region to remain static over time is unrealistic. Furthermore, this watershed-based approach is consistent with other Pacific salmon habitat conservation and recovery efforts such as those implemented under the ESA. Additional detail on Pacific salmon freshwater essential habitat is provided in Chapter 3 of this appendix.

Salmon EFH is designated for each species within the USGS 4th field HUs identified in Table 1 using current and historical distribution data. These 4th field HUs were identified using several databases of current salmon distribution, augmented with additional other historical and current distribution data identified in Table 2. Current distribution information in Washington, Oregon, and Idaho was obtained from StreamNet (2012a; 2012b; 2012c; and 2012d), and current distribution information in California was obtained from Calfish (2012) and NMFS (2005a; 2005b).

Salmon EFH includes the channels within the designated 4th field HUs with a lateral extent as defined by the ordinary high-water line (33 CFR 319.11). Salmon EFH excludes areas upstream of longstanding naturally impassable barriers (i.e., natural waterfalls in existence for several hundred years). Salmon EFH includes aquatic areas above all artificial barriers except the impassable barriers (dams) listed in Table 1. Although the habitats above these dams are not designated as EFH, activities in these areas that may adversely affect the EFH below the dams are subject to the consultation provisions of the MSA. The rationale used to identify these dams is described in detail in Section 2.2.

2.2 CONSIDERATION OF REINTRODUCTIONS UNDER SECTION 10(j) OF THE ESA

Throughout their historical range, salmon have been extirpated from many freshwater habitats that once supported self-sustaining populations. Man-made impassable barriers, such as dams and culverts, block access to a significant portion of historically occupied areas. In some areas that remain accessible, the habitats have been so degraded by anthropogenic activities that they no longer support salmon. Although many of these areas are currently unoccupied, they are recognized as important and reestablishing populations in most of these areas is necessary for maintaining a sustainable salmon fishery and the contribution of salmon to a healthy ecosystem.

Many of these extirpated populations were part of a larger population (i.e., an evolutionarily significant unit [ESU]) that has been listed as either threatened or endangered under the ESA. The ESA contains provisions under Section 10(j) that facilitate cooperative efforts to reintroduce listed species into historical habitats, where NMFS works with a range of stakeholders that include Federal, state, and local agencies, Tribal governments, industry, and private citizens, to reach agreement on where reintroductions will occur. Designation as an experimental population under Section 10(j) encourages stakeholder support by allowing for the easing of certain ESA liabilities, such as the consultation requirements under Section 7 or the prohibition of take under Section 9, for potentially affected parties within the reintroduction area. Cooperation is essential to these reintroduction efforts, and in certain cases, EFH designations that are not aligned with reintroduction planning could confuse the public and could have implications for ongoing and future efforts to build support to reestablish listed salmon populations in these areas. Therefore, the Council intends to consider these areas, on a case-by-case basis and in cooperation with NMFS, to determine whether it is appropriate to have EFH designations in areas where experimental populations have been, or are proposed to be, reintroduced.

2.3 CONSIDERATION OF IMPASSABLE DAMS

Numerous hydropower, water storage, and flood control projects have been built that block access to large areas that were historically used by salmon. This loss of habitat is widely recognized as a major factor in the decline of salmon populations throughout their range. The EFH regulations note that if degraded or inaccessible aquatic habitat has contributed to reduced yields of a species or assemblage and if those conditions can be reversed through such actions as improved fish passage techniques, improved water quality measures, and similar measures that are technologically and economically feasible, EFH should include those habitats that would be necessary to the species to obtain increased yields [50 CFR 600.815(a)(1)(iv)(F)]. In addition, the EFH regulations recognize the importance of ecosystem restoration and allows EFH to be designated in certain historical habitats, provided that they are necessary to support rebuilding the fishery and that restoration is technologically and economically feasible [50 CFR 600.815(a)]. These dams vary greatly in size, permanence, the feasibility of reestablishing fish passage, and the contribution that the habitats above the dam would make to a sustainable fishery and conservation of the species. Therefore the Council, in 1999, established a set of criteria for determining whether the habitat above them should be designated as EFH, or whether the dams should be designated as the upstream extent of EFH on that system. The Council applied these criteria to more than 50 large dams in Washington, Oregon, Idaho, and California, and designated 44 of them as the upstream extent of EFH. As part of the 5-year review, these 44 dams were re-evaluated, based on a modified set of criteria. These modified criteria are as follows:

1) Is the dam federally owned or operated, licensed by the Federal Energy Regulatory Commission (FERC), state licensed, or subject to state dam safety supervision? Is the dam of sufficient size, permanence, impassability, and legal identity to warrant consideration for inclusion in this list?
   - If Yes both question, go to 2
   - If No, then the dam is not the upstream extent and the habitat above the dam should be designated as EFH.

2) Is the dam upstream of any other impassable dam that is designated as the upstream extent of EFH?
   - If Yes, then the upstream extent of EFH is, by definition, downstream of the dam, and it should not be included in the list of impassable dams.
   - If No, then go to 3.

3) Is fish passage in the construction or planning phase by a state or Federal agency or facility operator?
   - If Yes, then the dam should not be considered the upstream extent, and the habitat above the dam should be designated as EFH.
   - If No, then go to 4.

4) Has NMFS or the Council determined that restoration of passage and conservation of the habitat above the dam is necessary for the long-term survival of the species and sustainability of the fishery? In making this determination, NMFS or the Council should consider information contained in official NMFS documents such as a biological opinion, critical habitat designation, NMFS recovery plan, fish passage prescription under the Federal Power Act, or other formal NMFS policy position. This criterion provides for designation of habitat upstream of dams that would otherwise be listed as the upstream extent of EFH, and reflects the fact that the habitats in many portions of watersheds have not previously been formally evaluated.
   - If Yes, then the dam should not be considered the upstream extent and the habitat above the dam should be designated as EFH.
   - If No, then the dam should be designated as the upstream extent of EFH.

In determining the upstream extent of EFH, the Council and NMFS also considered reintroduction efforts under Section 10(j) of the ESA. Consideration of new EFH designations should be aligned with reintroduction planning, to the extent feasible.

Using this process, the Council designated 43 dams as the upstream extent of EFH. These dams are identified in Table 1. The locations of these dams are also indicated on the species-specific maps of EFH (Figures 2 through 6). It is important to note that some of the dams block passage of one species of salmon but not another. For example, Chinook salmon are passed, via a trap and haul operation, at Big Cliff Dam on the North Santiam River, but coho salmon are not.

Throughout the range of Pacific salmon, numerous hydropower dams have undergone, or are scheduled for, relicensing by FERC. Information developed during the process of relicensing requires evaluation to determine whether fish passage facilities will be required at such dams to restore access to historically occupied habitat. Even though habitat above such barriers may not currently be designated as EFH, this conclusion does not diminish the potential importance of restoring access to these areas. The FERC relicensing process may result in requirements for the establishment of fish passage when the habitat above currently impassable FERC-licensed dams is necessary. Passage may also be required via other non-FERC mechanisms. If, through these processes, salmon access or reintroduction above any of the dams listed in Table 1 become feasible, the Council may remove them from the list and designate the areas above them as EFH.

2.4 HABITAT AREAS OF PARTICULAR CONCERN

The implementing regulations for the EFH provisions of the MSA (50 CFR part 600) recommend that the FMPs include specific types or areas of habitat within EFH as "habitat areas of particular concern" (HAPC) based on one or more of the following considerations: (1) the importance of the ecological function provided by the habitat; (2) the extent to which the habitat is sensitive to human-induced environmental degradation; (3) whether, and to what extent, development activities are, or will be, stressing the habitat type; and (4) the rarity of the habitat type. Based on these considerations, the Council designated five HAPCs: 1) complex channels and floodplain habitats; 2) thermal refugia; 3) spawning habitat; 4) estuaries; and 5) marine and estuarine SAV. With the exception of estuaries, none of these HAPCs have been comprehensively mapped, and some may vary in location and extent over time. For these reasons, the mapped extent of these areas is only a first approximation of their location. Defining criteria of these HAPCs are described below, which should be applied to determine whether a given area is designated as a HAPC for Pacific Coast salmon. It is important to note that HAPCs include all waters, substrates, and associated biological communities falling within the area defined by the criteria below. In some cases, HAPCs may overlap with each other (e.g., estuaries with marine and estuarine SAV), an indicator of the multiple habitat functions provided by, and the increased importance of, that area.

The intended goal of identifying HAPCs is to provide additional focus for conservation efforts. While the HAPC designation does not add any specific regulatory process, it highlights certain habitat types that are of high ecological importance. As a result, Federal actions with potential adverse impacts to HAPCs will be more carefully scrutinized during the EFH consultation process and may result in greater conservation of EFH.

2.4.1 Complex Channels and Floodplain Habitats

Complex channels consisting of meandering, island-braided, pool-riffle and forced pool-riffle channels and complex floodplain habitats consisting of wetlands, oxbows, side channels, sloughs and beaver ponds, and steeper, more constrained channels with high levels of large woody debris (LWD), provide valuable habitat for all Pacific salmon species. The densities of both spawning and rearing salmon are highest in areas of high quality naturally functioning floodplain habitat and in areas with LWD than in anthropogenically modified floodplains (Brown and Hartman 1988; Chapman and Knudsen 1980; Brown and Hartman 1988; Montgomery et al. 1999). These important habitats are typically found within complex floodplain channels defined as meandering or island-braided channel patterns and in pool-riffle or forced-pool mountain river systems (see Montgomery and Buffington 1998 and Beechie et al. 2006 for detailed description of these channel types). Complex floodplain habitats are dynamic systems that change over time. As such, the habitat-forming processes that create and maintain these habitats (e.g., erosion and aggradation, channel avulsion, input of large wood from riparian forests) should be considered as integral to the habitat.

An important component of these habitats is large wood, which typically occurs in the form of logjams in floodplains and larger rivers and accumulations of single or multiple logs in smaller mountain channels. LWD helps create complex channels and floodplain habitats and important spawning and rearing habitat by trapping sediment, nutrients, and organic matter, creating pools, sorting gravels, providing cover and hydrologic heterogeneity, and creating important spawning and rearing areas for salmon (Harmon et al. 1986; Abbe and Montgomery 1996; Bilby and Bisson 1998). Complex channels, floodplain habitat, and LWD are very sensitive to land, riparian, or river management. These areas also provide pools, off-channel areas, shade, cooler temperatures, and thermal refugia during both summer and winter (Crispin et al. 1993).

Juvenile coho salmon frequently move from main-channel habitats to off-channel habitats during the winter months, presumably to seek refuge from high winter flows (Cederholm and Scarlett 1982; Peterson 1982). Juvenile coho salmon inhabiting beaver ponds and other off-channel ponds exhibit higher densities, higher growth rates, and higher overwinter survival rates than coho salmon inhabiting other main-channel and side-channel habitats (Bustard and Narver 1975; Swales et al. 1986; Swales and Levings 1989).

Side channels are important spawning habitat for Chinook salmon as well as coho salmon, and complex floodplain habitat and associated channels have higher densities of spawning fish than modified or constrained habitats (Vronskiy 1972; Drucker 2006; NOAA unpublished data).

In higher-gradient reaches with more confined channels, large wood plays a major role in creating deep, complex pools that provide winter refuge where off-channel habitats are not available. Densities of juvenile coho salmon and other salmonids are often substantially higher in stream reaches with higher wood volumes compared to streams with little wood (reviewed in Bilby and Bisson 1998).

In most river systems throughout the Pacific Northwest and California, complex floodplain habitats have been subject to a high degree of direct anthropogenic modification. Floodplain areas have been cleared of woodland vegetation, drained, and filled to allow agricultural, residential, and urban development (Pess et al. 2002; 2003). Channelization and diking of rivers has effectively separated rivers from many off-channel habitats once available to salmonids (Beechie et al. 1994; Reeves et al. 1998). Clearing of large wood accumulations in rivers was commonplace to both improve navigation and facilitate transport of logs from upstream forest to mill sites downstream (Bilby and Bisson 1998). Active removal of beaver ponds or isolation of beaver ponds by levees has resulted in substantial losses of these habitats in many Pacific Northwest rivers (Beechie et al. 1994; 2001).

Low-gradient, unconstrained reaches that typify where complex floodplain habitats are expressed are also highly responsive to disturbances that happen higher up in the watershed. For example, sediments generated by land-use and road-building practices are typically routed through higher-gradient, transport reaches and are deposited in low-gradient reaches. This can lead to widening and shallowing of the river channel, filling in of pool habitats, and reductions in the average particle size of the substrate (Montgomery and Buffington 1998). These changes, in turn, diminish the quality of spawning and rearing habitats for salmon, as well the capacity of affected reaches to produce invertebrates that salmonids depend on for food.

In moderate-gradient stream reaches, historical land-use practices including logging of riparian forests, splash damming, and active removal of wood from the stream channel to facilitate fish passage and protect local infrastructure has fundamentally altered the structure and function of salmon habitats. Despite improvements in riparian forest management that have occurred in the last 40-50 years, the legacy of early practices remains apparent in diminished sources for recruitment of large wood (particularly of coniferous origin), decreased quantities of large wood in stream channels, and a shift in composition of large wood pieces from large-diameter pieces of coniferous origin to smaller diameter pieces of hardwood origin, which decompose at a much faster rate (Bilby and Bisson 1998).

Many areas that historically were part of complex floodplain habitats have been permanently lost to urban development. Restoration of other such habitats would require major shifts in land-use practices including abandonment of agricultural lands and removal of dikes and levees. Consequently, maintaining those few relatively intact floodplain habitats that remain on the landscape should be a high priority in salmon conservation.

Conditions in riparian forests along more confined channels are likely to improve over the long term in response to forest practice rules; however, the time lag between establishment of these rules and expected attainment of instream benefits is long (100-200 years). Consequently, ensuring protection of stream reaches that are characterized by intact, coniferous riparian stands and/or that currently have high amounts of inchannel wood is a high priority to bridge this gap.

Historically, neither complex floodplain habitats nor mid-gradient channels with large quantities of in-channel wood were inherently rare within forested landscapes of the Pacific Northwest and California, but they have become increasingly so in response to human alterations of the landscape. For example, in the Skagit and Stillaguamish River watersheds, agricultural and urban development in floodplain areas has led to a 50 percent loss of side-channel sloughs habitats, and roughly 90 percent of beaver ponds have been isolated from main channel habitats (Beechie et al. 1994; 2001). As a consequence of intensive forest management on the vast majority of landscape within the Pacific Coastal Ecoregion, streams throughout the region have experienced reductions in the quantity and average size of in-channel large wood, as well as loss of wood recruitment potential from adjacent riparian zones (Bilby and Bisson 1998).

The location and extent of these complex habitats can vary over space and time and have not been comprehensively mapped. Therefore, maps or spatial descriptions may not reliably identify them at the project scale. As such, this HAPC relies on the detailed text that describes the general attributes of these habitats, rather than spatially explicit descriptions or maps.

2.4.2 Thermal Refugia

Thermal refugia that provide areas to escape high water temperatures are critical to salmon survival, especially during hot, dry summers in California, Idaho, and eastern Oregon and Washington. Thermal refugia provide important holding and rearing habitat for adults and juveniles (Goniea et al. 2006; Sutton et al. 2007). Important thermal refugia often exist higher in HUs and are most susceptible to blockage by artificial barriers (Yoshiyama et al. 1998). Reduced flows that are either anthropogenic, natural or climate-change induced can also reduce or eliminate access to refugia (Battin et al. 2007; Riley et al. 2009). Loss of structural elements such as large wood can also influence the formation of thermal refugia. Thermal refugia typically include coolwater tributaries, lateral seeps, side channels, tributary junctions, deep pools, areas of groundwater upwelling and other mainstem river habitats that are cooler than surrounding waters (≥2° C cooler) (Torgersen et al. 1999; Ebersole et al. 2003). As such, refugia can occur at spatial scales ranging from entire tributaries (e.g., spring-fed streams), to stream reaches (e.g., alluvial reaches with high hyporheic flow), to highly localized pockets of water only a few square meters in size embedded within larger rivers.

Studies have shown that salmon increase their use of thermal refugia (e.g., cool water tributaries) when exposed to elevated water temperatures (Sutton et al. 2007), which can significantly reduce migration rates and suggests these areas provide crucial habitat in warm years (Goniea et al. 2006). Torgersen et al. (1999) state that the ability for cold water fish such as salmon to persist in warm water environments (>25°C) that experience elevated summer temperatures and seasonal low flows may be attributed to thermal refugia because even relatively minor differences in temperature are ecologically relevant for fish. In addition, climate change is expected to cause a rise in freshwater temperatures and a reduction in snowpack, which would lead to lower flows in the summer and fall (Battin et al. 2007; Mote et al. 2003; Stewart et al. 2004). These impacts would likely result in a reduction in the quantity and quality of fresh water salmon habitat, making thermal refugia even more important in the future.

Artificial barriers can block access to thermal refugia, which are often located at higher elevations. These barriers can also restrict flows, potentially increasing downstream temperatures (Yoshiyama et al. 1998). Land-use practices and resource extraction (e.g., agricultural and forestry practices) can affect riverine habitat and alter thermal spatial structure leading to elevated temperatures and reduced cool water habitat (Torgersen et al. 1999). Climate change is expected to exacerbate these impacts (ISAB 2007; Miles et al. 2000; Stewart et al. 2004).

The abundance of cool water habitat features can vary substantially depending upon many factors including geographic location, flow characteristics and time of year. However, in certain areas with hot, dry summers (e.g., lower Sacramento River); it is likely that little, if any, suitable holding habitat exists for salmon to take refuge from elevated water temperatures (NMFS 2009a). Moreover, because climate change is expected to cause an increase in freshwater temperatures and prolonged summer drought periods (Battin et al. 2007; Mote et al. 2003; Stewart et al. 2004), these habitat types can be expected to become more rare (ISAB 2007).

The location and extent of thermal refugia are poorly understood, and maps or spatial descriptions may not reliably identify them at the project scale. As such, this HAPC relies on the detailed text that describes the general attributes of these habitats, rather than spatially explicit descriptions or maps.

2.4.3 Spawning Habitat

Spawning habitat has an extremely high ecological importance, and it is especially sensitive to stress and degradation by a number of land- and water-use activities that affect the quality, quantity and stability of spawning habitat (e.g., sediment deposition from land disturbance, streambank armoring, water withdrawals) (Independent Scientific Group 2000; Snake River Salmon Recovery Board 2006). Salmon spawning habitat is typically defined as low gradient stream reaches (<3%), containing clean gravel with low levels of fine sediment and high inter gravel flow. Many spawning areas have been well defined by historical and current spawner surveys and detailed maps exist for some HUs.

Spawning is a particularly important element of the life history of any species of fish. Adverse effects on salmon spawning habitat can be caused by natural conditions such as drought, as well as from human activities. Regardless of potential impacts, the selection of suitable habitat and successful spawning can mean the difference between a successful recruitment year and a poor one.

Spawning habitat consists of the combination of gravel, depth, flow, temperature, and dissolved oxygen, among others. Impacts to any of these factors can make the difference between a successful spawning event and failure. Several anthropogenic activities are known to impact various physical, chemical, or biological features of spawning habitat, including road construction, timber harvest, agriculture, and residential development among others.

Although there are modest differences in spawning preferences between the species, all salmon require cold, highly oxygenated, flowing water as suitable spawning habitat. Many human activities and natural occurrences can affect spawning habitat, including road building, culvert construction, forestry activities, agriculture, dams, and others. The population of the contiguous U.S. west coast grew nearly 27 percent between 1990 and 2009 (U.S. Census 2010). This represents about 10 million people who need housing, transportation, and other infrastructure. As population growth continues to spur development, stresses to salmon habitat are inevitable.

Chinook salmon spawn in a broad range of habitats. Depths can range from a few centimeters to several meters deep, and in small tributaries to large river systems (PFMC 1999). Coho salmon typically spawn in smaller tributaries than Chinook salmon, but are known to also spawn in larger rivers and occasionally lakes. Puget Sound pink salmon tend to spawn in larger rivers, but can also spawn in the lower reaches of rivers and even the intertidal zone (Quinn 2005). But as with other salmon species, pink salmon require high dissolved oxygen and adequate temperatures. Although salmon do require suitable habitat for successful spawning, such habitat is generally available and therefore not considered rare.

The location and extent of spawning habitat can vary over space and time, and not all spawning habitat is adequately mapped. Therefore maps or spatial descriptions may not reliably identify them at the project scale. As such, this HAPC relies on the detailed text that describes the general attributes of these habitats, rather than spatially explicit descriptions or maps.

2.4.4 Estuaries

Estuaries are “waters that are semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, and in which seawater is at least occasionally diluted by freshwater runoff from land” (Dethier 1990), and include nearshore areas such as bays, sounds, inlets, river mouths and deltas, pocket estuaries, and lagoons influenced by ocean and freshwater. Because of tidal cycles and freshwater runoff, salinity varies within estuaries and results in great diversity, offering freshwater, brackish and marine habitats within close proximity (Haertel and Osterberg 1967). Such areas tend to be shallow, protected, nutrient rich, and are biologically productive, providing important habitat for marine organisms, including salmon.

The inland extent of the estuary HAPC is the high water tidal level along the shoreline or the upriver extent of saltwater intrusion, defined as upstream and landward to where ocean-derived salts measure less than 0.5 parts per thousand (ppt) during the period of average annual low flow. The seaward extent is an imaginary line closing the mouth of a river, bay, or sound; and to the seaward limit of wetland emergents, shrubs, or trees occurring beyond the lines closing rivers, bays, or sounds. This HAPC also includes those estuary-influenced offshore areas of continuously diluted seawater. This definition is based on Cowardin, et al. (1979).

Estuaries are complex systems that encompass a number of habitat types in a relatively small area, including sand and gravel beaches, mudflats, tidal creeks, shallow nearshore waters, pocket estuaries, and mixing zones, that are vital to the growth and survival of salmon, primarily during their juvenile phase. These systems provide protected habitat for juvenile salmon before entering the marine environment (Macdonald et al. 1988; Miller and Sadro 2003; Blackmon et al. 2006). Juvenile salmon are thought to utilize estuaries for three distinct purposes: (1) as a rich nursery area capable of sustaining increased growth rates; (2) to gain temporary refuge from marine predators; and (3) as a physiological transition zone where juveniles can gradually acclimate to saltwater (Bottom et al. 2005). Chinook salmon are well known for utilizing natal river tidal deltas, non-natal “pocket estuaries” (nearshore lagoons and marshes), and other estuarine habitats for rearing during outmigration (Ehinger et al. 2007). In the larger, deeper estuaries of the west coast of North America (e.g., Puget Sound, Columbia River, and San Francisco Bay), the shallow nearshore habitats of estuaries are especially important to juvenile salmon. For example, in Puget Sound, pink salmon and some ocean-type Chinook salmon enter the estuary at a very small size and rear in the shallow nearshore waters (<3 m deep) until they reach 70 mm in length, when they then move offshore. These shallow waters provide access to benthic prey and protection from predators. Functional estuaries also promote a diversity of life history types in salmon populations, with variation in estuarine use and residence time of juveniles contributing to variations in the timing and size of fish at ocean entry (Bottom et al. 2005). This diversity buffers populations from extreme events in the freshwater or marine environments, and may increase resilience of populations following such disturbances (Bottom et al. 2005).

Estuaries are highly sensitive to anthropogenic activities (Johnston 1994). A number of human activities (e.g., diking, dredging and filling, shoreline armoring, stormwater and wastewater discharge, industrialization, removal of riparian vegetation and large wood), including those that occur upstream in the rivers that flow into an estuary, can reduce both the quality and quantity of estuarine habitat that is available to salmon.

Degradation and loss of these sensitive habitats has been shown to have a detrimental effect on salmon populations (Magnusson and Hilborn 2003), and much estuarine habitat has been lost along the Pacific Coast. A number of human activities (e.g., diking, dredging and filling, shoreline armoring, stormwater and wastewater discharge, industrialization, removal of riparian vegetation and large wood), including those that occur upstream in the rivers that flow into an estuary, can reduce both the quality and quantity of estuarine habitat that is available to salmon. In Puget Sound alone, more than one third of the shoreline has been armored, with significant alteration of the shallow nearshore habitat (Shipman 2009). Shipping ports are often located in estuaries because they provide protected harbors. Development of port facilities (e.g., dredging and filling, armoring, overwater structures) has resulted in extensive loss of estuarine habitats along the West Coast. Although the effects of water withdrawals and control structures are little studied (Good 2000), there is evidence that they can alter the estuarine mixing zone (Jay and Simenstad 1996). Population growth is expected to increase water withdrawals from streams, which will reduce freshwater inflow to estuaries and lead to reduced flushing capacity for wastes, changes in habitat types and distribution, and other unknown risks to these ecosystems (Good 2000). Many estuaries have been converted to agriculture and urban land uses. For example, the Duwamish River has lost more than 99 percent of its tidal delta habitat (Simenstad et al. 1982), while the Skagit River, which contains the largest tidal delta in Puget Sound, has lost 80-90 percent of its aquatic habitat area (Collins et al. 2003).

Estuaries are not especially rare, although many have been reduced in size through diking, draining, filling, dredging, and other human activities. Therefore, much of the historical estuarine habitat has been lost and much of the remaining habitat is often severely degraded.

2.4.5 Marine and Estuarine Submerged Aquatic Vegetation

Submerged aquatic vegetation includes the kelps and eelgrass. These habitats have been shown to have some of the highest primary productivity in the marine environment (Foster and Schiel 1985; Herke and Rogers 1993; Hoss and Thayer 1993) and provide a significant contribution to the marine and estuarine food webs (see reviews by Fresh 2006 and Mumford 2007).

The kelps are brown macroalgae and include those that float to form canopies and those that do not, such as *Laminaria* spp. Canopy-forming kelps of the eastern Pacific Coast are dominated by two species, giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis leutkeana*). Kelp plants, besides requiring moderate to high water movement and energy levels, are most likely limited by the availability of suitable substrate (Mumford 2007). Native eelgrass (*Zostera marina*) forms dense beds of leafy shoots year-round in the soft sediments of the lower intertidal and shallow subtidal zone, and they form a three-dimensional structure in an otherwise two-dimensional (sand or mud) environment (Mumford 2007).

These habitats provide important nurseries, feeding grounds, and shelter to a variety of fish species, including salmon (Shaffer 2002; Mumford 2007), as well as spawning substrate to Pacific herring (*Clupea pallasii*), an important prey species for all marine life stages of Pacific salmon. Juvenile salmon utilize eelgrass beds as migratory corridors as they transition to the open ocean, and the beds provide both refuge from predators and an abundant food supply (see reviews by Fresh 2006 and Mumford 2007).

Both kelp and eelgrass are highly sensitive to human activities. Stressors include those that affect the amount of light available to the plant, and the direct and indirect effects of high or low nutrient levels, toxins, and physical disturbance (Mumford 2007). Activities that produce such stressors include shoreline development (bulkheads, docks and piers, etc.), dredging, faulty septic systems, and stormwater discharge. These activities can alter shoreline erosion and sediment transport, alter depth profiles, generate turbidity plumes, and impair water quality, all of which can degrade eelgrass habitat (Fresh 2006) and, presumably, kelp habitat as well. Vessels can directly damage SAV through prop scour, groundings, and anchoring (Nightingale and Simenstad 2001). Eelgrass beds near ferry terminals are often heavily impacted by the propwash from these large vessels, and those near recreational facilities often show clear propeller damage. A number of studies (e.g., Walker et al. 1989; Hastings et al. 1995) have shown that anchor chains, especially those anchoring a mooring buoy, can scour a sizable area of seagrass when they drag across the bottom.

Short et al. (2006) noted a world-wide decline in seagrass habitats, many of which were attributable to anthropogenic activities. Development has altered a significant portion of the estuarine and marine shores along the West Coast, and is expected to increase in the future.

Although marine and estuarine SAV are not especially rare across the geographic range of Pacific Coast salmon, they can be locally rare. In Puget Sound, for example, only 11 percent of the shoreline has kelp, while up to 34 percent of the shoreline has eelgrass (Mumford 2007).

The location and size of both kelp and seagrass beds vary over space and time, and they have not been comprehensively mapped. Therefore, maps or spatial descriptions may not reliably identify them at the project scale. As such, this HAPC should rely on detailed text that describes the general attributes of these habitats, rather than spatially explicit descriptions or maps.

3. ESSENTIAL FISH HABITAT DESCRIPTIONS

The following essential habitat and life-history descriptions were developed for the three species of Pacific salmon managed under the Pacific Coast Salmon FMP: Chinook salmon, coho salmon, and Puget Sound pink salmon.

3.1 GEOGRAPHIC EXTENT OF SALMON EFH

The geographic extent of salmon freshwater EFH is described as all water bodies currently or historically occupied by Council-managed salmon within the USGS 4th field hydrologic units (HU) identified in Table 1. The extent of current salmon freshwater and estuarine distribution was determined using two online databases: Streamnet.org for distribution in Washington, Oregon, and Idaho, and Calfish.org for distribution in California. Because current data do not represent the full historical extent of salmon distribution, the online databases were supplemented with historical data identified by the Council (PFMC 1999) to identify a number of 4th field HUs that were historically, but are not currently, occupied by salmon (Table 2) and are not above the dams listed in Table 1.

Both StreamNet and Calfish are small-scale, regional databases that incorporate data from various sources. They are suitable for portraying the overall distribution of salmon and have some utility for determining presence on the majority of specific stream reaches. Various life stages (migration, spawning and rearing, and rearing only) are delimited in the distribution data as well.

As described in Chapter 1, the formation and modification of stream channels and habitats is a dynamic process. Habitat available and utilized by salmon changes frequently in response to floods, landslides, woody debris inputs, sediment delivery, and other natural events (Sullivan et al. 1987; Naiman et al. 1992; Reeves et al. 1995). To expect the distribution of salmon within a stream, watershed, province, or region to remain static over time is unrealistic. Therefore, current information on salmon distribution is useful for determining which watersheds salmon inhabit, but not necessarily for identifying specific stream reaches and habitats utilized by the species. As such, the Council used an inclusive, watershed-based description of EFH using USGS 4th field HUs. This watershed-based approach is consistent with other Pacific salmon habitat conservation and recovery efforts such as those implemented under the ESA.

In the estuarine and marine areas, salmon EFH extends from the nearshore and tidal submerged environments within state territorial waters out to the full extent of the EEZ (370.4 km) offshore of Washington, Oregon, and California north of Point Conception. Foreign waters off Canada, while still salmon habitat, are not included in salmon EFH, because they are outside United States jurisdiction. Pacific Coast salmon EFH also includes the marine areas off Alaska designated as salmon EFH by the NPFMC.

3.2 ESSENTIAL FISH HABITAT DESCRIPTION FOR CHINOOK SALMON (*Oncorhynchus tshawytscha*)

3.2.1 General Distribution and Life History

The following is an overview of Chinook salmon life-history and habitat use as a basis for identifying EFH for Chinook salmon. More comprehensive reviews of Chinook salmon life-history can be found in Allen and Hassler (1986), Nicholas and Hankin (1988), Healey (1991), Myers et al. (1998), and Quinn (2005). This description serves as a general description of Chinook salmon life-history for Washington, Oregon, Idaho, and California and is not specific to any region, stock, or population.

Chinook salmon, also called king, spring, or tyee salmon, is the least abundant and largest of the Pacific salmon (Netboy 1958). They are distinguished from other species of Pacific salmon by their large size, the small black spots on both lobes of the caudal fin, black pigment at the base of the teeth, and a large number of pyloric caeca (McPhail and Lindsey 1970). Chinook salmon follow a generalized life-history, which includes the incubation and hatching of embryos; emergence and initial rearing of juveniles in freshwater; estuarine migration and rearing, migration to oceanic habitats for extended periods of feeding and growth; and return to natal waters for completion of maturation, spawning, and death. Within this general life-history strategy, however, Chinook salmon display diverse and complex life-history patterns. Their spawning environments range from just above tidewater to over 3,200 km from the ocean, from coastal rainforest streams to arid mountain tributaries at elevations over 1,500 m (Major et al. 1978). At least 16 age categories of mature Chinook salmon have been documented, involving 3 possible freshwater ages and total ages of 2-8 years, reflecting the high variability within and among populations in freshwater, estuarine, and oceanic residency (Healey 1986; Wissmar and Simenstad 1998). Chinook salmon also demonstrate variable ocean migration patterns and timing of spawning migrations (Ricker 1972; Healey 1991; Quinn 2005).

This variation in life-history has been partially explained by separating Chinook salmon into two distinct races: stream-type and ocean-type fish (Gilbert 1912; Healey 1983). Stream-type fish have long freshwater residence as juveniles (1-2 years), migrate rapidly to oceanic habitats, and adults often enter freshwater in spring and summer, spawning far upriver in late summer or early fall. Ocean-type fish have short, highly variable freshwater residency (from a few days to several months), extensive estuarine residency, and adults show considerable geographic variation in month of freshwater entry. Within some large systems like the Columbia River, these two types show extensive genetic divergence (Waples et al. 2010). However, for other systems, there is also substantial variability, due to a combination of phenotypic plasticity and genetic selection to local conditions (Myers et al. 1998).

The natural freshwater range of the species includes large portions of the Pacific rim of North America and Asia. In North America, Chinook salmon have been occasionally reported in systems as far south as the Ventura River in California (~34° N latitude), but the southern extent of the historical distribution is highly uncertain. Chinook salmon populations extend northward along the Pacific Coast and into the Arctic Ocean as far east as Mackenzie River (McPhail and Lindsey 1970; Major et al. 1978). At present, the southern-most populations occur in the San Joaquin River, although Chinook salmon are occasionally observed in rivers south of San Francisco Bay. In Asia, natural populations of Chinook salmon have been documented from Hokkaido Island, Japan (~42° N latitude), to the Andyr River in Russia (~64° N latitude). In marine environments, Chinook salmon from Washington, Oregon, and California range widely throughout the North Pacific Ocean and the Bering Sea, as far south as the U.S./Mexico border.

The largest rivers tend to support the largest aggregate runs of Chinook salmon and have the largest individual spawning populations (Healey 1991). Major rivers near the southern and northern extremes of the range support populations of Chinook salmon comparable to those near the middle of the range. For example, in North America, the Yukon River near the north edge of the range and the Sacramento-San Joaquin River system near the south edge of the range have historically supported Chinook salmon runs comparable to those of the Columbia and Fraser rivers, which are near the center of the species range in North America (Healey 1991).

Declines in the abundance of Chinook salmon have been well documented throughout the southern portion of the range. Concern over coast-wide declines from southeastern Alaska to California was a major factor leading to the signing of the Pacific Salmon Treaty between the United States and Canada in 1985. Wild Chinook salmon populations have been extirpated from large portions of their historical range in a number of watersheds in California, Oregon, Washington, Idaho, and southern British Columbia (Nehlsen et al. 1991), and a number of Evolutionarily Significant Units (ESUs) have been listed by NMFS as at risk of extinction under the ESA (70 FR 37160; 76 FR 50448). For example, the Columbia River formerly supported the world's largest Chinook salmon run, but currently four Columbia Basin ESUs are listed as "threatened" under the ESA (Snake River spring/summer, Snake River fall, lower Columbia River and upper Willamette River Chinook salmons) and one is listed as "endangered" (upper Columbia River spring-run) (50 FR 37160). Another ESU of Chinook salmon (upper Klamath and Trinity Rivers Basin) is a candidate for listing and is undergoing a status review (76 FR 20302).

Habitat degradation is the major cause for extinction of populations; many extinctions are related to dam construction and operation (NMFS 1996; Myers et al. 1998). Urbanization, agricultural land use, water diversion, logging, and some combination of these stressors are also factors contributing to habitat degradation and the decline of Chinook salmon (Nehlson et al. 1991; Spence et al. 1996; Hoekstra et al. 2007; Holsman et al. 2012). The developments of large-scale hatchery programs have, to some degree, mitigated the decline in abundance of Chinook salmon in some areas. However, genetic and ecological interactions of hatchery and wild fish have also been identified as risk factors for wild populations (Hoekstra et al. 2007; Buhle et al. 2009), and the high harvest rates directed at hatchery fish may cause over-exploitation of co-mingled wild populations (Mundy 1997; Reisenbichler 1997). Recent increases in pinniped populations also raise concerns over the impacts of pinniped predation on the recovery of salmonids in certain situations (NMFS 1997c; Stansell et al. 2010), and southern resident orca whales appear to rely extensively on adult Chinook salmon as prey (Ford and Ellis 2006; Hanson et al. 2010; Williams et al. 2011), raising the question as to whether one listed species is effecting the status of another.

3.2.2 Relevant Trophic Information

Chinook salmon eggs, alevins, and juveniles in freshwater streams provide an important nutrient input and food source for aquatic invertebrates, other fishes including salmonids, birds, and small mammals. The carcasses of Chinook salmon adults can also be an important nutrient input in their natal watersheds, as well as providing food sources for terrestrial mammals such as bears, otters, minks, and birds such as gulls, eagles, and ravens (Cederholm et al. 1989; Bilby et al. 1996; Ben-David et al. 1997; Helfeld and Naiman 2001; Schindler et al. 2003). Because of their relatively low abundance in coastal and oceanic waters, Chinook salmon in the marine environment are typically only an incidental food item in the diet of other fishes, marine mammals, and coastal sea birds (Botkin et al. 1995; Duffy et al. 2008; Evans et al. 2012), although they are a major prey item for some orca populations (Ford and Ellis 2006; Hanson et al. 2010). Predator impacts on juvenile Chinook salmon in the open ocean may vary with climatic conditions. Emmett et al. (2006) observed greater abundances of Pacific hake and jack mackerel in onshore waters coincident with juvenile salmonids during years with a late spring transition and warmer ocean waters. Moreover, pinniped predation on migrating salmonids, both adult spawners and downstream migrating smolts, can be substantial (~2-3 percent of total run) especially at sites of restricted passage and small salmonid populations (NMFS 1997c; Stansell et al. 2010). Recent studies also show that predation by birds (e.g., gulls, terns, Stephenson et al. 2005) and non-native fish species can be substantial in the Columbia River system (Major et al. 2005; Sanderson et al. 2009). Parasites are also an overlooked source of Chinook salmon mortality (Fujiwara et al. 2011), and rates of infection may increase with water temperature (Ferguson et al. 2011).

3.2.3 Habitat and Biological Associations

An overview of major diet items by habitat and life stage for Chinook salmon is in Table 3. Table 4 summarizes Chinook salmon habitat use by life stage.

3.2.3.1 Eggs and Spawning

Chinook salmon spawning generally occurs from July to March depending primarily upon the geographic location and the specific race or population. In general, northern populations tend to spawn from July to October and southern populations from October to February. The Sacramento River supports a unique winter run Chinook salmon that spawn from March through July with peak spawning occurring in June (Myers et al. 1998). There is a general tendency for stream-type fish to spawn earlier than ocean-type fish in the central and southern parts of the species range, but the difference is generally less than one to two months in most streams. However, spawn timing may vary several months among some Chinook salmon populations in larger river systems such as the Columbia or the Sacramento (Healey 1991; Quinn 2005).

Chinook salmon fecundity and size of eggs, like that of other salmon species, is related to female size, and exhibits considerable small-scale geographic and temporal variability. Fecundity in Chinook salmon increases with latitude and ranges from 2,000-17,000 eggs per female, with females in most populations having 4,000-7,000 eggs (Healey and Heard 1984; Beacham and Murray 1993). Stream-type fish also tend to have higher fecundity than ocean-type fish, and northern populations are dominated by stream-type fish (Healey and Heard 1984).

Chinook salmon spawn in a broad range of habitats but appear to prefer pool-riffle channel types (Montgomery et al. 1999) and spawning areas with high connectivity and large size (Isaak et al. 2007). In some Columbia River tributaries with relatively warm summer water temperatures (>20° C), adult Chinook salmon require deep holding pools with riparian cover that provide cool water refugia near spawning areas (Torgersen et al. 1999). They have been known to spawn in water depths ranging from a few centimeters to several meters deep, and in small tributaries 2-3 m wide to large rivers such as the Columbia and the Sacramento (Chapman 1943; Burner 1951; Vronskiy 1972; Healey 1991). Chinook salmon redds (nests) range in size from 2 to 40 m^2, occur at depths of 10-700 cm and at water velocities of 10-150 cm/s (Healey 1991). Typically, Chinook salmon redds are 5-15 m^2 and located in areas with water velocities of 40-60 cm/s. The depth of the redd is inversely related to water velocity, and the female buries her eggs in clean gravel or cobble 10-80 cm in depth (Healey 1991). Because of their large size, Chinook salmon are able to spawn in higher water velocities and utilize coarser substrates than other salmon species. Female Chinook salmon select areas of the spawning stream with high subgravel flow such as pool tailouts, runs, and riffles (Vronskiy 1972; Burger et al. 1985; Healey 1991). Chinook salmon egg to fry survival can range from 0 to as high as 80 percent depending upon the quality of spawning habitat including factors such as levels of fine sediment, depth of scour, and dissolved oxygen (Healey 1991; Johnson et al. 2012). For example, egg survival is negatively related fine sediment (<0.85 mm) levels in spawning gravels, with models based on empirical data suggesting that every 1 percent increase in fine sediment in spawning gravels leads to a 10 to 15 percent reduction in egg to fry survival (Jensen et al. 2009). Parental effects may explain a significant source of variation in egg-to-fry survival in systems with low fine sediment loads (Johnson et al. 2012). Because their eggs are the largest of the Pacific salmon, ranging from 6 to 9 mm in diameter (Rounsefell 1957; Nicholas and Hankin 1988), with a correspondingly small surface-to-volume ratio, they may be more sensitive to reduced oxygen levels and require a higher rate of irrigation than other salmonids. Fertilization of the eggs occurs simultaneous with deposition. Males compete for spawning females. Chinook salmon females have been reported to remain on their redds from 6 to 25 days after spawning (Neilson and Geen 1981; Neilson and Banford 1983), defending the area from superimposition of eggs from another female. This period of redd protection roughly coincides with the period the eggs are most sensitive to physical shock.

3.2.3.2 Larvae/Alevins

Fertilized eggs begin their two- to-eight month (typically three- to-four month) period of embryonic development and growth in intragravel interstices. The length of the incubation period is primarily determined by water temperature, dissolved oxygen concentrations, and egg size. To survive successfully, the eggs, alevins, and pre-emergent fry must first be protected from freezing, desiccation, stream bed scouring or shifting, sediment inputs and predators. Water surrounding them must be non-toxic, and of sufficient quality and quantity to provide basic requirements of suitable temperatures, adequate supply of oxygen, and removal of waste materials. Rates of egg development, survival, size of hatched alevins and percentage of deformed fry are related to temperature and oxygen levels during incubation. Under natural conditions, 30 percent or less of the eggs survive to emerge from the gravel as fry (Healey 1991) though a recent study using egg boxes showed Chinook salmon egg-to-fry survival ranged from 60-87 percent in the

Yakima River tributaries (Johnson et al. 2012).

3.2.3.3 Juveniles (Freshwater)

Chinook salmon fry are typically 33-36 mm in length when they emerge, though there is considerable variation among populations and size at emergence is determined in part by egg size. Juvenile residence in freshwater and size and timing of seawater migration are highly variable. Ocean-type fish can migrate seaward immediately after yolk absorption, but most migrate 30-90 days after emergence. At the higher end of the residence period, juveniles move seaward as fingerlings in the summer or fall of their first year (Reimers 1973). In less-productive or cold water systems, juveniles often overwinter and migrate as yearling or two-year old fish (Taylor 1990a; 1990b). The proportion of fingerling and yearling migrants within a population may vary significantly among years (Roni 1992; Myers et al. 1998) and hydrology (Beechie et al. 2006).

In contrast, stream-type fish generally spend at least one year in freshwater before emigrating to sea. Alaskan fish are predominantly stream-type, while Chinook salmon from northern British Columbia are approximately half stream-type and half ocean-type (Taylor 1990a; Healey 1991). Ocean-type life histories are most common in central and southern British Columbia, Washington, Oregon, and California, with the exception of populations inhabiting the upper reaches of large river basins such as the Fraser, Columbia, Snake, Sacramento, and to a lesser extent the Klamath. Within a region, hydrologic regime may determine the relative proportion of stream and ocean-type fish. For example, in the Puget Sound region tributaries with snowmelt-dominated hydrographs had a higher proportion of the stream-type life-history; however, salmon have lost access to many of these tributaries because of habitat fragmentation (Beechie et al. 2006).

Water quality, habitat quality and quantity, and prey availability determine the productivity of a watershed for Chinook salmon. Both stream- and ocean-type fish utilize a wide variety of habitats during their freshwater residency, and are dependent on the quality of the entire watershed, from headwater to estuary. Juvenile Chinook salmon inhabit primarily pools and stream margins, particularly undercut banks, behind woody debris accumulations, and other areas with cover and reduced water velocity while maintaining access to locations of high prey availability (Lister and Genoe 1970; Bjornn and Reiser 1991; Sommer et al. 2001). Although their habitat preferences are similar to coho salmon, Chinook salmon prefer slightly deeper (15-120 cm) and higher velocity (0-38 cm/s) areas than coho salmon (Bjornn and Reiser 1991; Healey 1991). The stream or river must provide adequate summer and winter rearing habitat, and migration corridors from spawning and rearing areas to the sea. Stream-type juveniles are more dependent on freshwater ecosystems, because of their extended residence in these areas. The length of freshwater residence and growth conditions is determined partially by water temperature and food resources. Spring-type Chinook salmon in particular use off-channel habitats such as wetlands, side-channels, sloughs and other floodplain habitat (Sommer et al. 2001). Recent evidence suggests juvenile Chinook salmon rearing in these areas have much higher growth than those rearing in mainstem areas (Jeffres et al. 2008; Bellmore et al. 2013).

Growth rates during the period of initial freshwater residency depend on the quality (i.e., habitat complexity prey availability, water temperature, and density of competitors) of habitats occupied by the fish. Growth rates between 0.21 mm/d and 0.62 mm/d have been reported for ocean-type fish and between 0.09 mm/d and 0.33 mm/d for stream-type fish (Kjelson et al. 1982; Healey 1991; Rich 1920; Mains and Smith 1964; Meeh and Siniff 1962; Loftus and Lenon 1977). For ocean-type fish, growth rates in estuarine habitats are generally much higher than they are in riverine or stream habitats, most likely due to a higher abundance of prey.

The foraging ecology of juvenile Chinook salmon is dependent on a variety of factors including time of year, body size, stream and riparian conditions, density and composition of fish community. Juvenile Chinook salmon are generally opportunistic predators that consume prey based on availability though they can exhibit selectivity as well (Macneale et al. 2009). In freshwater systems, they consume aquatic and terrestrial insects (larvae/nymphs and adult life stages) with major prey items (by number and biomass) including Chironomidae and Ephemeroptera (Merz 2001; Macneale et al. 2009; Sanderson et al. in prep).

3.2.3.4 Juvenile (Estuarine)

Although both stream- and ocean-type Chinook salmon may reside in estuaries, stream-type Chinook salmon generally spend a very brief period in the lower estuary before moving into coastal waters and the open ocean (Healey 1980; 1982; 1983; Levy and Northcote 1981; Beamer et al. 2005; Jacobson et al. 2012). In contrast, ocean-type Chinook salmon typically reside in estuaries for several months before entering coastal waters of higher salinity (Healey 1980; 1982; Congleton et al. 1981; Levy and Northcote 1981; Kjelson et al. 1982; Beamer et al. 2005; Bottom et al. 2005). Wild juvenile Chinook salmon show more protracted seasonal presence in estuarine and nearshore habitats than hatchery fish (Levings et al. 1986; Beamer et al. 2005; Rice et al. 2011) and disproportionately high use of shallow fringing delta habitats compared to hatchery fish (Beamer et al. 2005). Historical populations of outmigrant Chinook salmon showed greater life-history diversity and more extensive seasonal presence than contemporary populations (Burke 2004; Bottom et al. 2005).

Ocean-type Chinook salmon typically begin their estuarine residence as fry immediately after emergence or as fingerling after spending several months in freshwater. Fry generally enter the upper reaches of estuaries in late winter or early spring, beginning in January at the southern end of their range in the Sacramento-San Joaquin Delta, to February in Puget Sound (Beamer et al. 2005), and April farther north, such as in the Fraser River Delta (Sasaki 1966; Dunford 1975; Levy et al. 1979; Healey 1980; 1982; Gordon and Levings 1984). In contrast, Chinook salmon fingerling typically enter estuarine habitats in May, June, and July (April through June in the Sacramento), or approximately as the earlier timed fry are emigrating to higher salinity marine waters. Regardless of time of entrance, juvenile ocean-type Chinook salmon spend from one to three months in estuarine habitats (Rich 1920; Reimers 1973; Myers 1980; Kjelson et al. 1982; Levy and Northcote 1981; Healey 1980; 1982; Levings 1982; Bottom et al. 2005; Jacobson et al. 2012).

Chinook salmon fry prefer protected estuarine habitats with lower salinity, moving from the edges of marshes during high tide to protected tidal channels and creeks during low tide, although they venture into less-protected areas at night (Healey 1980; 1982; Levy and Northcote 1981; 1982; Kjelson et al. 1982; Levings 1982). As the fish grow larger, they are increasingly found in higher-salinity waters and increasingly utilize less-protected habitats, including delta fronts or the edges of the estuary before finally dispersing into marine habitats (Beamer et al. 2005). In contrast to fry, Chinook salmon fingerling, with their larger size, immediately take up residence in deeper-water estuarine habitats (Everest and Chapman 1972; Healey 1991).

The Chinook salmon diet during estuarine residence is highly variable and is particularly dependent upon the fish size, as well as the particular estuary, year, season, and prey abundance (Brodeur 1991; Schabetsberger et al. 2003; Brennan et al. 2004; Sweeting et al. 2007; Bollens et al. 2010; Duffy et al. 2010). In general, Chinook salmon are opportunistic feeders, consuming larval and adult insects, polychaetes, copepods, mysid shrimp, and amphipods when they first enter estuaries, with increasing dependence on larval and juvenile fish (including other salmonids) as they grow larger (Brennan et al. 2004; Duffy 2010). Preferred diet items for Chinook salmon include aquatic and terrestrial insects such as psocoptera, chironomid larvae and other dipterans, cladoceans such as *Daphnia*, amphipods including *Eogammarus* and *Corophium*, and other crustacea such as *Neomysis*, crab larvae, and cumaceans (Sasaki 1966; Dunford 1975; Birtwell 1978; Levy et al. 1979; Northcote et al. 1979; Healey 1980; 1982; Kjelson et al. 1982; Levy and Northcote 1981; Levings 1982; Gordon and Levings 1984; Myers 1980; Reimers 1973; Brennan 2004; Sweeting et al. 2007; Duffy et al. 2010). Larger juvenile Chinook salmon consume juvenile fishes such as herring *(Clupeidae)*, anchovy *(Engraulidae)*, smelt *(Osmeridae)*, sandlance

(Ammodytidae) and stickleback *(Gasterosteidae)*.

Growth in estuaries is quite rapid and Chinook salmon may enter the upper reaches of estuarine environments as 35-40 mm fry, and leave as 70-110 mm smolts (Rich 1920; Levy and Northcote 1981; 1982; Reimers 1973; Healey 1980). Growth rates during this period are difficult to estimate because small individuals are continually entering the estuary from upstream, while larger individuals depart for marine waters. Reported growth for populations range from 0.22 mm/d to 0.86 mm/d, and is as high as 1.32 mm/d for groups of marked fish (Rich 1920; Levy and Northcote 1981; 1982; Reimers 1973; Healey 1980; Kjelson et al. 1982; Healey 1991; Levings et al. 1986).

3.2.3.5 Juveniles (Marine)

After leaving the freshwater and estuarine environment, juvenile Chinook salmon disperse to marine feeding areas. Ocean-type fish, which have a longer estuarine residence, tend to be coastal oriented, preferring protected waters and waters along the continental shelf (Healey 1983). In contrast, stream-type fish pass quickly through estuaries, are highly migratory, and may migrate great distances into the open ocean. In addition, a subset of Chinook salmon populations ("blackmouth") throughout Puget Sound and the Strait of Georgia remain within the protected waters of the Salish Sea to feed before returning to their natal systems as adults (Pressey 1953; Chamberlin et al. 2011).

Chinook salmon typically remain at sea for one to six years. They have been found in oceanic waters at temperatures ranging from 1-15 ºC, although few Chinook salmon are found in waters below 5° C (Major et al. 1978). They do not concentrate at the surface as do other Pacific salmon, but are most abundant at depths of 30-70 m and often associated with bottom topography (Taylor 1969; Argue 1970). However, during their first several months at sea, juvenile Chinook salmon < 130 mm are predominantly found at depths less than 37 m (Fisher and Pearcy 1995). Because of their distribution in the water column, the majority of Chinook salmon harvested in commercial troll fisheries are caught at depths of 30 m or greater.

Chinook salmon range widely throughout the North Pacific Ocean and the Bering Sea, occurring as far south as the U.S./Mexico border (Godfrey 1968; Major et al. 1978). Chinook salmon from California, Oregon, Washington, and Idaho have been recovered in coastal areas throughout the Strait of Georgia and Inland Passage, along the Alaskan coast into Cook Inlet and waters surrounding Kodiak Island, extending out into the Aleutian/Rat Island chains to 180° W longitude, and northward in the Bering Sea to the Pribilof Islands (Hart and Dell 1986; Myers et al. 1996).

Chinook salmon may stay in coastal waters or may migrate into offshore oceanic habitats. Migration from coastal to more oceanic waters may begin off the coast of Vancouver Island, or may be delayed until reaching as far as Kodiak Island (Hartt and Dell 1986). Limited tag release and recovery data have found Washington origin Chinook salmon in the Emperor Sea Mounts area, at ~44° N latitude and 175° W longitude (Myers et al. 1996). Based on high seas tagging data presented in Myers et al. (1996) and Hartt and Dell (1986), the oceanic distribution of Pacific Northwest Chinook salmon appears to include the Pacific Ocean and Gulf of Alaska north of ~44° N latitude and east of 180° W longitude, including some areas of the Bering Sea.

The coastal distribution of Chinook salmon is similar to coho salmon (Hartt and Dell 1986), with high concentrations in areas of pronounced coastal upwelling. Juvenile Chinook salmon are generally found within 55 km of the Washington, Oregon, and California coast, with the vast majority of fish found less than 28 km offshore (Pearcy and Fisher 1990; Fisher and Pearcy 1995). Winans et al. (2001) reported on adult Chinook salmon captured in the region between Point Mugu and Point Lopez, California, demonstrating that this species occurs, at least occasionally, as far south as Ventura, California. Point Conception (34° 30' N latitude), California, is considered the faunal break for marine fishes, with salmon and other temperate water fishes found north and subtropical fishes found south of this point (Allen and

Smith 1988). Therefore, the historical southern edge of the marine distribution appears to be near Point Conception, California, and expands and contracts seasonally and between years depending on ocean temperature patterns and upwelling.

Ocean migration patterns are influenced by both genetics and environmental factors (Healey 1991). Migratory patterns in the ocean may have evolved as a balance between the benefits of accessing specific feeding grounds and the energy expenditure and dispersion risks (i.e., predation) necessary to reach them. Along the eastern Pacific Rim, Chinook salmon originating north of Cape Blanco on the Oregon coast tend to migrate north towards and into the Gulf of Alaska, while those originating south of Cape Blanco migrate south and west into waters off Oregon and California (Godfrey 1968; Major et al. 1978; Cleaver 1969; Wahle and Vreeland 1977; Wahle et al. 1981; Healey and Groot 1987).

While the marine distribution of Chinook salmon can be highly variable within and among populations, migration and ocean distribution patterns show similarities among some geographic areas. For example, Chinook salmon that spawn in rivers south of the Rogue River in Oregon disperse and rear in marine waters off the Oregon and California coast, while those spawning north of the Rogue River migrate north and west along the Pacific coast (Godfrey 1968; Major et al. 1978; Cleaver 1969; Wahle and Vreeland 1977; Wahle et al. 1981; Healey and Groot 1987). In Puget Sound, up to 30 percent of hatchery releases remain as “residents” but it is unknown how common this migratory variation is in wild fish, though their presence clearly pre-dates significant hatchery input into the region (Pressey 1953; O’Neill and West 2009; Chamberlin et al. 2011). These migration patterns result in the harvest of fish from Oregon, Washington, and British Columbia within the EEZ off the Alaskan coast.

Chinook salmon are the most piscivorous of the Pacific salmon, and the proportion of fish in the diet increases with size (Brodeur 1991; Schabetsberger et al. 2003; Sweeting et al. 2007; Duffy et al. 2010). Accordingly, fishes make up the largest component of their diet at sea, although squids, pelagic amphipods, copepods, euphausiids, and insects are also important at times (Merkel 1957; Prakash 1962; Ito 1964; Hart 1973; Healey 1991; Brodeur et al. 1991; Schabetsberger et al. 2003).

3.2.3.6 Adults

Throughout their range, adult Chinook salmon enter freshwater during almost any month of the year, although there are generally one to three peaks of migratory activity in most areas. In northern areas, Chinook salmon river entry peaks in June, while in rivers such as the Fraser and Columbia, Chinook salmon enter freshwater between March and November, with peaks in spring (March through May), summer (May through July), and fall (August through September). The Sacramento River has a winter-run population that enters freshwater between December and July, in addition to spring, fall, and late-fall runs.

Chinook salmon exhibit a wide array of life histories that vary in freshwater, estuarine and ocean residence (Wissmar and Simenstad 1998). They become sexually mature at a wide range of ages from two to eight years, with “jacks" or precocious males maturing after one to two years. Within the Columbia River, “minijacks” – precocious males that migrate only to the lower river but do not leave freshwater – also exist for systems associated with large production hatcheries (Beckman and Larsen 2005). Overall, the most common age of ocean- and stream-type maturing adults is three to five years, with males tending to be slightly younger than females. In general, stream-type fish have a longer generation time than do ocean-type fish, presumably owning to their longer freshwater residence, and Chinook salmon from Alaska and more northern latitudes typically mature a year or more later than their southern counterparts (Roni and Quinn 1995; Myers et al. 1998).

The size and age of adults varies considerably among populations and years and is influenced by genetic and environmental factors, as well as by fishing pressure. Adult Chinook salmon size is thought to represent adaptation to local spawning environment (Ricker 1980; Healey 1991; Roni and Quinn 1995). Most adult Chinook salmon females are 65-85 cm in length, while the slightly younger males are 50-85 cm. However, male and female fish larger than 100 cm in length are not uncommon in many populations.

A variety of factors influence the foraging ecology of adult Chinook salmon including migration patterns, ocean conditions (e.g., El Niño events), and density of other salmon species. They primarily consume fish in the open ocean including cottids, anchovies, clupeids, and sand lance, as well as squid and euphausiids (Kaeriyama et al. 2004; Daly et al. 2009). Chinook salmon show a positive relationship between fork length and the relative proportion of fish in the diet; at > 376 mm in fork length fish make up 90 percent (by weight) of their stomach contents (Daly et al. 2009). Recent studies indicate that the relative importance of some prey items may change with climatic events, such as El Niño events. During the 1997 El Niño and 1999 La Niña events, squid consumption by adult Chinook salmon decreased sharply. Based on $\delta^{15}N$ levels, studies show that adult Chinook salmon feed at a higher trophic level than other salmon species except coho salmon and they likely feed extensively on coastal food webs based on enriched $\delta^{13}C$ levels (Johnson and Schindler 2009).

During upriver migrations prior to spawning, adult Chinook salmon often hold in large, deep, low velocity pools, with abundant LWD or other cover features. These areas may serve as a refuge from high river temperatures, predators, or a refuge to reduce metabolic demands and reserve energy until spawning commences (Berman and Quinn 1991; Torgersen et al. 1999). The spawning densities of Chinook salmon and coho salmon have been correlated with a number of factors including channel type, LWD, pool frequency, and habitat connectivity and area (Montgomery et al. 1999; Isaak et al. 2007).

The survival of Chinook salmon is affected by factors including run type (i.e., spring, summer, fall), freshwater migration length, ocean conditions, and predator abundance. Hatchery spring and summer Chinook salmon have smolt-to-adult survival rates that average 1 percent, although survival of many upper Columbia and Snake River basin hatchery stocks is typically less than 0.2 percent (Coronado-Hernandez 1995). Wild stocks from these areas are thought to have ocean survival rates 2-10 times greater than hatchery fish (Coronado-Hernandez 1995). Fall Chinook salmon hatchery stocks also survive from smolt to adult at approximately 1 percent, although fish from some areas, such as the Oregon coast, are consistently higher, but typically less than 5 percent (Coronado-Hernandez 1995).

3.2.3.7 Freshwater Essential Fish Habitat

Freshwater EFH for Chinook salmon consists of four major components, (1) spawning and incubation; (2) juvenile rearing; (3) juvenile migration corridors; and (4) adult migration corridors and holding habitat. Freshwater EFH depends on lateral (e.g., floodplain, riparian), vertical (e.g., hyporheic) and longitudinal connectivity to create habitat conditions for spawning, rearing, and migration including: (1) water quality (e.g., dissolved oxygen, nutrients, temperature, etc.); (2) water quantity, depth, and velocity; (3) riparian-stream-marine energy exchanges; (4) channel gradient and stability; (5) prey availability; (6) cover and habitat complexity (e.g., LWD, pools, aquatic and terrestrial vegetation, etc.); (7) space; (8) habitat connectivity from headwaters to the ocean (e.g., dispersal corridors); (9) groundwater-stream interactions; and (10) substrate composition. This incorporates, but is not limited to, life-stage specific habitat criteria summarized in Table 4.

Chinook salmon EFH includes all habitat currently or historically occupied within Washington, Oregon, Idaho, and California. Figure 2 illustrates the 4th field HUs designated as EFH for Chinook salmon in Washington, Oregon, and Idaho and Figure 3 illustrates the 4th field HUs designated as EFH in California within the USGS 4th field HUs identified in Table 1.

The diversity of habitats utilized by Chinook salmon makes it difficult to identify all specific stream reaches, wetlands, and water bodies essential for the species at this time. Defining specific river reaches is also complicated, because of the current low abundance of the species and our imperfect understanding of the species' freshwater distribution, both current and historical. Adopting a more inclusive, watershed-based description of EFH is appropriate, because it (1) recognizes the species' use of diverse habitats and underscores the need to account for all of the habitat types supporting the species' freshwater and estuarine life stages, from small headwater streams to migration corridors and estuarine rearing areas; (2) takes into account the natural variability in habitat quality and use (e.g., some streams may have fish present only in years with plentiful rainfall) that makes precise mapping difficult; and (3) reinforces the important linkage between aquatic areas and adjacent upslope areas. Therefore, the geographic extent of Chinook salmon essential habitat was delineated using USGS cataloging unit boundaries.

3.2.3.8 Marine Essential Fish Habitat

The important elements of Chinook salmon marine EFH are (1) estuarine rearing; (2) ocean rearing; and (3) juvenile and adult migration. Important features of this estuarine and marine habitat are (1) good water quality; (2) cool water temperatures; (3) abundant prey species and forage base (food); (4) connectivity with terrestrial ecosystems; and (4) adequate depth and habitat complexity including marine vegetation and algae in estuarine and near-shore habitats. The available information on the habitat needs for each life-history stage is summarized in Table 4. Overall Chinook salmon marine distribution is extensive, varies seasonally, interannually, and can be identified in general terms only.

Limited information exists on Chinook salmon habitat use in marine waters but recent efforts are expanding our understanding of their marine ecology (Johnson and Schindler 2009; Jacobson et al. 2012). Chinook salmon are found throughout the North Pacific and have been encountered in waters far offshore. Available research (Pearcy and Fisher 1990; Fisher and Pearcy 1995), suggests that ocean-type juvenile Chinook salmon are found in highest concentrations over the continental shelf. However, Fisher et al. (1983; 1984) found no clear evidence that young Chinook salmon were more abundant close to the coast. Ocean-type juvenile Chinook salmon appear to utilize different marine areas for rearing than stream-type juvenile Chinook salmon which are believed to migrate to ocean waters further offshore early in their ocean residence (Healey 1991). CWT recoveries of Chinook salmon from high-seas fisheries and tagging programs (Myers et al. 1996; Healey 1991; Fig.18) provide evidence that Chinook salmon utilize areas outside the continental shelf. Catch data and interviews with commercial fishermen indicate that maturing Chinook salmon are found in highest concentrations along the continental shelf within 60 km of the Washington, Oregon, and California coast lines. Recent ocean surveys indicate that different Chinook salmon stocks occupy different habitats in the coastal ocean (Jacobson et al. 2012). For example, Columbia River fall-run Chinook salmon are commonly found in the near-shore areas from the intertidal to within a few kilometers off shore. Spring-run Chinook salmon are most often found from the near-shore zone to mid-shelf waters. Based on natural abundance levels of ^{13}C and ^{15}N, Johnson and Schindler (2009) suggested that Chinook salmon fed mostly on coastal food webs (i.e., benthic vs. pelagic based).

Many stream-type Chinook salmon populations do not appear to be as heavily exploited as ocean-type Chinook salmon, indicating that stream-type fish may be vulnerable to coastal fisheries for only a short time during their spawning migrations (Healey 1991). Determination of a specific or uniform westward boundary within the EEZ which covers the distribution of essential marine habitat is difficult and would contain considerable uncertainty. Therefore, the geographic extent of essential marine habitat for Chinook salmon includes all marine waters within the EEZ north of Point Conception, California (Figure 1) and the marine areas off Alaska designated as salmon EFH by the NPFMC.

3.3 ESSENTIAL FISH HABITAT DESCRIPTION FOR COHO SALMON *(Oncorhynchus kisutch)*

3.3.1 General Distribution and Life History

The following is an overview of coho salmon life-history and habitat use as a basis for identifying EFH for coho salmon. Comprehensive reviews of coho salmon life-history and habitat requirements can be found in Shapovalov and Taft (1954), Sandercock (1991), Weitkamp et al. (1995), Quinn (2005) and others. This description serves as a general description of coho salmon life-history for Washington, Oregon, and California, and is not specific to any region, stock, or population.

Coho salmon or "silver" salmon are a commercially and recreationally important species found in small streams and rivers throughout much of the Pacific Rim, from central California to Korea and northern Hokkaido, Japan (Godfrey 1965; Scott and Crossman 1973). They are distinguished from other Pacific salmon by the presence of irregular black spots confined to the back and the upper lobe of the caudal fin, and bright red sides and a bright green back and head when sexually mature (Godfrey 1965; Scott and Crossman 1973). Coho salmon spawn in freshwater streams and most juveniles rear in freshwater for one year and spend about 18 months at sea before reaching maturity as adults. However, there is increasing evidence that some coho salmon fry and parr may rear in estuarine environments in summer and fall before returning to freshwater habitats to overwinter (Miller and Sadro 2003; Koski 2009). Moreover, recent studies of streams without estuaries that flow directly into near-shore areas have found that some juveniles emigrate directly to sea in the fall at age-0 and that some of these do survive to return as adults (Bennett et al. 2011; Roni et al. 2012). Other age 0 coho salmon appear to briefly enter the estuarine environment before entering other nearby streams to overwinter (Koski 2009; Roni et al. 2012). This suggests that the juvenile coho salmon life-history is much more complex than previously thought. Precocious male coho salmon or “jacks” become sexually mature after only 6 months at sea, one year earlier than typical adult fish. Most coho salmon populations south of central British Columbia consist of two-year-old jacks and three-year-old adults, while populations north of central British Columbia have two or three-year-old jacks and three or four-year-old adults (Gilbert 1912; Pritchard 1940; Shapovalov and Taft 1954; Wright 1970; Godfrey et al. 1975; Crone and Bond 1976). The older age at maturity of more northern populations is a product of the juveniles spending two years in freshwater as opposed to one year residence of more southern populations.

Unlike some other Pacific salmon species, where the majority of production comes from large spawning populations in a few river basins, coho salmon production results from spawners using numerous small streams (Sandercock 1991). North American coho salmon populations are widely distributed along the Pacific coast and historically spawned in tributaries to most coastal streams and rivers from the southern Santa Cruz Mountains, California, to Point Hope, Alaska, and through the Aleutian Islands (Godfrey 1965; Sandercock 1991; Spence et al. 2011). The species is most abundant in coastal areas from central Oregon through southeast Alaska and widely distributed throughout the North Pacific (Manzer et al. 1965; French et al. 1975; Godfrey et al. 1975).

In Alaska, coho salmon catches have recently achieved historically high levels, and trends in abundance of most stocks are stable (Baker et al. 1996; Slaney et al. 1996; Northcote and Atagi 1997; Wertheimer 1997). However, many coho salmon populations in southern British Columbia, Washington, Oregon, and California are depressed from historical levels with stocks at the southern-most end of the range generally at greatest risk of extinction (Nehlsen et al. 1991; Nelson 1993; 1994; Brown et al. 1994; Bryant 1994; Good et al. 2005; Spence and Williams 2011). Some stocks, particularly those in the Columbia River Basin above Bonneville Dam (*e.g.*, Idaho coho salmon stocks), are thought to be extinct (Nehlsen et al. 1991). All coastal stocks of coho salmon from the lower Columbia River to the southern extent of their range in Central California are listed as either "threatened" or “endangered” species under the ESA (70 FR 37160; 76 FR 50448), while coho salmon in Puget Sound and the Strait of Georgia are considered by NMFS to be a species of concern (NMFS 2009).

Hatchery production of coho salmon is extensive in southern British Columbia, Washington, Oregon, and California, and is used to provide sport and commercial harvest opportunities (Bledsoe et al. 1989). The Columbia River is the world's largest producer of hatchery coho salmon, with over 50 million fry and smolts released annually in recent years, followed closely by Puget Sound (Flagg et al. 1995; Weitkamp et al. 1995). In contrast, most production of coho salmon from northern British Columbia and Alaska is natural, with minimal hatchery influence (Baker et al. 1996; Slaney et al. 1996). Coho salmon are also used in net-pen cultures in Washington and British Columbia, and attempts to establish coho salmon runs in other areas of the world have met with limited success (Sandercock 1991). On the Oregon coast, hatchery coho salmon negatively influence survival of wild stocks (Buhle et al. 2009).

3.3.2 Relevant Trophic Information

Coho salmon (both live and carcasses) provide important food for bald eagles and other avian scavengers, and terrestrial, plants, invertebrates and mammals (e.g., bear, river otter, raccoon, weasels), aquatic invertebrates and fish, marine mammals (e.g., California and Steller sea lion, harbor seal, and orca), and salmon sharks (Scott and Crossman 1973; Cederholm et al. 1989). Carcasses also transfer essential nutrients from marine to freshwater and terrestrial environments (Bilby et al. 1996). Eggs, larvae, and alevins are consumed by various fishes, including juvenile steelhead, coho salmon, and cutthroat trout. Juveniles are eaten by a variety of birds (e.g., gulls, terns, kingfishers, cormorants, mergansers, herons), fish (e.g., Dolly Varden, steelhead, cutthroat trout, sculpins, and arctic char), and mammals (e.g., mink and water shrew) (Shapovalov and Taft 1954; Chapman 1965; Godfrey 1965; Scott and Crossman 1973; Frechette et al. 2012). Pinniped predation on migrating salmonids, both adult spawners and downstream migrating smolts, can be substantial especially at sites of restricted passage and small salmonid populations (NMFS 1997c; Stansell et al. 2010). Juvenile coho salmon are also predators of pink salmon, sockeye, and Chinook salmon fry and may be cannibalistic on the succeeding year's eggs and alevins (Gribanov 1948; Shapovalov and Taft 1954; Scott and Crossman 1973; Beacham 1986; Bilby et al. 1996).

3.3.3 Habitat and Biological Associations

An overview of major diet items by habitat and life stage for coho salmon is in Table 3. Table 5 summarizes coho salmon habitat use by life stage.

Coho salmon can exhibit substantial movement at each stage of their life and are dependent on high-quality spawning, rearing, and migration habitat. Water depth, water velocity, water quality, cover, and lack of physical obstruction are important elements in all migration habitats. Soon after emergence in spring, fry move from spawning areas to rearing areas. In fall, juveniles may move from summer rearing areas to areas with suitable winter habitat (Sumner 1953; Skeesick 1970; Swales et al. 1988). Such juvenile movements may be extensive within the natal stream basin, or, less frequently, fish may move between basins through salt water or connecting estuaries (Koski 2009; Roni et al. 2012). As noted previously, in some populations some fry and parr may overwinter in the estuarine environment or migrate directly to marine environment to overwinter. Seaward migration of coho salmon smolts in Washington, Oregon, and California occurs predominantly after one year in fresh water, but may not occur until two or more years in more northern or less productive environments. This migration is primarily triggered by photoperiod and usually coincides with spring freshet (Shapovalov and Taft 1954; Chapman 1962; Crone and Bond 1976; Quinn 2005). During this transition, coho salmon undergo major physiological changes to enable them to osmoregulate in salt water and are especially sensitive to environmental stress at that time. Although migration patterns at sea differ considerably by province and stock, juvenile coho salmon generally migrate north or south in coastal waters and may move north and offshore into the North Pacific Ocean (Loeffel and Forster 1970; Hartt 1980; Miller et al. 1983; Pearcy and Fisher 1988; Jacobson et al. 2012). After 12 to 14 months at sea they migrate along the coast to their natal streams.

3.3.3.1 Eggs and spawning

Most coho salmon spawn between November and January, with occasional individuals in certain populations spawning as late as March (Godfrey et al. 1965; Sandercock 1991; Weitkamp et al. 1995). Populations spawning in the northern portion of the species range or at higher elevations generally spawn earlier than those at lower elevations or in the southern portion of the range (Godfrey et al. 1965; Sandercock 1991; Weitkamp et al. 1995). Spawn timing also exhibits considerable small-scale geographical and interannual variability.

In general, coho salmon select sites in coarse gravel where the gradient increases and the currents are moderate, such as pool tailouts and riffles (e.g., Mull 2005). In these areas, intergravel flow must be sufficient for adequate dissolved oxygen delivery to eggs and alevins. Coho salmon typically spawn in small streams where flows are 0.3-0.5 m^3/s, although they also spawn in large rivers and lakes (Burner 1951; Bjornn and Reiser 1991). Coho salmon spawning habitat consist primarily of coarse gravel with a few large cobbles, a mixture of sand, and a small amount of silt. High quality spawning grounds of coho salmon can best be summarized as clean, coarse gravel. Typically, redd (nest) size is 1.5 $m^{2;}$ constructed in relatively silt-free gravels ranging from 0.2 to 10 cm in diameter, with well-oxygenated intragravel flow and nearby cover (Burner 1951; Willis 1954; Bjornn and Reiser 1991; van den Berghe and Gross 1984).

Coho salmon eggs are typically 4.5-6 mm in diameter, smaller than most other Pacific salmon (Beacham and Murray 1987; Fleming and Gross 1990). The fecundity of female coho salmon is dependent on body size, population, and year, and is generally between 2,500 and 3,500 eggs (Shapovalov and Taft 1954; Beacham 1982; Fleming and Gross 1990). Several males may compete for each female, but larger males usually dominate by driving off smaller males (Holtby and Healey 1986; van den Berghe and Gross 1989). After spawning, coho salmon females remain on their redds one to three weeks before dying, defending the area from superimposition of eggs from other females (Briggs 1953; Willis 1954; Crone and Bond 1976; Fleming and Gross 1990).

3.3.3.2 Larvae/Alevins

Egg incubation time is influenced largely by water temperature and lasts from approximately 38 days at 10.7°C to 137 days at 2.2°C (Shapovalov and Taft 1954; Koski 1965; McPhail and Lindsey 1970; Fraser et al. 1983; Murray et al. 1990). Eggs, alevins, and pre-emergent fry must be protected from freezing, desiccation, stream bed scouring or shifting, fine sediment inputs and predators to survive to emergence. Water surrounding them must be non-toxic and of sufficient quality and quantity to provide basic requirements of suitable temperatures, adequate supply of oxygen, and removal of organic waste materials and fine sediment. Under natural "average" conditions, 15-27 percent of the eggs survive to emerge from the gravel as fry, although values of 85 percent survival have been reported under "optimal" conditions, and survival in degraded habitats or under harsh conditions may be essentially zero (Briggs 1953; Shapovalov and Taft 1954; Koski 1965; Crone and Bond 1976). Similar to Chinook salmon and other salmon, the levels of fine sediment in spawning gravels are negatively correlated with egg to fry survival (Jensen et al. 2009).

As the yolk sac is absorbed, the larvae become photopositive and emerge from the substrate (Shapovalov and Taft 1954; Koski 1965). Fry emerge between March and July, with most emergence occurring between March and May, depending on when the eggs were fertilized and the water temperature during development (Briggs 1953; Shapovalov and Taft 1954; Koski 1965; Crone and Bond 1976). These 30 mm-long newly emerged fry initially congregate in schools in protected, low-velocity areas such as quiet backwaters, side channels, and small creeks before venturing into protected areas with stronger currents (Shapovalov and Taft 1954; Godfrey 1965; Scrivener and Anderson 1984).

3.3.3.3 Juveniles (Freshwater)

The majority of juvenile coho salmon from California to southern British Columbia spend one year in freshwater or estuaries before migrating to sea as 85-115 mm-long smolts (Pritchard 1940; Sumner 1953; Drucker 1972; Blankenship and Tivel 1980; Seiler et al. 1981; 1984; Blankenship et al. 1983; Lenzi 1983; 1985; 1987; Irvine and Ward 1989; Lestelle and Weller 1994). Because growth rates are lower in colder water, juveniles from northerly areas require two years in fresh water to attain this size, and some individuals may need as many as four to five years to reach this size (Gribanov 1948; Drucker 1972; Crone and Bond 1976).

Coho salmon smolt production is most often limited by the availability of summer and winter freshwater rearing habitats (Williams et al. 1975; Reeves et al. 1989; Nickelson et al. 1992). Limited winter rearing habitat, such as small tributaries, backwater pools, beaver ponds, lakes, wetlands, and other off-channel rearing areas, is considered the primary factor limiting coho salmon production in many coastal streams (Cederholm and Scarlett 1981; Swales et al. 1988; Nickelson et al. 1992). If spawning escapement is adequate, sufficient fry are usually produced to exceed the carrying capacity of rearing habitat (Bradford et al. 2000). In such cases, carrying capacity of summer habitats set a density-dependent limit on the juvenile population, which then may suffer density-independent mortality during winter depending on the severity of conditions, fish size, prey availability, and quality of winter habitat.

Coastal streams, wetlands, lakes, sloughs, tributaries, estuaries, and to large rivers can all provide coho salmon rearing habitat. The most productive habitats exist in smaller streams less than fourth-order having low-gradient alluvial channels with intact riparian zones that provide abundant pools formed by LWD (Foerster and Ricker 1953; Chapman 1965) and high prey availability (Rosenfeld et al. 2005). Beaver ponds, small lakes and large slackwater areas can provide some of the best rearing areas for juvenile coho salmon (Bustard and Narver 1975; Nickelson et al. 1992; Pollock et al. 2005). Loss of beaver ponds was hypothesized to be the main cause for an estimated 89 percent and 94 percent reduction in summer and winter smolt production potential, respectively, in the Stillagamish River, WA (Pollock et al. 2005). Small ephemeral streams can also provide important winter rearing habitat for juvenile coho salmon (Ebersole et al. 2005). Coho salmon juveniles may also use brackish-water estuarine areas in summer and migrate upstream to fresh water to overwinter (Crone and Bond 1976). In addition, some age-0 coho salmon may migrate to coastal waters in fall rather than overwinter in freshwater habitats in streams that drain directly to the ocean (Bennett et al. 2011; Roni et al. 2012).

During spring-summer rearing, the highest juvenile coho salmon densities tend to occur in areas with abundant prey (e.g., drifting aquatic invertebrates and terrestrial insects that fall into the water) and structural habitat elements (e.g., LWD and associated pools, side channels). Preferred habitats primarily include slow water environments (pools, sloughs, off-channel) with cover (e.g., wood debris) but juvenile coho salmon will also use a glides and riffles with LWD, undercut banks, and overhanging vegetation, which provide advantageous positions for feeding (Foerster and Ricker 1953; Chapman 1965; Reeves et al. 1989; Bjornn and Reiser 1991). Coho salmon grow best where water temperature is between 10° and 15°C, and dissolved oxygen (DO) is near saturation. Juvenile coho salmon can tolerate temperatures between 0° and 25°C if changes are not abrupt (Brett 1952; Konecki et al. 1995; McCullough et al. 2001) and there are temporal or spatial refugia (Welsh et al. 2001; McCullough et al. 2009). Moreover, defining thermal limits for salmon under natural conditions is a challenge because these limits depend on several factors, including the duration of exposure, frequency of stressful thermal events, food availability, and fish density, to name a few. In terms of changes in DO, salmon growth and stamina decline significantly when DO levels drop below 4 mg/l, and a sustained concentration less than 2 mg/l is lethal (Reeves et al. 1989). Summer populations are usually constrained by density-dependent effects mediated through territorial behavior and prey availability. In flowing water, juvenile coho salmon usually establish individual feeding territories, whereas in lakes, large pools, and estuaries they are less likely to establish territories and may aggregate where food is abundant (Chapman 1962; McMahon 1983). Because growth in summer is often density-dependent, the size of juveniles in late summer is often inversely related to population density.

In winter, territorial behavior is diminished, and juveniles aggregate in freshwater habitats that provide cover with relatively stable depth, velocity, and water quality. Winter mortality factors include winter peak stream flow (e.g., scour, high velocities), stranding of fish during floods or by ice damming, physiological stress from low temperature, and starvation (Hartman et al. 1984). In winter, juveniles prefer a narrower range of habitats than in summer, especially large mainstream pools, backwaters, beaver ponds, off-channel ponds, sloughs, and secondary channel pools with abundant LWD, and undercut banks and debris along riffle margins (Skeesick 1970; Nickelson et al. 1992). Survival in winter, in contrast to summer, is generally density-independent, and varies directly with fish size and amount of cover and ponded water, prey availability and inversely with the magnitude of the peak stream flow. Juvenile coho salmon overwinter survival can range from 11 to 87 percent depending upon environmental factors and fish condition (Brakensiek and Hankin 2007; Roni et al. 2012). Survival from eggs to smolts is usually less than 6 percent (Neave and Wickett 1953; Bradford 1995).

Habitat requirements during seaward migration are similar to those of rearing juveniles. High streamflow potentially aids coho salmon migration by flushing them downstream and reducing their vulnerability to predators. Migrating smolts are particularly vulnerable to predation, because they are concentrated and moving through areas of reduced cover. Mortality during seaward migration can be quite high (Tytler et al. 1978; Dawley et al. 1986; Seiler 1989). The seaward migration of smolts in native stocks is thought to be timed so that the smolts arrive in the estuary and nearshore marine waters when food is plentiful (Foerster and Ricker 1953; Shapovalov and Taft 1954; Drucker 1972; Spence and Hall 2010). In California the seaward migration generally occurs prior to closing of some estuaries and tidal reaches by the formation of impassable sand bars (Bryant 1994). Rapid growth during the early period in the estuary and nearshore ocean is critical to survival, because of mortality from predation which may be size dependent (Myers and Horton 1982; Dawley et al. 1986; Pearcy and Fisher 1988; Holtby et al. 1990; Pearcy 1992; Moss et al. 2005).

Similar to juvenile Chinook salmon in freshwater, coho salmon are opportunistic predators that feed on a variety of food items depending on availability. On average, juvenile coho salmon primarily consume aquatic and terrestrial insects; most studies indicate that the dominant prey items in coho salmon stomachs are Diptera (especially Chironomidae) and Ephemeroptera (Gonzales 2006; Olegario 2006). In systems with abundant salmon populations, juvenile coho salmon obtain most of their energy needs for growth by consuming salmon eggs, but this subsidy was limited to individuals > 70 mm in length due to gape limitation (Armstrong et al. 2010).

3.3.3.4 Juveniles (Estuarine)

The amount of time juvenile coho salmon rear in estuaries appears to be highly variable, with more northern populations generally dwelling longer in estuaries than more southern populations (Pearce et al. 1982; Simenstad et al. 1982; Tschaplinksi 1982). For example, Oregon coast, Columbia River, and Puget Sound, coho salmon are thought to remain in estuarine areas for several days to nearly two months (Miller and Sadro 2003; Brennan et al, 2004; Sweeting et al. 2007), while many British Columbian, and Alaskan populations remain in estuaries for several months (Myers and Horton 1982; Pearce et al. 1982; Simenstad et al. 1982; Tschaplinksi 1982; Levings et al. 1995). Similar to the stream environment, LWD is also an important element of juvenile coho salmon habitat in estuaries (McMahon and Holtby 1992). In estuarine environments, coho salmon consume large planktonic or small nektonic animals, such as amphipods (*Corophium* spp., *Eogammarus* spp.), insects, mysids, decapod larvae, and larval and juvenile fishes (Myers and Horton 1982; Simenstad et al. 1982; Dawley et al. 1986; Brodeur 1991; Schabetsberger et al. 2003; Brennan et al, 2004; Sweeting et al. 2007; Bollens et al. 2010). They are in turn preyed upon by marine fishes, birds, and mammals. In estuaries, smolts occur in intertidal and pelagic habitats, with deep, marine-influenced habitats often preferred (Pearce et al. 1982; Dawley et al. 1986).

3.3.3.5 Juveniles (Marine)

Two primary dispersal patterns have been observed in coho salmon after emigrating from freshwater. Some juveniles spend several weeks in coastal waters before migrating northwards into offshore waters of the Pacific Ocean (Hartt 1980; Hartt and Dell 1986; Pearcy and Fisher 1988; Pearcy 1992; Jacobson et al. 2012), while others remain in coastal waters near their natal stream for at least the first summer before migrating north. The later dispersal pattern is commonly seen in coho salmon from California, Oregon, and Washington (Shapovalov and Taft 1954; Godfrey 1965; Miller et al. 1983). It is not clear whether these less-migratory fish, particularly those from coastal areas, make extensive migrations after the first summer. However, it is known that some Puget Sound/Strait of Georgia-origin coho salmon spend their entire ocean residence in the Sound and Strait, while others migrate to the open ocean in late summer (Healey 1980; Godfrey et al. 1975; Buckley 1969; Hartt and Dell 1986; Rohde et al. in review). The spatial distribution of suitable habitat conditions is affected by annual and seasonal changes in oceanographic conditions and may affect the tendency for fish to migrate from, or reside in, coastal areas after ocean entry.

Juvenile coho salmon generally stay in nearshore coastal and inland waters well into October (Hartt and Dell 1986). Juvenile coho salmon from Oregon and presumably other areas will initially be found south of their natal streams, moved by strong southerly currents (Pearcy 1992). When these currents weaken in the winter months, juvenile coho salmon migrate northward. In strong upwelling years, where the band of favorable temperatures and available prey is more extensive, coho salmon appear to be more dispersed off shore. In weak upwelling years, coho salmon concentrate in upwelling zones closer to the shore (Pearcy 1992), and often near submarine canyons and other areas of consistent upwelling (N. Bingham, Pacific Coast Federation of Fishermen’s Associations, pers. comm., February 1998). Generally, juvenile coho salmon are found in highest concentrations within 60 km of the California, Oregon, and Washington coast, with the majority found within 37 km of the coast (Pearcy and Fisher 1990; Pearcy 1992). Puget Sound origin coho salmon are typically found in the Strait of Juan de Fuca and coastal waters of Vancouver Island throughout summer months (Hartt and Dell 1986).

Coho salmon leaving Puget Sound and other inland waters are found to migrate north along the east or West Coast of Vancouver Island and out into the Pacific Ocean (Williams et al. 1975; Hartt and Dell 1986). Tag, release, and recovery studies suggest that immature coho salmon from Washington and Oregon are found as far north as 60° N latitude along the Pacific Coast, and California-origin coho salmon as far north as 58° N latitude in Southeast Alaska (Myers et al. 1996). Coho salmon from Oregon streams have been taken in offshore waters near Kodiak Island in the northern Gulf of Alaska (Hart and Dell 1986; Myers et al. 1996). Westward migration of coho salmon into offshore oceanic waters appears to extend beyond the EEZ beginning around 45° N latitude, off the Oregon coast (Myers et al. 1996). Coded-wire and high-seas tag data for Washington and Oregon suggest that oceanic migration for these coho salmon stocks can extend as far south and west as 43° N latitude and 175° E. longitude around the Emperor Sea Mounts (Myers et al. 1996), believed to be an area of high prey abundance. Thus it appears that coho salmon stocks from Washington, Oregon, and California are found at least occasionally in the Pacific Ocean and Gulf of Alaska north of 44° N latitude to 57° N latitude, extending westward and southward along the Aleutian chain to the Emperor Sea Mounts area near 43° N latitude and 175° E longitude.

While juvenile and maturing coho salmon are found in the open North Pacific, the highest concentrations appear to be found in more productive waters of the continental shelf within 60 km of the coast. Coho salmon have been occasionally reported off the coast of southern California near the Mexican border (Schofield 1937). However, Point Conception (34° 30' N latitude), California, is considered the faunal break for marine fishes, with salmon and other temperate water fishes primarily found north and subtropical fishes to the south (Allen and Smith 1988), although the southern limit expands and contracts seasonally and between years depending on ocean temperature patterns and upwelling.

Coho salmon in coastal and oceanic waters are comprised of stocks from a wide variety of streams from Washington, Oregon, and California (Godfrey et al. 1975; French et al. 1975; Burgner 1980; Hartt 1980; Hartt and Dell 1986; Weitkamp et al. 1995). Analysis of coded-wire tag (CWT) data indicates distinct migration patterns for various basins, provinces, and states. For example, coho salmon from the Columbia River make up a high proportion of fish captured in Oregon waters, whereas coho salmon from the Washington coast are rarely recovered in Oregon waters, but frequently recovered in British Columbia (Weitkamp et al. 1995). The vast majority of CWT coho salmon are recovered in coastal waters where coho salmon fisheries occur.

Coho salmon foraging ecology in marine waters is dependent on fish size, migratory patterns, density of competitors, and ocean conditions. Marine invertebrates, such as copepods, euphausiids, amphipods, and crab larvae, are the primary food when coho salmon first enter salt water (King and Beamish 2000; Weitkamp et al. 2008; Daly et al. 2009). Fish represent an increasing proportion of the diet as coho salmon grow and mature (Shapovalov and Taft 1954; Healey 1978; Myers and Horton 1982; Pearcy 1992; Sweeting et al. 2007; Weitkamp et al. 2008; Daly et al. 2009) showed that this shift to consuming mostly fish occurred at about 160 mm fork length. Growth is controlled mainly by food quantity, food quality, and temperature (e.g., Weitkamp et al. 2008). Growth is best in pelagic habitats where forage is abundant and sea surface temperature is between 12 and 15°C (Godfrey et al. 1975; Hartt 1980; Healey 1980). Coho salmon rarely use areas where sea surface temperature exceeds 15°C and are generally found in the uppermost 10 m of the water column. Coho salmon do not aggregate in offshore oceanic waters and prefer slightly warmer ocean temperatures than do other Pacific salmon (Godfrey 1965; Manzer et al. 1965; Welch 1995). Before entering fresh water, most coho salmon slow their feeding and begin to lose weight as they develop secondary sexual characteristics and large gonads. Precocious males return to spawn after approximately six months at sea, but most coho salmon remain at sea for about 16-19 months before returning to coastal areas and entering fresh water to spawn (Godfrey 1965; Wright 1968; 1970; Sandercock 1991). Marine survival of coho salmon in the California Current is strongly linked to prey and growth indicators (Beckman et al. 2004; Burke et al. 2012).

3.3.3.6 Adults

Sub-adult and adult coho salmon in marine waters consume primarily fish including capelin, northern anchovy, clupeids, and osmerids. For example, at fork lengths > 376 mm coho salmon diets are made up of about 90 percent fish (by weight). Invertebrates can also be important to adult coho salmon diets including squid, euphasiids, copepods and crabs (Kaeriyama et al. 2004; Weitkamp et al. 2008; Daly et al. 2009).

Adult coho salmon enter fresh water from early July through December, often after the onset of fall freshets, with peak river entry occurring as early as September in Alaska, in October and November in British Columbia, Washington, and Oregon, and in December and even January in California (Briggs 1953; Godfrey 1965; Ricker 1972; Fraser et al. 1983; Bryant 1994). Some populations, often referred to as the "summer-run" coho salmon, are exceptionally early, entering rivers in late spring and early summer (Aro and Shepard 1967; Houston 1983; Washington Department of Fisheries [WDF] et al. 1993). In general, larger river basins have a wider range of river entry times than do smaller systems, and river entry occurs later the farther south a river is situated (Godfrey 1965; Sandercock 1991). The fish feed little and migrate upstream to their natal stream using olfactory cues imprinted in early development (Harden Jones 1968; Quinn and Tolson 1986; Sandercock 1991). Fidelity of mature fish to natal streams is high, and straying rates are generally 15 percent or less (Shapovalov and Taft 1954; Lister et al. 1981; Labelle 1992). Adult coho salmon may travel for a short time and distance upstream to spawn in small streams or may enter large river systems and travel for weeks to reach spawning areas more than 2,000 km upstream (Godfrey 1965; Aro and Shepard 1967; McPhail and Lindsay 1970; Sandercock 1991; WDF et al. 1993).

Most coho salmon spawn at approximately the same time regardless of when they entered fresh water (Foerster and Ricker 1953; Shapovalov and Taft 1954; Sandercock 1991). Consequently, populations that enter fresh water in late summer and early fall may reside in fresh water three to four months before spawning, while fish entering fresh water in late fall may spawn within weeks of fresh water entry. At the extreme southern end of their range in central California, most coho salmon enter fresh water in late December or January and spawn shortly thereafter (Briggs 1953; Shapovalov and Taft 1954; Bryant 1994).

The survival of coho salmon is generally affected by numerous factors in both salt and fresh water, including ocean conditions, location of natal stream, freshwater migration length, stream flow, and other environmental factors Marine survival rates for coho salmon can vary significantly among years and areas. Beamish et al. (2000) reported survival rates for hatchery coho salmon in Puget Sound and the Strait of Georgia ranging from a low of 1 percent to a high of 21 percent for the brood years of 1970 through 1993. In contrast, this same study found far lower survival rates for hatchery coho salmon along the Oregon Coast, ranging from 0.4 to 9.3 percent for these same brood years. Wild stocks from the northern stocks typically show a higher marine survival rate than those from southern stocks, and stocks from Puget Sound show a higher survival rate than those from the Washington Coast (Lestelle et al. 2007). The observed differences in survival of the wild stocks are thought to reflect the different ocean conditions encountered by the various stocks. Wild stocks typically show marine survival rates two- to three-times greater than hatchery fish (Seiler 1989; Pearcy 1992; Coronado-Hernandez 1995).

3.3.3.7 Freshwater Essential Fish Habitat

Freshwater EFH for coho salmon consists of four major components, (1) spawning and incubation; (2) juvenile rearing; (3) juvenile migration corridors; and (4) adult migration corridors and holding habitat. Freshwater EFH depends on lateral (e.g., floodplain, riparian), vertical (e.g., hyporheic) and longitudinal connectivity to create habitat conditions for spawning, rearing, and migration including: (1) water quality (e.g., dissolved oxygen, nutrients, temperature, etc.); (2) water quantity, depth, and velocity; (3) riparian-stream-marine energy exchanges (4) channel gradient and stability; (5) prey availability; (6) cover and habitat complexity (e.g., LWD, pools, aquatic and terrestrial vegetation, etc.); (7) space; (8) habitat connectivity from headwaters to the ocean (e.g., dispersal corridors, floodplain connectivity), (9) groundwater-stream interactions and (10) substrate composition. This incorporates, but is not limited to, life-stage specific habitat criteria summarized in Table 5.

Coho salmon EFH includes all habitats currently or historically occupied within Washington, Oregon, and California. Figure 4 illustrates the 4th field HUs designated as EFH for coho salmon in Washington, Oregon, and Idaho and Figure 5 depicts the 4th field HUs designated as EFH for coho salmon in California within the USGS 4th field HUs identified in Table 1.

The diversity of habitats utilized by coho salmon makes it extremely difficult to identify all specific stream reaches, wetlands, and water bodies essential for the species at this time. Designating each specific river reach would invariably exclude small important tributaries from designation as EFH. Defining specific river reaches is also complicated, because of the current low abundance of the species and of our imperfect understanding of the species' freshwater distribution, both current and historical. Adopting a more inclusive, watershed-based description of EFH is appropriate because, it (1) recognizes the species' use of diverse habitats and underscores the need to account for all of the habitat types supporting the species' freshwater and estuarine life stages, from small headwater streams to migration corridors and estuarine rearing areas; (2) takes into account the natural variability in habitat quality and use (e.g., some streams may have fish present only in years with plentiful rainfall) that makes precise mapping difficult; and (3) reinforces the important linkage between aquatic areas and adjacent upslope areas. Therefore, the geographic extent of coho salmon essential habitat was delineated using USGS cataloging units.

3.3.3.8 Marine Essential Fish Habitat

The important elements of coho salmon marine EFH are (1) estuarine rearing; (2) ocean-rearing; and (3) juvenile and adult migration. Important features of this estuarine and marine habitat are (1) adequate water quality; (2) adequate temperature; (3) adequate prey species and forage base (food); and (4) adequate depth, cover, and marine vegetation in estuarine and nearshore habitats. Overall, coho salmon marine distribution is extensive, varies seasonally, interannually, and can be identified in general terms only (Figure 5).

Limited information exists on coho salmon habitat use in marine waters. While juvenile and maturing coho salmon are found in the open north Pacific, the highest concentrations appear to be found in more productive waters of the continental shelf, coho salmon have also been encountered in an extensive offshore area as far west as 44° N latitude, 175° W longitude (Sandercock 1991). CWT recoveries of coho salmon from high seas fisheries and tagging programs (Myers et al. 1996; Healey 1991; fig.18) provide evidence that coho salmon utilize offshore areas. Shapovalov and Taft (1954) reported coho salmon within 150 km offshore in their study of Waddell Creek coho salmon. Catch data and interviews with commercial fishermen indicate that maturing coho salmon are found in highest concentrations along the continental shelf within 60 km of the Washington, Oregon, and California coast lines. However, determination of a specific or uniform westward boundary within the EEZ which covers the distribution of essential marine habitat is difficult and would contain considerable uncertainty. Therefore, the geographic extent of essential marine habitat for coho salmon includes all marine waters within the EEZ north of Point Conception, California (Figure 1) and the marine areas off Alaska designated as salmon EFH by the NPFMC.

3.4 ESSENTIAL FISH HABITAT DESCRIPTION FOR PUGET SOUND PINK SALMON (*Oncorhynchus gorbuscha*)

3.4.1 General Distribution and Life History

The following is an overview of pink salmon life-history and habitat use as a basis for identifying EFH for Puget Sound pink salmon. Comprehensive reviews of pink salmon life-history and habitat requirements can be found in Aro and Shepard (1967), Neave (1966), Heard (1991), Hard et al. (1996), and others. This description serves as a general description of pink salmon life-history with an emphasis on populations from Puget Sound and the Fraser River.

Pink (or "humpback") salmon are the smallest of the Pacific salmon, averaging just 1.0-2.5 kg at maturity (Scott and Crossman 1973). Adult pink salmon are distinguished from other Pacific salmon by the presence of large dark oval spots on the back and entire caudal fin, and their general coloration and morphology (Scott and Crossman 1973). Maturing males develop a marked hump on their back, which is responsible for their vernacular name "humpback" salmon. Pink salmon are unique among Pacific salmon by exhibiting a nearly invariant two-year life span within their natural range (Gilbert 1912; Davidson 1934; Pritchard 1939; Bilton and Ricker 1965; Turner and Bilton 1968). Upon emergence, pink salmon fry migrate quickly to sea and grow rapidly as they make extensive feeding migrations. After 18 months in the ocean the maturing fish return to freshwater to spawn and die. Pink salmon spawn closer to tidewater than most other Pacific salmon species, generally within 50 km of a river mouth, although some populations may migrate up to 700 km upstream to spawn (Groot and Margolis 1991; Pess et al. 2012), and a substantial fraction of other populations may spawn intertidally (Hanavan and Skud 1954; Hunter 1959; Atkinson et al. 1967; Aro and Shepard 1967; Helle 1970; WDF et al. 1993). Pink salmon often have extremely large spawning populations throughout much of their range, exceeding hundreds of thousands of adult fish in many populations (Takagi et al. 1981; Heard 1991; WDF et al. 1993).

The natural range of pink salmon includes the Pacific rim of Asia and North America north of approximately 40° N latitude. However, the spawning distribution is more restricted, ranging from 48° N latitude (Puget Sound) to 64° N latitude (Norton Sound, Alaska) in North America and 44° N latitude (North Korea) to 65° N latitude (Anadyr Gulf, Russia) in Asia (Neave et al. 1967; Takagi et al. 1981). Within this vast area, spawning pink salmon are widely distributed in streams of both continents as far north as the Bering Strait. North, east, and west of the Bering Strait, spawning populations become more irregular and occasional. In marine environments along both the Asian and North American coastlines, pink salmon occupy waters south of the limits of spawning streams. In North America, pink salmon regularly spawn as far south as Puget Sound and the Olympic Peninsula. However, most Washington state spawning occurs in northern Puget Sound (Williams et al. 1975; WDF et al. 1993). On rare occasions, pink salmon are observed in rivers along the Washington, Oregon, and California coasts, with recent, verified reports of pink salmon in Big Creek and the Salinas River in California (Skiles et al. 2013) but it is unlikely spawning populations regularly occur south of northwestern Washington (Hubbs 1946; Ayers 1955; Herrmann 1959; Hallock and Fry 1967; Williams et al. 1975; Moyle et al. 1995; Hard et al. 1996).

Because of its fixed two-year life cycle, pink salmon spawning in a particular river system in odd- and even-numbered years are reproductively isolated from each other and exist as genetically distinct lines (Neave 1952; Beacham et al. 1988; Gharret et al. 1988; Shaklee et al. 1991; 1995; Hard et al. 1996). In some river systems, such as the Fraser River in British Columbia, the odd-year line dominates; returns to the same systems in even-numbered years are negligible (Vernon 1962; Aro and Shepard 1967). In Bristol Bay, Alaska, the major runs occur in even-numbered years, whereas the coastal area between these two river systems is characterized by runs in both even- and odd-numbered years. In Washington state and southern British Columbia, odd-numbered-year pink salmon are the most abundant (Ellis and Noble 1959; Aro and Shepard 1967; Ricker and Manzer 1974; WDF et al. 1993). However, small even-numbered-year populations exist in the Snohomish River in Puget Sound and in several Vancouver Island rivers (Aro and Shepard 1967; Ricker and Manzer 1974; WDF et al. 1993), although within Puget Sound the even-year pink salmon are sharply declining and will likely soon disappear.

3.4.2 Relevant Trophic Information

Pink salmon eggs, alevins, and fry in freshwater streams provide an important nutrient input and food source for aquatic invertebrates, other fishes, especially sculpins, birds, and small mammals (Pritchard 1934; Hoar 1958; Hunter 1959; Tagmazyan 1971; Khorevin et al. 1981). Recent studies suggest that the productivity of coho salmon stocks in the Skagit River, WA are related to the abundance of spawning pink salmon in the previous year (Michael 1995). In the marine environment, pink salmon fry and juveniles are food for a host of other fishes, including other Pacific salmon and coastal sea birds (Thorsteinson 1962; Parker 1971; Bakshtansky 1980; Karpenko 1982). Within Puget Sound, pink salmon may compete with Chinook salmon populations, as marine survival of hatchery releases decreases when juvenile pink salmon are abundant (Ruggerone and Goetz 2004).

Subadult and adult pink salmon are known to be eaten by 15 different marine mammal species, sharks, other fishes such as Pacific halibut, and humpback whales (Fiscus 1980). Because pink salmon are the most abundant salmon in the North Pacific, it is likely they comprise a significant portion of the salmonids eaten by marine mammals.

Pink salmon spawning populations often number in the hundreds of thousands of fish, consequently, their carcasses provide significant nutrient input into many coastal watersheds. Adult pink salmon in streams are major food sources for gulls, eagles, and other birds, along with bear, otter, mink and other mammals, fishes, and aquatic invertebrates (Cederholm et al. 1989; Michael 1995; Bilby et al. 1996).

3.4.3 Habitat and Biological Associations

An overview of major diet items by habitat and life stage for Puget Sound (PS) pink salmon is in Table 3. Table 6 summarizes PS pink salmon habitat use by life-history stage.

3.4.3.1 Eggs and Spawning

Pink salmon choose a fairly uniform spawning bed in both small and large streams in Asia and North America. Generally, these spawning beds are situated on riffles with clean gravel, or along the borders between pools and riffles in shallow water with moderate to fast currents (Semko 1954; Heard 1991; Mathisen 1994). In large rivers, they may spawn in discrete sections of main channels or in tributary channels. Pink salmon avoid spawning in deep, quiet water, in pools, in areas with slow current, or over heavily silted or mud-covered streambeds. Places selected for egg deposition is determined primarily by the optimal combination of water depth and velocity. Although intertidal spawning is extensive in some areas of the North Pacific such as Prince William Sound (Hanavan and Skud 1954; Helle 1970), it is not in Washington, Oregon, and California (Williams et al. 1975; WDF et al. 1993; Hard et al. 1996).

On both the Asian and North American sides of the Pacific Ocean, pink salmon generally spawn at depths of 30-100 cm (Dvinin 1952; Hourston and MacKinnon 1956; Graybill 1979; Goloranov 1982). High densities of spawning pink salmon are usually found at depths of 20-25 cm, but occasionally to depths of 100-150 cm. In dry years, on crowded spawning grounds, nests can be found at shallower depths of 10-15 cm. Water velocities in pink salmon spawning grounds vary from 30-100 cm/s, sometimes reaching 140 cm/s (Hourston and MacKinnon 1956; Smirnov 1975; Graybill 1979; Golovanov 1982), but usually average 60-80 cm/s.

In general, pink salmon select sites in gravel where the gradient increases and the currents are relatively fast. In these areas, surface stream water must have permeated sufficiently to provide intragravel flow for dissolved oxygen delivery to eggs and alevins. Pink salmon spawning beds consist primarily of coarse gravel with a few large cobbles, a mixture of sand, and a small amount of silt. Pink salmon are often found spawning in the same river reaches and habitats as Chinook salmon. High quality spawning grounds of pink salmon can best be summarized as clean, coarse gravel (Hunter 1959).

Pink salmon have the lowest fecundity of Pacific salmon, averaging 1,200-1,900 eggs per female, and also some of the smallest eggs (Pritchard 1937; Neave 1948; Beacham et al. 1988; Beacham and Murray 1993). In Washington and southern British Columbia spawning areas, eggs are deposited from August to October slightly earlier in northern Puget Sound and the upper Dungeness River than elsewhere in northwestern Washington (WDF et al. 1993; Hard et al. 1996).

3.4.3.2 Larvae/Alevins

Fertilized eggs begin their five- to eight-month period of embryonic development and growth in intragravel interstices (Heard 1991). To survive successfully, the eggs, alevins, and pre-emergent fry must first be protected from freezing, desiccation, stream bed scouring or shifting, mechanical injury, and predators. Water surrounding them must be non-toxic and of sufficient quality and quantity to provide basic requirements of suitable temperatures, adequate supply of oxygen, and removal of waste materials. These requirements are only met partially even under the most favorable natural conditions. Overall, freshwater survival of pink salmon from egg to advanced alevin and emerged fry is frequently 10-20 percent, but can be as low as 1 percent (Neave 1953; Hunter 1959; Wickett 1962; Taylor 1983). Some British Columbia artificial spawning channels have achieved egg-to-fry survival as high as 57 percent (MacKinnon 1963; Cooper 1977).

3.4.3.3 Juveniles (Freshwater)

Newly emerged pink salmon fry are fully capable of osmoregulation in sea water. Schools of pink salmon fry may move quickly from the natal stream area or remain to feed along shorelines up to several weeks. The timing and pattern of seaward dispersal is influenced by many factors, including general size and location of the spawning stream, characteristics of adjacent shoreline and marine basin topography, extent of tidal fluctuations and associated current patterns, physiological and behavioral changes with growth, and possibly different genetic characteristics of individual stocks (Heard 1991).

Pink salmon fry emerge from gravels at a size of 28-35 mm, and begin migrating downstream shortly thereafter. This downstream migration timing varies widely by region and from year to year within regions and individual streams. In Puget Sound and southern British Columbia, fry migrate downstream in March and April, occasionally extending into May.

Pink salmon spend a short time in freshwater and rarely feed while there (Robins et al. 2005), but one study indicated that juveniles not migrating directly to saltwater consume aquatic insects (immature stages, pupae, adults) and zooplankton (Robins et al. 2005).

3.4.3.4 Juveniles (Estuarine)

The use of estuarine areas by pink salmon varies widely, ranging from passing directly through the estuary en route to nearshore areas to residing in estuaries for one to two months before moving to the ocean (Hoar 1956; McDonald 1960; Vernon 1966; Heard 1991). In general, most pink salmon populations use this former pattern and, therefore, depend on nearshore, rather than estuarine environments, for their initial rapid growth.

Pink salmon populations that reside in estuaries for extended periods utilize shallow, protected habitats such as tidal channels and consume a variety of prey items, such as larvae and pupae of various insects (especially chironomids), cladocerans, and copepods (Bailey et al. 1975; Hiss 1995). Even more estuarine-dependent pink salmon populations have relatively short residence period when compared to fall Chinook salmon and chum salmon that use estuaries extensively. For example, while these other species reside in estuaries throughout the summer and early fall, pink salmon are rarely encountered in estuaries beyond June (Hiss 1995).

3.4.3.5 Juveniles (Marine)

Immediately after entering marine waters, pink salmon fry form schools, often in tens or hundreds of thousands of fish (McDonald 1960; Vernon 1966; Heard 1991). During this time, they tend to follow shorelines and, at least for the first few weeks at sea, spend much of their time in shallow water of only a few centimeters deep (LeBrasseur and Parker 1964; Healey 1967; Bailey et al. 1975; Simenstad et al. 1982). It has been suggested that this inshore period involves a distinct ecological life-history stage in pink salmon (Kaczynski et al. 1973). In many areas throughout their ranges, pink salmon and chum salmon fry of similar age and size co-mingle in both large and small schools during early sea life (Heard 1991).

Pink salmon juveniles routinely obtain large quantities of food sufficient to sustain rapid growth from a broad range of habitats providing pelagic and epibenthic foods (Parker 1965; Martin 1966; Neave 1966; Healey 1967; Bailey et al. 1975). Collectively, diet studies show that pink salmon are both opportunistic and generalized feeders and, on occasion, they specialize on specific prey items. Diel stomachs sampling suggests that juvenile pink salmon are diurnal feeders, foraging primarily at night (Parker and LeBrasseur 1974; Bailey et al. 1975; Simenstad et al. 1982; Godin 1981). Common prey items include copepods (especially harpacticoids), pteropods (Armstrong et al. 2008), barnacle nauplii, mysids, amphipods, euphausiids, decapod larvae, insects, larvaceans, eggs of invertebrates and fishes, and fish larvae (Gerke and Kaczynski 1972; Bailey et al. 1975; Healey 1980; Simenstad et al. 1982; Godin 1981; Takagi et al. 1981; Landingham 1982; Boldt and Haldorson 2003; Bollens et al. 2010). Growth rates during this period of early marine residence range from 3.5-7 percent of body weight per day, equivalent to an approximately 1 mm increase in length per day (LeBrasseur and Parker 1964; Phillips and Barraclough 1978; Healey 1980; Karpenko 1987).

At approximately 45-70 mm in length, pink salmon move out of the nearshore environment into deeper, colder waters to begin their ocean migration (Manzer and Shepard 1962; LeBrasseur and Parker 1964; Phillips and Barraclough 1978; Healey 1980). For populations originating from Puget Sound and southern British Columbia rivers, this movement begins in July and lasts through October as fish migrate out of protected waters and northward along the coast towards Alaska (Pritchard and DeLacy 1944; Barraclough and Phillips 1978; Hartt 1980; Healey 1980). After reaching approximately Yakutat in central Alaska, Washington-origin pink salmon move out into the Gulf of Alaska and follow the main current in the gyre, subsequently migrating southward during their first fall and winter in the ocean, then northward the following spring and summer. They then begin their homewards migration, again entering coastal waters as they move south toward their natal streams (Manzer et al. 1965; Neave et al. 1967; Takagi et al. 1981; Ogura 1994). Tagging studies indicate that juvenile and maturing Puget Sound pink salmon are most concentrated in nearshore areas of Vancouver Island and the Hecate Strait extending as far north as approximately 58° N latitude (Yukatat Bay, Alaska), and seaward to approximately 140° W longitude (Myers et al. 1996). The southernmost distribution of Puget Sound pink salmon is not clear, but in general the largest concentrations of pink salmon of British Columbia and Washington-origin are found north of 48° N latitude (Hartt and Dell 1986; Myers et al. 1996).

Pink salmon from Washington State and British Columbia and those originating in southeastern, central, and southwestern Alaska, occur in marine waters where they might interact in some way with the salmon fisheries off the coast of southeast Alaska. Pink salmon from these regions also co-mingle in the Gulf of Alaska during their second summer at sea while migrating toward natal areas (Manzer et al. 1965; Neave et al. 1967; Takagi et al. 1981).

In contrast to this extended ocean migration, it is believed that some Stillaguamish River and possibly other Puget Sound pink salmon remain within Puget Sound for their entire ocean residence period (Jensen 1956; Hartt and Dell 1986). This tendency to reside in Puget Sound and the Strait of Georgia is commonly exhibited by both coho salmon and Chinook salmon, but is unusual for pink salmon. These "resident" fish are much smaller than individuals that migrated to the ocean, reaching only 35-45 cm as adults, some 10 cm shorter than migratory fish from the same area (Hartt and Dell 1986).

In the ocean, pink salmon primarily consume fish, squid, euphausiids, and amphipods, with lesser numbers of pteropods, decapod larvae, and copepods (Allen and Aron 1958; Ito 1964; LeBrasseur 1966; Manzer 1968; Takagi et al. 1981). During this phase, most pink salmon are found in the upper-most 12 m of the water column, the actual depth varying with seasonal and diurnal patterns (Manzer and LeBrasseur 1959; Manzer 1964).

3.4.3.6 Adults

Ocean growth of pink salmon is a matter of considerable interest; because, although this species has the shortest life span among Pacific salmon, it also is among the fastest growing (Heard 1991). Entering the estuary as fry at around 30 mm in length, maturing adults return to the same area 14-16 months later ranging in length from 450 to 550 mm. Adults display a latitudinal trend in size, with the largest fish occurring in the southern portion of the range (Heard 1991). Most odd-year Fraser River and Washington fish weigh approximately 2.5 kg, while Washington even-year fish may be slightly smaller at 2.1 kg. By comparison, pink salmon from central and southeast Alaska typically weigh 1.3-1.8 kg (Takagi et al. 1981; Heard 1991).

Based on stable isotope levels (^{15}N, ^{13}C), adult pink salmon feed at a lower tropic level than Chinook salmon and coho salmon and feed primarily in off-shore pelagic waters (Johnson and Schindler 2009). They feed less on fish relative to coho salmon and Chinook salmon and more on invertebrates including squid, copepods, amphipods and pteropods (Kaeriyama et al. 2004; Armstrong et al. 2005; Armstrong et al. 2008).

Adult pink salmon enter freshwater between June and September, with northern populations generally entering earlier than southern populations (Neave et al. 1967; Takagi et al. 1981). Odd-year pink salmon from Puget Sound typically enter freshwater between mid-July and late September, with considerable local variation the earliest run (Dungeness River) begin entering freshwater in mid-July, while the median return date of the latest-returning runs is October 15 (WDF et al. 1993; Hiss 1995). Snohomish River even-year fish enter freshwater three to four weeks earlier than the odd-year run in the same system, even though the two populations use the same habitat (WDF et al. 1993). As noted above, the even-year coho salmon runs are rapidly declining.

As with other Pacific salmon, fertilization of pink salmon eggs occurs upon deposition (Heard 1991). Males compete with each other to breed with spawning females. Pink salmon females remain on their redds one to two weeks after spawning, defending the area from superimposition of eggs from another female (McNeil 1962; Ellis 1969; Smirnov 1975).

Measured marine survivals of pink salmon, from entry of fry into stream mouth estuaries to returning adults, have ranged from 0.2 percent to over 20 percent. For North America, estimated fry-to-adult survival averages between 1.7 percent and 4.7 percent (Pritchard 1948; Parker 1962; Ricker 1964; Ellis 1969; McNeil 1980; Taylor 1980; Vallion et al. 1981; Blackbourn 1990). Generally, much of the natural mortality of pink salmon in the marine environment occurs within the first few months before advanced juveniles move offshore into more pelagic ocean waters (Parker 1965; 1968). Pink salmon populations can be very resilient, rebounding from weak to strong run strength in regional stock groups within one or two generations. Conversely, strong runs may also become weak within several generations, causing pink salmon populations to exhibit high natural variability (Neave 1962; Ricker 1962).

3.4.3.7 Freshwater Essential Fish Habitat

Freshwater EFH for Puget Sound pink salmon consists of three major components, (1) spawning and incubation; (2) juvenile migration corridors; and (3) adult migration corridors and holding habitat. Important features of essential habitat for spawning, rearing, and migration include adequate, (1) substrate composition; (2) water quality (e.g., dissolved oxygen, nutrients, temperature, etc.); (3) water quantity, depth, and velocity; (4) channel gradient and stability; (5) prey availability; (6) cover and habitat complexity (e.g., LWD, channel complexity, etc.); (7) space; (8) access and passage; and (9) habitat and flood plain connectivity. This incorporates, but is not limited to, life-stage specific habitat criteria summarized in Table 6. Puget Sound pink salmon EFH includes all habitats currently or historically within Washington. Figure 6 illustrates the watersheds designated as EFH for PS pink salmon within the USGS 4th field HUs identified in Table 1.

The inadequacy of existing species distribution maps makes it extremely difficult to identify all specific stream reaches essential for the species at this time. Designating each specific river reach would invariably exclude small, important tributaries from designation as EFH. Adopting a more inclusive, watershed-based description of EFH is appropriate, because it (1) recognizes the species' use of diverse habitats and underscores the need to account for all of the habitat types supporting the species' freshwater and estuarine life stages, from small headwater streams to migration corridors and estuarine rearing areas; (2) takes into account the natural variability in habitat quality and habitat use (e.g., some streams may have fish present only in years with plentiful rainfall) that makes precise mapping difficult; and (3) reinforces the important linkage between aquatic and adjacent upslope areas. Therefore, the geographic extent of Puget Sound pink salmon essential habitat was delineated using USGS cataloging unit boundaries.

3.4.3.8 Marine Essential Fish Habitat

The important elements of pink salmon marine EFH are (1) estuarine rearing; (2) early ocean rearing; and (3) juvenile and adult migration. Important features of this estuarine and marine habitat are (1) adequate water quality; (2) adequate temperature; (3) adequate prey species and forage base (food); and (4) adequate depth, cover, and marine vegetation in estuarine and nearshore habitats. Overall pink salmon marine distribution is extensive, varies seasonally, interannually, and can be identified in general terms only. Estuarine and nearshore areas such as Puget Sound and other inland marine waters of Washington State and British Columbia are critical to the early marine survival of pink salmon. Therefore, essential marine habitat for PS pink salmon includes all nearshore marine waters north and east of Cape Flattery, Washington, including Puget Sound, the Strait of Juan de Fuca and Strait of Georgia, and waters of the U.S. EEZ north of 48° N latitude (Figure 6). It is difficult to determine a western limit for pink salmon essential marine habitat, because of limited information on their ocean distribution, but it is clear that the vast majority are found in Canadian, Alaskan, and international waters both within and outside the EEZ north of Cape Flattery, Washington. Accordingly, EFH for PS pink salmon also includes the marine areas off Alaska designated as pink salmon EFH by the NPFMC.

4. DESCRIPTION OF ADVERSE EFFECTS ON PACIFIC SALMON ESSENTIAL FISH HABITAT AND ACTIONS TO ENCOURAGE THE CONSERVATION AND ENHANCEMENT OF ESSENTIAL FISH HABITAT

4.1 FISHING ACTIVITIES AFFECTING SALMON ESSENTIAL FISH HABITAT

Pacific salmon are highly prized in commercial, recreational, and tribal fisheries, and represent major economic benefits to the region. In addition to economic benefits, spawning salmon are a significant contributor of nutrients to streams, supporting the stream ecology, aquatic insects, and ultimately, juvenile salmon.

The MSA requires FMCs for each FMP to identify fishing activities that may adversely affect EFH and to minimize adverse effects of those activities to the extent practicable. Fishing activities should include those regulated under the Pacific salmon FMP that affect EFH identified under any FMPs, as well as those fishing activities regulated under other FMPs that affect EFH designated under the Pacific salmon FMP. The fishing activities that have the potential to adversely affect EFH for Pacific Coast salmon are shown in Table 7 These include fishing activities managed under the MSA as well as non-MSA fishing activities that may adversely affect salmon EFH. In many cases, MSA and non-MSA activities operate in similar locations and use similar gears. Therefore, they are described here together.

Fishing activities, derelict gear, harvest of prey species, vessel operations, and the removal of salmon carcasses and their nutrients from streams are identified as fishing-related activities that can affect Pacific Coast salmon EFH. Some of these activities are controlled by the Council and some are not.

Although it is unlikely that any potential effects to Pacific salmon EFH from commercial and recreational fishing activities have increases substantially since 1999, the activities identified in Amendment 14 warrant a more thorough review and description. In addition, the identified marine debris (and derelict fishing gear, separately) are included as activities that may adversely affect EFH. Although minor changes in location may have occurred, it is unlikely that these would have a substantial effect on impacts to EFH for Pacific salmon. Further, it is likely that overall fishing activities have remained level or have decreased since 1999.

Ocean fisheries targeting Chinook salmon use hook-and-line gear, but gill nets are used in commercial and tribal freshwater fisheries in the Columbia and Klamath Rivers, Puget Sound, Grays Harbor, Willapa Bay, and other river systems (PFMC 2011). Chinook salmon fisheries have some bycatch associated with them, most often other salmonids and undersized Chinook salmon. While the majority of these fish survive the hooking encounter, substantial (> 25 percent) mortality may occur (Wertheimer 1988, Wertheimer *et al*. 1989, Gjernes *et al*. 1993). A complete and current description of ocean fisheries, harvest levels, and management framework can be found in the most recent versions of the annual Stock Assessment and Fishery Evaluation (SAFE) document *Review of Ocean Salmon Fisheries* (PFMC 2011a).

Commercial, tribal, sport, and subsistence fisheries for coho historically and currently occur from the eastern Pacific through the Bering Sea and along the West Coast of North America as far south as central California (Godfrey 1965). Hook-and-line is the primary gear type used in ocean fisheries; however, gill nets and purse seines are used in near-shore or in-river commercial fisheries. Sport catches of coho are typically taken by hook-and-line.

Most coho salmon from Washington, Oregon, and California recruit to fisheries after one year in fresh water and about 16 months at sea. These fisheries take place in coastal adult migration corridors, near the mouths of river and in freshwater and marine migration areas (Williams *et al*. 1975) and largely target fish returning to hatcheries.

Bycatch in coho salmon fisheries is usually limited to other salmon species, primarily Chinook and chum salmon, and occasionally pink salmon. Species such as steelhead, Dolly Varden, pollock, Pacific cod, halibut, salmon sharks, and coastal rockfish make up a small part of the catch. Coho salmon are also taken incidentally in other salmon fisheries. When regulations prohibit the retention of coho, the majority of released fish survive the hooking encounter, however, large numbers can be hooked and substantial mortality incurred. Substantial coho salmon bycatch can lead to restrictions on these fisheries (PFMC 1998). A complete and current description of ocean fisheries, harvest levels, and management framework can be found in the most recent versions of the annual SAFE Report (PFMC 2011a).

Pink salmon are the most abundant Pacific salmon, contributing about 39 percent by weight and 54 percent in numbers of all salmon caught commercially in the North Pacific Ocean and adjacent waters (AKDFG 2012). Coastal fisheries for pink salmon presently occur in Asia (Japan and Russia) and North America (Canada and the United States), with major fisheries in Russia, Canada, and the U.S. Historically, some pink salmon were caught in high seas fisheries by Japan and Russia. Most pink salmon in the U.S. are caught in Alaska where major fisheries occur in the Southeast, Prince William Sound, and Kodiak regions; with lesser fisheries in the Cook Inlet, Alaska Peninsula, and Bristol Bay regions (Heard 1991). Catches of pink salmon decrease south of Alaska, with about 10 million fish caught annually in British Columbia, 2-3 million in Washington, and a negligible number in Oregon and California (Heard 1991, PFMC 1999a). More recently, the Duwamish River has experienced pink salmon returns estimated at 2.875 million fish in 2009 and 864,000 fish in 2011 (A. Bosworth, pers comm. 2012). Most pink salmon are harvested in the marine environment by purse seines with smaller commercial catches made by set and drift gill net and troll fisheries. Marine recreational fisheries primarily use troll gear. Washington marine pink salmon harvests are predominantly composed of Fraser River-origin fish (Hard *et al*.1996, PFMC 1984). The Pacific Salmon Commission (PSC) manages fisheries for pink salmon in U.S. Convention waters north of 48° N latitude to meet Fraser River natural spawning escapement and U.S./Canada allocation requirements. Fisheries for pink salmon have some bycatch associated with them, primarily other Pacific salmon species.

4.1.1 Potential Effects to EFH by Gear Type

Roundhaul Gear (includes purse seines, lampara nets, dip nets, and drum seines): Fisheries for coastal pelagic and highly migratory species use purse seines, lampara nets, and other roundhaul gear to target Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel, market squid, and tuna. Most tuna fishing occurs in the western and central Pacific, and tropical eastern Pacific. However, tuna are highly migratory and are present off the U.S. West Coast. They are therefore included in this consideration of habitat impacts from fishing activities.

Roundhaul gear can potentially affect EFH for all three managed Pacific salmon species by direct removal of species that are prey for Pacific salmon, as well as for other managed species. It could potentially also affect squid, which are prey for salmon, if nets are allowed to contact the benthos of squid spawning areas. Although roundhaul gear co-occurs with waters that are EFH for Pacific salmon, it is unlikely that there would be more than a temporary negligible effect on the habitat.

Pot and Trap Gear: This gear type is dominated by commercial and recreational crab fisheries prevalent in estuaries and the marine environment along the entire West Coast. Lobster traps are used in California, but not typically north of the central California coast. To a lesser extent, pot gear is used in the sablefish fishery but typically at depths in the marine environment much greater than are associated with salmon (NWFSC 2009).

Pot and trap gear can adversely affect Pacific salmon EFH by damaging estuarine eelgrass beds and other marine/estuarine benthic habitats such as cobble and vegetated surfaces utilized by Pacific salmon. Although typically placed in areas of sandy bottom, gear can also be deployed in more sensitive habitats and are often dragged across the benthos by strong tidal or ocean currents. Lost trap and pot gear could potentially affect EFH and are discussed below under Derelict Gear.

Bottom Trawling: Bottom trawling activity is conducted primarily by the West Coast groundfish fishery, harvesting over 90 species. These include 64 species of rockfish (e.g., widow, cowcod, yelloweye, and Pacific ocean perch); 12 species of flatfish (e.g., English sole, starry flounder, sanddab); six species of roundfish (e.g., lingcod, sablefish, and whiting); six species of sharks and skates (e.g., leopard shark, big skate and spiny dogfish); and several other species (e.g., ratfish, finescale codling, and Pacific rattail grenadier).

Appendix C to Amendment 19 of the Pacific Coast Groundfish FMP (PFMC 2005) presents a risk assessment framework, including a sensitivity index and recovery rates for a variety of groundfish habitats. Several habitats considered would likely overlap with salmonid habitat in the marine environment. Chinook salmon may be associated with "bottom topography" at depths of 30-70 meters, and juveniles are associated with pinnacles, reefs and vertical walls.

Impacts of bottom trawling to physical and biogenic habitats may include removal of vegetation, corals, and sponges that provide structure for prey species; disturbance of sediments; and possible alteration of physical formations such as boulders and rocky reef formations (NMFS 2005b).

Bottom trawling is managed under biennial specifications and includes a complicated matrix of sectors, seasons, and spatial limitations. There are many areas closed to bottom contact gear, including bottom trawling, many based on the designated HAPCs in the groundfish FMP EFH designations (PFMC 2008). In addition, the groundfish fishery underwent rationalization and currently operates under a catch share system. Overall effort, duration, and intensity has generally decreased in recent years. Given the significant minimization measures implemented in the groundfish fishery, coupled with the fact that there is minimal co-occurrence of bottom trawling with benthic Pacific salmon EFH, it is unlikely that there is more than a temporary, minimal impact from this fishing activity.

Midwater trawling: Midwater trawls are used to harvest Pacific whiting, shrimp, and other species (PFMC 2008). Like bottom trawling, it is managed under the Pacific groundfish FMP. Effects are generally limited to the effects of (1) removal of prey species, (2) direct removal of adult and juvenile salmon (Bellinger 2009), and (3) effects resulting from loss of trawl gear, potentially resulting in impacts to bottom habitats and ghost fishing (see Section 4.1.2.4 Derelict Gear).

Long Line: Pelagic and bottom long-line fishing in the marine environment is prevalent on the Pacific Coast. Pelagic long-lining targets chiefly tuna and swordfish, while bottom long lining targets halibut, sablefish, and other species. Both types of long lining can incidentally harvest managed species as well as prey species. If long-line gear breaks loose and is lost, it can continue ghost fishing and potentially harm bottom habitat (see Section 4.1.2.4 Derelict Gear).

4.1.2 Fishing-related potential impacts

4.1.2.1 Removal of Salmon Carcasses

Salmon carcasses provide vital nutrients to stream and lake ecosystems (Scheuerell et al. 2005). Carcasses enhance salmonid growth and survival, but fishing activities remove a portion of returning adults that would otherwise supply nutrients to stream systems. This is especially relevant to nutrient-poor streams that depend on the phosphorous, nitrogen, and other nutrients provided by salmon carcasses. In the Willapa Bay basin an estimated several thousand metric tons of salmon tissue have been lost each year as a nutrient source to streams because of reductions in salmon returns (Naiman et al. 2002), while net transport of marine-derived phosphorous into the Snake River basin over the past 40 years was estimated at less than 2 percent of historical levels (Scheuerell et al. 2005). Gresh et al (2000) estimated that just 6-7 percent of the marine-derived nitrogen and phosphorous once delivered to the rivers of the Pacific Northwest by salmon carcasses is currently reaching those streams.

Carcasses have been shown to be an important habitat component, enhancing smolt growth and survival by contributing significant amounts of nitrogen and phosphorus compounds to streams (Spence et al. 1996). These are the nutrients that most often limit production in oligotrophic systems.

4.1.2.2 Vessel Operations

The variety of fishing and other vessels on the Pacific Coast range can be found in freshwater streams, estuaries, and the marine environment. Vessel size ranges from small single-person vessels used in streams and estuaries, to mid-size commercial or recreational vessels, to large-scale vessels limited to deep-draft harbors and marine waters. See Section 4.2.2.28 Vessel Operations for a detailed description of the effects of this activity on EFH.

4.1.2.3 Harvest of Prey Species

Prey species can be considered a component of EFH (NMFS 2006). For Pacific salmon, commercial and recreational fisheries for many types of prey species potentially decrease the amount of prey available to Pacific salmon. Herring, sardine, anchovy, squid, smelt, groundfish, shrimp, crab, burrowing shrimp, and other species of finfish and shellfish are potential salmon prey species that are directly fished, either commercially or recreationally.

Some prey species (e.g., herring and crab) are state-managed while others are federally managed, and it concluded that both state and Federal management already includes considerations for the forage needs of predator species, including salmon. For example, the harvest guideline formula for Pacific sardine incorporates a 150,000 metric ton (mt) cutoff and a relatively low harvest fraction, both of which are intended in part to provide adequate forage for dependent species. Other prey species such as krill, copepods, and amphipods, are salmon prey species that are not directly fished (krill harvest is prohibited under the CPS FMP), but that can be adversely affected by fishing activities.

4.1.2.4 Derelict Gear

When gear associated with commercial or recreational fishing breaks free, is abandoned, or becomes otherwise lost in the aquatic environment, it becomes derelict gear. This phenomenon occurs in fishing activities managed under all four Pacific Coast FMPs, as well as recreational fishing and fishing activities not managed by the Council. In commercial fisheries, trawl nets, gillnets, long lines, purse seines, crab and lobster pots, and other material, are occasionally lost to the aquatic environment. Recreational fisheries also contribute to the problem, mostly via lost crab pots.

Derelict fishing gear, as with other types of marine debris, can directly affect salmon habitat and can directly affect managed species via “ghost fishing.” Ghost fishing is included here as an impact to EFH because the presence of marine debris affects the physical, chemical, or biological properties of EFH. For example, once plastics enter the water column, they contribute to the properties of the water. If debris is ingested by fish, it would likely cause harm to the individual. Another example is in the case of a lost net in a river. Once lost, the net becomes not only a potential barrier to fish passage, but also a more immediate entanglement threat to the individual.

Along the Pacific Coast, Dungeness crab pots are especially prevalent as derelict gear (NWSI 2010). Commercial pots are required to use degradable cord that allows the trap lid to open after some time. This is thought to significantly reduce the effects of ghost fishing. However, only the State of Washington has such a requirement for recreational crab pots. There is little reliable information regarding the numbers or impacts of lost recreational crab pots.

Derelict gear can adversely affect salmon EFH directly by such means as physical harm to eelgrass beds or other estuarine benthic habitats; harm to coral and sponge habitats or rocky reefs in the marine environment; and by simply occupying space that would otherwise be available to salmon. Derelict gear also causes direct harm to salmon (and potentially prey species) by entanglement. Once derelict gear becomes a part of the aquatic environment, it affects the utility of the habitat in terms of passive use and passage to adjacent habitats. More specifically, if a derelict net is in the path of a migrating fish, that net can entangle and kill the individual fish.

The Northwest Straits Initiative (NWSI) estimates that 2493 lost nets were removed in Puget Sound by a project funded under the American Recovery and Reinvestment Act (NWSI 2011b). Since 2002, over 3,800 partial gillnets (average size 7,000 square feet) have been removed from Puget Sound, with an estimated 1000 additional gillnets remaining in the shallow subtidal areas. An analysis of 870 derelict gillnets recovered from Puget Sound found 154 salmon were entangled at the time of recovery (Good et al. 2010). Some of these gillnets that had been derelict as long as 24 years were still catching marine fish, although the report did not note if salmon were among those caught. Most derelict gear removal efforts in Puget Sound are conducted during the winter, when fewer adult salmon are present (NWSF 2007). Nets recovered when adult salmon are more abundant have greater numbers of salmon. For instance, two nets recovered off of Lummi Island after the 2003 chum salmon season had 157 salmon, at least 12 of which were Chinook salmon (NWSF 2007). In 2008, a derelict gillnet was recovered with 14 salmon, and caught an estimated 450 salmon in the 23 weeks since it was lost (NWSI 2011a).

The Columbia River Inter-Tribal Fish Commission recovered a total of 33 derelict gillnets in 2002 and 2004 from the Bonneville and Dalles Reservoirs on the Columbia River (Kappenman and Parker 2007). While Kappenman and Parker (2007) provided no estimate of the number of nets remaining in these reservoirs or in the rest of the Columbia River, they estimated that approximately 10 gillnets are lost each year. In contrast to the derelict gillnets recovered in Puget Sound, white sturgeon, *Acipenser transmontanus*, was the only species found in these nets, some of which had been derelict for as long as seven years. However, the authors acknowledged that the recovery operations were conducted during the winter, when few adult salmon are present. Kappenman and Parker (2004) suggested that in the Columbia River, surface-fishing gillnets targeting salmon are likely to be quickly retrieved by other commercial fishers, river users, or state agencies and do not continue fishing for extended periods, thereby reducing the risk to salmon. In addition, currents in the Columbia River may also cause derelict gillnets to collapse and spin into balls relatively quickly (Kappenman and Parker 2007). Although it is clear that there are derelict gillnets in these reservoirs, the impact that such gear has on salmon in the Columbia River, or other West Coast river systems where the issue has not been examined, is presently unknown.

4.1.2.5 Recreational Fishing

Most recreational fishing impacts are combined in the sections above. One activity not yet captured is the potential for impacts to juvenile salmon and eggs in redds resulting from trampling by recreational fishers. In freshwater streams, recreational fishers often use waders and boots to walk in streams to access good fishing spots. This can crush eggs and alevins in a salmon redd. Trampling of redds has potential to cause high mortality of salmonids. Most information on redd disturbance is anecdotal. However, one study showed that trampling by anglers can kill eggs and pre-emergent fry in trout redds (Roberts and White 1992).

4.1.2.6 Minimizing Effects

FMPs are required to minimize adverse effects to EFH to the extent practicable. Minimization measures can include, but are not limited to, time/area closures, fishing equipment restrictions, and harvest limits. Adverse impacts include incidental harvest of managed species through legal fishing activity, but incidental harvest is addressed in other sections of FMPs, rather than under EFH provisions. All four FMPs include management measures that are intended to protect habitat, species, or both. There are no additional management measures proposed to conserve Pacific salmon EFH.

4.2 NONFISHING ACTIVITIES AFFECTING SALMON ESSENTIAL FISH HABITAT

In addition to the effects from fishing activities, the adverse effects of habitat alterations, dams and hatchery operations are widely recognized as major contributors to the decline of salmon in the region. Nehlsen et al. (1991) associate these activities with over 90 percent of the documented stock extinctions or declines. The importance of habitat is underscored in undammed coastal watersheds with declining salmon populations. Surveys of both public and private lands in the Pacific Northwest reveal widespread degradation of freshwater, wetland, and estuarine habitat conditions. Attempts to improve salmon survival by reduction in fishing pressure may have little effect on salmon populations if EFH quantity and quality are inadequate. Ocean survival by adults, for example, is of little value if appropriate tributary habitat is not available for spawning and early life history survival of offspring (Gregory and Bisson 1997).

Section 305(b)(2) of the MSA directs Federal agencies to consult with NMFS on all actions authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by such agency that may adversely affect EFH[2]. In order to facilitate this process and promote the conservation of EFH, FMPs are

2 An adverse effect means any impact that reduces either the quantity or quality of EFH [50 CFR 600.810(a)]. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality and/or quantity of EFH. Adverse effects on EFH may result from actions occurring within EFH or outside of EFH and may include site specific or

required to identify non-fishing activities that may adversely affect EFH and describe the adverse effects from those activities. The FMP must also identify potential conservation measures to avoid, minimize, mitigate, or otherwise offset those adverse effects. Incorporation of the appropriate conservation measures into the design of the project can, in some cases, obviate the need for consultation.

Section 4.2.1 describes the EFH consultation requirements and process. Section 4.2.2 describes 31 non-fishing activities that may adversely affect salmon EFH and, for each of these activities, identifies potential measures to conserve EFH.

4.2.1 The EFH Consultation Process

As described above, Federal agencies must consult with NMFS on any action that is authorized, funded, or undertaken, or proposed to be so, if it may adversely affect EFH. Adverse effects may result from actions that take place within EFH as well as those that take place outside of EFH (e.g., road construction upslope of a stream designated as EFH) [50 CFR 600.910(a)]. Activities proposed to occur in EFH areas do not automatically require consultation. Consultations are triggered only when the proposed action may adversely affect EFH, and then, only Federal actions require consultation.

The consultation process is summarized here. The complete regulations to implement the EFH provisions of the MSA can be found at 50 CFR 600.

Before consultation begins, the Federal agency must first assess the effects of their action on EFH. If they determine that the action will not adversely affect EFH, then no consultation is required. But if they determine that the action "may adversely affect" EFH, they must prepare and submit a written assessment of the effects of their action (EFH assessment). The EFH Assessment must include the following: (1) a description of the action; (2) an analysis of the potential adverse effects of the action on EFH and the managed species; (3) the Federal agency's conclusions regarding the effects of the action on EFH; and (4) proposed mitigation, if applicable. The assessment should also contain additional information. If appropriate, including: (1) the results of an on-site inspection to evaluate the habitat and the site-specific effects of the project; (2) the views of recognized experts on the habitat or species that may be affected; (3) a review of pertinent literature and related information; (4) an analysis of alternatives to the action, including alternatives that could avoid or minimize adverse effects on EFH; and (5) other relevant information. The level of detail in an EFH assessment should be commensurate with the complexity of the action and the severity of the adverse effects on EFH.

NMFS then reviews the EFH assessment and provides the Federal agency with EFH Conservation Recommendations that avoid, minimize, mitigate, or otherwise offset those adverse effects. Councils may also provide comments or recommendations to the Federal agency on actions that may adversely affect EFH and must do so for actions that are likely to substantially affect the habitat, including EFH, of anadromous fishery resources under its authority, such as salmon.

The Federal agency must provide a detailed response in writing to NMFS, and to any Council commenting on the action, within 30 days after receiving EFH Conservation Recommendations. The response must include a description of measures proposed by the agency for avoiding, minimizing, mitigating, or offsetting the impact of the activity on EFH. If the Federal agency chooses not to adopt the EFH Conservation Recommendations, it must provide an explanation. The response must also include the scientific justification for any disagreements with NMFS over the anticipated effects of the action or the measures needed to conserve EFH.

---

habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions.

To provide the greatest level of efficiency, the EFH consultation process is often integrated into existing environmental review procedures such as the National Environmental Policy Act, ESA, or the Fish and Wildlife Coordination Act. However, the existing procedure, or a modified version of it, must meet the requirements described at 50 CFR 600.920. These requirements ensure that NMFS is notified of the action in a timely manner and that it provides all of the information normally contained in an EFH assessment. Combining these procedures can reduce the consultation workload, and associated costs, on both the Federal agency and NMFS.

The consultation requirement applies to Federal agencies only. While state agencies are not required to consult, NMFS can provide EFH Conservation Recommendations for state actions that would adversely affect EFH. However, states are not required to respond to NMFS's recommendations.

The regulations identify four basic types of consultations, where the type selected will depend on the nature of the action and the effects on EFH.

- Programmatic consultations occur when NMFS consults on a group of similar actions that fall within a program (e.g., a road maintenance program). In most cases, when EFH conservation recommendations are accepted by the Federal agency, no further consultation will be required.
- General concurrences can be issued for specific types of actions that do not cause greater than minimal adverse effects on EFH and *no further consultation* will generally be required.
- Abbreviated consultations are conducted if no general concurrence, programmatic consultation, or existing environmental review process is available or appropriate for the action and where the effect on EHF will *not be substantial*.
- Expanded consultation takes place when no other review process is available or appropriate for the Federal action, and that action might result in *substantial adverse effects on EFH*. Procedures for expanded consultation allow for more detailed analysis of effects and more time for NMFS to coordinate with the action agency and develop EFH conservation recommendations.

4.2.2 Description of Non-Fishing Activities That May Adversely Affect Salmon EFH and Potential Conservations Measures

Broad categories of activities which can adversely affect salmon EFH include, but are not limited to:

- Activities causing high intensity underwater acoustic or pressure waves
- Agriculture
- Alternative energy development
- Artificial Propagation of Fish and Shellfish
- Bank Stabilization
- Beaver Removal and Habitat Alteration
- Coal export terminal activities
- Construction/Urbanization
- Culvert construction
- Dam Construction/Operation
- Debris Removal
- Desalination
- Dredging and Dredged Spoil Disposal
- Estuarine Alteration
- Flood control maintenance
- Forestry
- Grazing

- Habitat Restoration Projects
- Introduction/Spread of Invasive Alien Species (IAS)
- Irrigation Water Withdrawal, Storage, and Management
- Liquefied natural gas projects
- Mineral Mining
- Offshore Oil and Gas Exploration, Drilling and Transportation Activities
- Over-water structures
- Pesticide use
- Power plant intakes
- Road Building and Maintenance
- Sand and Gravel Mining
- Vessel Operations
- Wastewater/Pollutant Discharge
- Wetland and Floodplain Alteration

This list of activities is not prioritized by the magnitude of the threat it poses to EFH, nor is it intended to be comprehensive. Federal agencies are required to consult on any activity that may adversely affect EFH, regardless of whether or not it is described in this document. Each of these activities may directly indirectly, cumulatively, temporarily, or permanently, threaten the physical, chemical, and biological properties of the habitat used by salmon species and/or their prey. The results of these threats are that the quality or quantity of salmon EFH may be reduced. The list includes common activities with known or potential impacts to salmon EFH.

Each of these activities is described below along with potential conservation measures and management alternatives. It is important to note that many actions consist of a combination of activities that may adversely affect EFH. For example, construction of a marina may involve overwater structures, pile driving, bank armoring, and dredging. Therefore, it is necessary to break each project into its constituent activities and assess the full suite of adverse effects from all of those activities.

The conservation measures and management alternatives are not designed to be site-specific, but rather to be indicative of the spectrum of possible considerations for the conservation and enhancement of salmon EFH and that might be applied to specific activities. The menu of suggested conservation options is based on the best scientific information available at this time. Not all of these measures are necessarily applicable to every action that includes these activities. Additional measures based on the most current scientific information and project-specific factors may be developed during, or prior to, the consultation process.

4.2.2.1 Activities causing high intensity underwater acoustic or pressure waves

A number of human activities can introduce high levels of sound into the aquatic environment. Some of these sounds are incidental to the purpose of the activity, such as the intense impulsive sounds produced when a pile is driven by an impact hammer or the lower level continuous sounds produced by a cargo ship. Other sounds are an integral and necessary part of the activity, such as the high energy impulsive sounds generated by seismic airguns when exploring for oil and gas or the continuous sounds produced by a sonar array. All of these activities can have unintended consequences to living aquatic resources such as fishes and marine mammals that can range from disrupting important behaviors to injury or even death.

While the effects of underwater sound on fishes has received increased attention over the past decade, a review by Popper and Hastings (2009b) point out that that different sources of noise have widely different characteristics (e.g., frequencies, durations, and intensities) and that different species and sizes of fishes can vary widely in their anatomy and, therefore, in their sensitivity to underwater noise. Fishes with swimbladders are far more susceptible to injury from underwater sound than are fishes that lack swimbladders. Additionally, sound level, and the effects on fishes, declines rapidly with distance from the sound source. Consequently, it is very difficult to extrapolate study results from one noise source, one species of fish, or one size of fish to another source, species, or size. This difficulty is especially relevant when trying to extrapolate between impulsive and continuous sounds. Impulsive sounds are those with high peak pressures, rapid rise and fall times, and relatively short duration while continuous sounds are longer in duration and lack the steep rise and fall times. Current research suggests that impulsive sounds pose the greatest risk to fishes.

Despite the difficulty in extrapolating between sources, species, and sizes of fishes, the paucity of data for most of these makes extrapolating necessary. For example, a coalition of Federal and state resources and transportation agencies along the West Coast, the Fisheries Hydroacoustic Working Group (FHWG), used data from a variety of sound sources (primarily underwater explosions and seismic airguns) and species to establish interim acoustic criteria for the onset of injury to fishes from impact pile driving (FHWG 2008). As a result, they are considered to be conservative (i.e., protective) estimates of the impulsive sound levels that can injure fishes. These criteria, in turn, are also used to estimate the risk to fishes from other types of impulsive sounds. They are not appropriate, however, for non-impulsive, continuous sounds.

Most historical studies have used peak pressure, impulse, or energy flux density to evaluate the effects on fishes form underwater sound. Current research, however, suggests that sound exposure level (SEL), a measure of the total sound energy expressed as the time-integrated, sound pressure squared, is the most relevant metric for evaluating the effects of sound on fishes. An advantage of the SEL metric is that the acoustic energy can be accumulated across multiple events and expressed as the cumulative SEL (SEL_{cum}). The interim criteria established by the FHWG includes a threshold for peak pressure[3] (206 dB re: 1µPa) and SEL_{cum}[4] (187 dB re: 1µPa^2·sec for fishes 2 grams or larger and 183 dB for fishes smaller than 2 grams). Injury would be expected if either threshold is exceeded. These criteria were based on the available information at the time and are subject to change as new information comes to light.

According to Popper and Fay (2010), the most common mode of hearing in fishes involves sensitivity to acoustic particle motion via direct inertial stimulation of the otolith organ(s). Sensitivity to acoustic pressure is the result of the presence of an air bubble (e.g., the swim bladder). Fishes that possess anatomical specializations such as connections or close proximity between the inner ear and that gas bubble may have greater ability to detect, and therefore respond to, sound pressure. Salmon lack these specializations and, as such, they are unlikely to detect sounds when far from the source, except perhaps when the sounds are transmitted through the substrate and reradiated into the water closer to the fish, such as may occur during pile driving. While this may limit the range at which behavioral and auditory effects can occur, the range at which non-auditory effects (e.g., damage to the swimbladder or other barotrauma) can occur will be determined by the sound source, the surrounding environment, and the non-auditory anatomy of the fish.

Anthropogenic noise differs from many other aquatic stressors, such as turbidity or contaminants, in that it does not persist beyond the activity itself – once the activity ceases so does the stressor. In addition, the effects of this stressor are directly on the fish, and are not often recognized as effects on the habitat. These differences raise the question of whether or not acoustic effects meet the definition of an adverse effect under the EFH mandate. The definition of EFH includes "aquatic areas and their associated physical, chemical and biological properties that are used by fish" (50CFR 600), and an adverse effect is any effect that reduces either the quality or quantity of EFH. Underwater sound is but one of the many physical properties of the aquatic habitat used by fishes, and the addition of anthropogenic sound may alter the physical properties of the habitat. Therefore, it is appropriate to consider anthropogenic sound an adverse effect when it reduces the quality of the habitat, even for a very short period of time.

---

3 dB peak pressure is referenced to 1 µPa throughout the rest of this document.
4 dB SEL and SEL_{cum} are references to 1 µPa^2·sec throughout this document

While many activities introduce noise into the aquatic environment, it is not realistic to describe them all because of the lack of information on the effects of the activity or the frequency with which they occur. Therefore, this document will focus on the three activities that pose the greatest risk because they produce impulsive sounds and are frequently conducted: 1) pile driving; 2) underwater explosions; and 3) seismic surveys.

4.2.2.1.1 Pile driving

Piles are an integral component of many overwater and in-water structures. They provide support for the decking of piers and docks, function as fenders and dolphins to protect structures, support navigation markers, and are used for breakwaters and bulkheads. Piles can be made of steel, concrete, wood (both treated and untreated), plastic, or a combination thereof. Piles are usually driven into the substrate using one of two types of hammer: impact hammers and vibratory hammers. Impact hammers consist of a heavy weight that is repeatedly dropped onto the top of the pile, driving it into the substrate. Vibratory hammers utilize a combination of a stationary, heavy weight and vibration, in the plane perpendicular to the long axis of the pile, to force the pile into the substrate. The type of hammer used depends on a variety of factors, including pile material and substrate type. Impact hammers can be used to drive all types of piles, while vibratory hammers are generally most efficient at driving piles with a cutting edge (e.g., hollow steel pipe) and are less efficient at driving “displacement” piles (those without a cutting edge that must displace the substrate). Displacement piles include solid concrete, wood, and closed-end steel pipe. While impact hammers are able to drive piles into most substrates (including hardpan, glacial till, etc.), vibratory hammers are limited to softer, unconsolidated substrates (e.g., sand, mud, gravel). Since vibratory hammers do not use force to drive the piles, the bearing capacity is not known and the piles must often be “proofed” with an impact hammer. This involves striking the pile a number of times with the impact hammer to ensure that it meets the designed bearing capacity. Although less common, the bearing capacity of a pile can be tested using a static load.

Under certain circumstances, piles may be driven using a combination of vibratory and impact hammers. The vibratory hammer makes positioning and plumbing of the pile easier; therefore, it is often used to drive the pile through the soft, overlying material. Once the pile stops penetrating the sediment, the impact hammer is used to finish driving the pile to final depth. An additional advantage of this method is that the vibratory hammer can be used to extract and reposition the pile, while the impact hammer cannot.

Overwater structures must often meet seismic stability and bearing capacity criteria, requiring that the supporting piles are attached to, or driven into, the underlying hard material. This requirement often means that at least some impact driving is necessary. Piles that do not need to be seismically stable, including temporary piles, fender piles, and some dolphin piles, may be driven with a vibratory hammer, providing the surrounding sediments provide sufficient lateral support.

Piles can be removed using a variety of methods, including vibratory hammer, direct pull, clam shell grab, or cutting/breaking the pile below the mudline. Vibratory hammers can be used to remove all types of pile, including wood, concrete, and steel. However, old, brittle piles may break under the vibrations and necessitate another method. The direct pull method involves placing a choker around the pile and pulling upward with a crane or other equipment. Broken stubs are often removed with a clam shell and crane. In this method, the clam shell grips the pile near the mudline and pulls it out. In other instances, piles may be cut or broken below the mudline, leaving the buried section in place.

<u>Potential adverse effects from pile driving</u>

Pile driving can generate intense underwater sound pressure waves that have been observed to injure and kill a number of species of fishes, including Pacific salmon (e.g., Caltrans 2001; Longmuir and Lively 2001; Stotz and Colby 2001; Abbott and Bing-Sawyer 2002; Stadler, pers. obs. 2002). It is one of the most frequent sources of intense underwater sound in coastal waters. This issue came to light in 2001 and has gained considerable attention from Federal and state resource and transportation agencies because of the large number of piles that are driven into aquatic habitats for transportation infrastructure and other purposes. Injuries to non-auditory tissues associated directly with pile driving (collectively known as barotrauma) include rupture of the swimbladder, bruising of the internal organs, and internal or external hemorrhaging. The sounds can over-stimulate the auditory system of fishes and may result in temporary threshold shifts (a non-injurious temporary reduction in hearing sensitivity) or physical injury, such as a loss of hair cells of the sensory maculae (Hastings and Popper 2005).

The type and intensity of the sounds produced during pile driving depend on a variety of factors including, but not limited to, the type and size of the pile-driving hammer, the type and size of the pile, the type of substrate, and the depth of water. All reported instances of fishes killed or injured during pile driving have occurred when impact hammers were used, and none were associated with vibratory hammers. One reason for these observed differences is the different types of sounds that each hammer produces. Impact hammers produce intermittent but intense impulse sounds while vibratory hammers produce continuous sounds of lower intensity. While injury and death have not been observed from vibratory hammers, there are no data to show they are harmless. Firmer substrates require more energy to drive piles, and produce more intense sound pressures. Water depth affects the propagation of the sound, which attenuates more rapidly with distance from the source in shallow water than in deep water (Rogers and Cox 1988).

The magnitude of the effect on salmon that are exposed to the sounds from pile driving will depend on the size and physical condition, depth in the water column, and buoyance state of the fish, as well as the characteristics of the received sound including the shape and energy content of the sound pressure wave. Injury or death associated with pile driving appears to be positively correlated with the size of the pile because driving larger piles requires more energy than smaller piles and produce higher sound levels. The type of pile seems to influence the severity of impacts to fishes. All of the observed fish-kills have been associated with impact driving of hollow steel piles ranging from 24 to 96 inches in diameter. Wood and concrete piles appear to produce lower sound pressures than hollow steel piles of a similar size, although it is not yet clear if the sounds produced by wood or concrete piles are harmful to fishes.

Transportation and resources agencies along the West Coast share a common concern about the effects of pile driving on living resources and a common interest in developing consistent approaches to assessing and minimizing the risk to those resources. As a result, these agencies formed the FHWG that developed and adopted a set of interim criteria to estimate the response of fishes exposed to these sounds (FHWG 2008). These are dual criteria based on protective thresholds for two sound metrics: peak pressure and SEL. SEL is an energy index that is indicative of mechanical work done on the tissues and can be summed over all pile strikes to which the fishes are exposed (SEL_{cum}). Injury is expected to any fish that is exposed to either a peak pressure that exceeds 206 dB or a size-dependent SEL_{cum} that exceeds 187 dB for fishes larger than 2 grams, and 183 dB for fishes smaller than 2 grams. It is important to note that these criteria represent the onset of injury and that higher sound levels are required to cause serious injury or death. When setting these criteria, the FHWG acknowledged that they were based on sparse data and sound sources other than pile driving and are likely to be conservative. The criteria are interim until new information upon which to base changes becomes available.

In recent years, a few field studies were designed to take advantage of a project with pile driving (e.g., Abbott et al. 2005; Ruggerone et al. 2008; Caltrans 2010a, 2010b). However, such “opportunistic” field studies cannot control the levels of sound to which the fish are exposed. In addition, Halvorsen et al. (2012) noted that these studies lacked appropriate biological control groups because the experimental fishes may not have been neutrally buoyant. All salmonids are physostomous, inflating and deflating their swimbladder by gulping in or burping out air, and may have deflated the swimbladder when handled prior to the experiment. A deflated swimbladder could put the fish at a lower risk of injury from the sounds, leaving the validity of the results open to question

To address these issues, Halvorsen et al. (2011, 2012) conducted a laboratory study on juvenile Chinook salmon using an apparatus that was specially designed to simulate, and precisely control, the sounds and intensities produced during impact pile driving. It also incorporated a protocol to ensure that the test fish were neutrally buoyant before exposure to the sound. This study attempted to establish thresholds for the sound levels that would cause physical injury to juvenile Chinook salmon. Juvenile Chinook salmon (mean standard length 103 mm, mean weight 11.8 g) were exposed to between 204 dB and 220 dB SEL_{cum}, at single strike SELs of 171 dB to 187 dB. The authors concluded that the onset of injury to Chinook salmon occurred at 210 dB SEL_{cum}.

Based on these results, the authors suggested that a minimum SEL_{cum} of 210 dB was required to inflict injury on these fish, far lower than the 187 dB or 183 dB set by the FHWG. However, the FHWG has not yet revised its criteria because of several concerns. First, the study developed a novel model to reflect the onset of injury from impulsive sounds that used undescribed energetic costs to weight the injuries. Without knowing these costs, it is difficult to evaluate the validity of the model. Second, the study was unable to assess the effects of noise exposure on the inner ear, an important sensory system that can be damaged by exposure to sounds. Finally, although eye hemorrhaging and bruising of the spleen were observed, they were excluded from the analysis because they were inconsistently scored and recorded (Halvorsen, pers. com). Because the studies did not account for these injuries, there remains uncertainty around the proposed 210 dB SEL_{cum} threshold. It should be noted here that the interim criteria developed by the FHWG were intended for the protection of salmonids listed under the ESA. Under the ESA, any form of injury, even apparently non-life threatening injuries such, as eye hemorrhage or bruises to the spleen, are to be avoided when possible. However, the EFH mandate is intended to maintain a species or stock at a level that supports a sustainable fishery. As such, the interim criteria should be viewed as conservative.

Despite the uncertainty regarding the acoustic threshold for onset of injury to Chinook salmon, this study provides important new insights into the effects on Chinook salmon from pile driving. First, no fish died immediately to SEL_{cum} as high as 220 dB (Halvorsen et al. 2012). And second, there was 100 percent survival and near full recovery from injuries in fish held for two weeks in the laboratory (Casper et al. 2012). These findings are important because it is a first step in distinguishing acoustic thresholds that inflict mortal injuries from those for the onset of injury. While these studies showed that the observed injuries were not directly fatal to fish held in the safety of the laboratory, the survival of fish with these types of injuries has yet to be tested in the wild, where injured fishes could be more susceptible to predation or disease or be less efficient at foraging or reproducing.

The behavioral response of fishes to underwater sound depends on a variety of factors, including the species of fish, the type of sound (impulsive vs continuous), and the intensity of the sound (see review by Hastings and Popper 2005). The observed behavioral changes include startle responses, changes in swimming activity, and increases in stress hormones. However, few studies have examined the behavioral response of fishes to the sounds that are comparable to those from pile driving. A number of species of fishes, including chinook salmon and Atlantic salmon (*Salmo salar*), have been shown to avoid continuous sounds (similar to vibratory pile driving) at frequencies below 30 Hz (infrasound), but not impulsive-type sounds (similar to those from impact pile driving) at frequencies above 100 Hz (e.g., Knudsen et al. 1992; Enger et al. 1993; Knudsen, et al. 1997; Sand et al. 2001). In contrast, McKinley and Patrick (1988) successfully used impulsive-type sounds to divert downstream migrating sockeye salmon (*O. nerka*) smolts from at a hydroelectric dam. Feist et al. (1992) observed that juvenile pink salmon and chum salmon appeared to be less prone to spooking by an observer on the shore when piles were being driven. This reduced awareness could lead to increased predation. Ruggerone et al. (2008) found no observable changes in the behavior of caged coho salmon in the vicinity of impact pile driving; however, the behavior may have been affected by the cages themselves. Atlantic cod (*Gadus morhua*) and Dover sole (*Solea solea*) increased swimming speed in response to impact pile driving sounds at levels as low as 140 dB (re: 1µPa rms) (Mueller-Blenkle et al. 2010). Atlantic cod also showed significant freezing response at the onset and cessation of these sounds. Fewtrell and McCauley (2011) found that two species of demersal/pelagic schooling fish demonstrated significant increases in alarm responses to airgun noise exceeding 147 dB SEL, and that alarm responses increased with increasing noise levels, but the responses differed between the two species. Faced with the paucity of data on the response of salmon to pile driving sounds, the FHWA is currently using a conservative level of 150 dB (re: 1 µPa) root-mean-square as a trigger for closer analysis of potential adverse behavioral effects from all types of sounds, including those from impact and vibratory hammers. The potential for adverse behavioral effects will depend on a number of factors, including the life stages that are present. For example, the level of concern would be higher for juvenile salmon that are migrating through an area to the ocean and face a greater risk of predation than a subadult or adult in marine waters.

Potential conservation measures for pile driving

- When possible, avoid driving piles when salmon are present, especially the younger life stages and spawning adults.
- Avoid driving piles with an impact hammer when salmon or their prey are present. Alternatives include vibratory hammers or press-in pile drivers.
- In cases where an impact hammer must be used, drive the piles as far as possible with a vibratory or other method that produces lower levels of sound before using an impact hammer.
- Select piles that are made of alternate materials that produce less-harmful sounds than those from hollow steel piles, such as concrete or untreated wood instead of steel.
- When driving piles in intertidal or shallow subtidal areas, do so during periods of low tide. Sound does not propagate as well in shallow water as it does in deep water.
- Implement measures to attenuate the sound. Such measures include the use of a bubble curtain or a dewatered pile sleeve or coffer dam. Monitor the sound levels during pile driving to ensure that the attenuation measures are functioning as expected.
- Where tidal currents can be strong, drive the piles when the current is reduced (i.e., centered on slack current) to minimize the number of fish exposed to adverse levels of underwater sound. Strong currents can bring more fish into close proximity to the pile than would a weak current.
- Monitor, and report back to NMFS, the sound levels during pile driving to verify that the assumptions in the analysis were correct and to ensure that any attenuation device is properly functioning. Develop the monitoring and reporting protocols according to guidance provided by the FHWG (2013). The report should be provided to NMFS according to the individual project requirements, but no later than 60 days after completion of the pile driving.
    - The FHWG (2013) developed a hydroacoustic monitoring protocol and reporting template for use on pile driving projects along the West Coast.

4.2.2.1.2 Underwater explosions

Explosives are detonated underwater for a number of reasons, such as deepening a shipping channel or demolishing in-water structures such as a bridge pier or an offshore oil rig. Seismic surveys were historically conducted using explosives but have since been replaced by other methods. Explosives produce two types of waves: shock waves and pressure waves.

Potential adverse effects of underwater explosions

The effects of underwater explosions on fishes have been studied for at least 60 years and have been shown to depend on a variety of factors, including the type of explosive and the anatomy of the fish. Hubbs and Rechnitzer (1952) used caged-fish experiments to compare the effects of two types of explosives – black powder and trinitrotoluene (TNT). The study found that black powder charges inflicted fewer injuries and killed fewer fishes than did TNT charges that produced the same peak pressure. The authors attributed this difference to the slower detonation rate and associated slower rise time of the low explosive black powder charges. Baldwin (1954) found that adult Pacific salmon were not killed during a seismic survey that used black powder charges and caught salmon by trolling within close proximity to the seismic shots, indicating that they did not leave the area and were still feeding.

Yelverton et al. (1975) exposed eight species of freshwater fishes to underwater explosions and found that smaller individuals were more sensitive to the explosion than were larger individuals, regardless of the species. There also did not appear to be a difference in sensitivity between those species with ducted swimbladders (physostomous) and non-ducted swimbladders (physoclistous). The authors found impulse, to be a better predictor of injury rather than peak pressure and provided equations to predict impulse levels that would kill 50 percent and 1 percent of individuals and the levels that would cause no injury. Unfortunately, the there is no clear way to convert the impulse metric used by Yelverton et al. to SEL. In contrast to the lack of a difference between species found by Yelverton et al. (1975), Teleki and Chamberlain (1978) found that laterally compressed fishes were more susceptible to blast injury than were fusiform fishes. In addition, they reported that approximately 47 percent of the fishes killed sank and were not visible from the surface.

Several efforts have been made to estimate the distances at which fishes will be affected by underwater explosions. Young (1991) provides equations for calculating the distance, based on charge weight body mass, where the probability of survival was 90 percent. Wright and Hopky (1998) assumed a peak pressure threshold for impacts to fishes at 100 kPa (220 dB) and provide equations for calculating the distance from the explosion to the 220 dB isopleth.

More recently, Govoni et al. (2003; 2008) exposed juvenile and larvae of two species, spot (*Lieostomus xanthurus*) and pinfish (*Lagodon rhomboids*), to underwater explosions and considered impulse and energy flux density to be the relevant metrics. Hastings (2007) subsequently calculated the SEL for each treatment using the original waveform data and suggested that SELs as low as 183 dB was sufficient to injure fishes smaller than 2 g.

Keevin et al. (1997) found that bubble curtains, created by injecting compressed air into the water column were highly effective at reducing the mortality of caged bluegills (*Lepomis macrochirus*) during detonation of a 2kg high-explosive charge. The bubble curtain reduced peak pressure, impulse, and energy flux density by 88 to 99 percent. Another potential mitigation measure is dividing large explosive charges into smaller charges by use of blasting caps with timing delays (Keevin 1998). The use of delays effectively reduces each detonation to a series of small explosions rather than one larger one. However, the effectiveness of delays and defining the delay period that provides maximum protection requires further examination.

Potential conservation recommendations for underwater explosions

- Evaluate the need to use explosives and use practical alternatives if they are available.
- Avoid times of the year when salmon are present. If it is not practicable to conduct the activity when salmon are absent, avoid doing so when the smallest, and therefore most vulnerable, life stages are present.
- Do not conduct the activity where it could affect spawning adult salmon.
- Rather than use a single large charge, use a series of smaller charges that are separated by delays that are longer than the duration of the blast wave.
- Plan the blasting program to minimize the size of explosive charges per delay and the number of days that explosives are used.
- Surround the explosion with a bubble curtain or other sound attenuation device to minimize the extent of the habitat area where salmon could be injured.

4.2.2.1.3 Seismic surveys

Seismic surveys direct sound waves at, and into, the seafloor and use the reflected waves to map the geology of the earth's subsurface. The most common use of seismic surveys is to explore for oil and gas, both onshore and offshore, but they have other uses such as assessing the geology underlying roads and bridges (OGP 2011). Towed in arrays behind ships, the air guns release repetitive bursts of compressed air underwater to produce the high-energy, low-frequency impulsive sound waves used in the survey. The sounds produced by an airgun array can reach nominal peak-to-peak pressures of up to 264 dB (LGL and MAI 2011). Sound waves can also be generated by marine vibroseis, a technology that uses hydraulic or electrical vibrators to generate continuous, low-frequency sounds (5-250 Hz) at levels that are considerably lower than an airgun array (LGL and MAI 2011). In addition to the lower sound levels, marine vibroseis produces a continuous sound, with strong suppression of unwanted higher frequencies associated with airguns, and, under most conditions, would be less damaging to the environment than would airguns (LGL and MAI 2011).

Potential adverse effects of seismic surveys

The possible impact of seismic surveys on marine life has been of great concern and a number of experimental studies have been conducted to investigate these effects on fishes. However, few studies, to date, have investigated the effects of seismic surveys on salmonids. Svedrup et al. (1994) exposed Atlantic salmon to detonating blasting caps, which simulated the blast from a seismic survey. The vascular endothelium showed signs of injury within 30 minutes of exposure, as compare to control specimens that did not show these effects. The fish recovered from their injuries within one week. The study also found short-term changes in the levels of stress hormones that were attributed to exposure the seismic shots. However, the received SEL_{cum} was not reported so it is difficult to assess the actual risk to salmon. These results are consistent with those of Santulli et al. (1999), who found that European sea bass (*Dicentrarchus labrax*) exposed to airgun blasts also showed short-term (48 hours) variations in several biochemical stress indicators.

A study on the effects of seismic airguns on three species of fishes found temporary auditory threshold shifts in two of them [adult northern pike (*Esox lucius*), and lake chub (*Couesius plumbeus*)] after exposure to 5 to 20 airgun blasts with a SEL_{cum} of 185 to 191 dB (Popper et al. 2005). Normal hearing returned in less than 24 hours. In contrast, no threshold shift was observed in broad whitefish (*Coregonus nasus*), a salmonid and close relative of Pacific salmon, exposed to 5 airgun blasts with a SEL_{cum} of 187 dB. They also found no damage to the inner ears or any signs of external injury in the exposed fish and no significant difference in the survival of experimental and control fish (Popper et al. 2005; Song et al. 2008). Unfortunately, the study did not include detailed necropsies so it is unknown if the exposed fishes incurred any internal damage.

Several studies have investigated how the sounds from seismic surveys affect non-salmonids, with differing results. McCauley et al (2003) exposed caged pink snapper (*Pagrus auratus*) to hundreds of shots from an air gun as it approached and moved over and beyond the cages. Received SELs reached 180 dB for several of the individual shots, but the SEL_{cum} from all the shots was not reported. The results showed that 2-7 percent of the sensory hair cells in the inner ears were lost in several of the animals after a post exposure period of 58 days, and that the damage did not become apparent until sometime after exposure. Popper and Hastings (2009a) pointed out that this was only a visual manifestation of what may have been a much greater effect. Hastings et al. (2008) found no hearing loss in three species of reef fishes following exposures up to 190 dB SEL_{cum}. These results reinforce the need for caution when extrapolating the effects of seismic airguns on one species to the effects on another species.

Booman et al. (1996, cited in Hastings and Popper 2005) found significant death of the eggs, larvae, and fry of Atlantic cod (*Gadus morhua*), saith (*Pollachius virens*), and Atlantic Herring (*Clupea harengus*), as well as damage to the neuromasts of the lateral line, but only when the specimens were within about 5 m of the source, with the most substantial effects occurring when the fishes were within 1.4 m of the source. However, at such close distances to the air-gun, the hydrodynamic motion would be huge and could have been the case of the injury, but the received sound pressure and fluid motion were not reported in this study (Popper and Hastings 2009a).

Seismic surveys have been shown to affect the behavior of a number of fish species. These effects include changes in distribution (e.g., Skalski et al. 1992; Engås et al. 1996; Engås and Løkkeborg 2002; Slotte et al, 2004) and other minor behavioral effects such as an initial startle response at the beginning of the exposure that wanes as the airgun shots continue (Wardle et al. 2001; Boeger et al, 2006). Fewtrell and McCauley (2011) found that two species of demersal/pelagic schooling fish demonstrated significant increases in alarm responses to airgun noise exceeding 147 dB SEL, and that alarm responses increased with increasing noise levels, but the responses differed between the two species.

How a Pacific salmon would respond to these seismic sounds has not been investigated, but even minor injuries, small but temporary changes in hearing sensitivity, or short-term changes in behavior could interfere with their ability to perform normal functions, such as detecting predators. Feist, et al. (1992) reported that juvenile pink salmon and chum salmon appeared to be less apt to startle when approached by observers when pile driving was occurring compared to when it was not, perhaps making them more susceptible to predators. The likelihood that such small changes could affect Pacific salmon will depend in large part on the life stage and activity, with small juveniles likely being more sensitive than the larger sub-adults and adults. Fortunately, the most sensitive life stages – eggs, alevins, fry, and spawning adults – reside in riverine habitats, where seismic surveys are less likely to occur.

As described above, the FHWG established interim criteria for the onset of injury to fishes exposed to impulsive sounds. However, several factors complicate our ability to predict whether or not those criteria will be exceeded: 1) an airgun array produces sound from multiple sources; 2) the array moves as it is towed along the transect; 3) the movements of the salmon are unpredictable; and 4) salmon do not appear to avoid vessels at sea and may come in close proximity to the airgun array. As such, it may be more practical to simply implement measures to minimize the exposure risk.

Most discussions of techniques to mitigate or minimize the effects of seismic surveys address the effects to marine mammals (e.g., JNCC 2010; Nowacek 2013). Passive acoustic monitoring or the use of observers will not benefit salmon, and ramping up the power of the airgun array ("soft start") to allow time for the animals to move out of the area is likely of little benefit. However, several other mitigation measures, such as using the least powerful airgun necessary to conduct the survey and minimizing the footprint of the survey to the extent feasible, can benefit salmon. Although marine vibroseis is not commonly used, it is likely to be less damaging to aquatic animals than airguns (LGL and MAI 2011), because the signals are continuous, at lower levels, and have better suppression of unwanted higher frequencies.

Potential conservation measures for seismic surveys

- Avoid areas and times of year when salmon, such as smaller juveniles, are present. If surveys must be conducted when salmon are present, do so when the abundances are relatively low.
- Avoid areas and times of year when the fish species that salmon prey upon are present. If surveys must be conducted with these species are present, so when the abundances are relatively low.
- When salmon are migrating through the area, provide sufficient breaks in the survey to allow transit through the area.
- Use marine vibroseis instead of airguns when possible.
- Use the least powerful airguns that will meet the needs of the survey.
- Survey the smallest area possible to meet the needs of the survey.

4.2.2.2 Agriculture

Potential adverse effects from agriculture

The nature of agricultural activities and their potential effects cover a very broad range. Meat and milk production can have effects ranging from the nutrient discharges that may be associated with large confined animal feeding operations to slight modification of natural vegetation that may occur with properly managed grazing on rangelands. The effects of crop production range from significant soil disturbance and use of chemicals producing row crops to the minimal effects that may occur in pasture and hay production on organic farms. Agriculture activities often take place on historical flood plains of river systems, where they have a direct effect on stream channels and riparian functions. Furthermore, irrigated agriculture frequently requires significant use of water, which may decrease streamflow, lower water tables, and increase water quality problems, e.g., higher water temperatures. (see Section 4.2.2.19 Irrigation Water Withdrawal, Storage, and Management).

Replacing natural grasslands, forests, and wetlands with annual crops may leave areas unvegetated during part of the year and can change the function of plants and soil microbes in the tilled areas. Repeated tillage, fertilization, pesticide application and harvest can permanently alter soil character, resulting in reduced infiltration and increased surface runoff. These changes alter seasonal streamflow patterns by increasing high flows, lowering water tables, and reducing summer base flows in streams.

Agricultural land use can contribute substantial quantities of sediments to streams (Spence et al. 1996). Deposited sediment can reduce juvenile salmonid rearing and adult habitat by the filling of pools (Waters 1995), filling the interstitial spaces of bottom gravel, and by reducing the overall surface area available for invertebrates (i.e., prey) and fish production. Suspended sediment can decrease primary productivity, deplete invertebrate populations (by increasing downstream drifting) as well as interfere with feeding behavior (Waters 1995).

Agriculture can negatively affect stream temperatures by the removal of riparian forests and shrubs which reduces shading and increases wind speeds. In addition, bare soils may retain greater heat energy than vegetated soils, thus increasing conductive transfer of heat to water that infiltrates the soil or flows overland into streams (Spence et al. 1996). In areas of irrigated agriculture, temperature increases during the summer may be exacerbated by heated return flows (Dauble 1994). Warm water temperatures can harm fish directly through various mechanisms including oxygen depletion and increased stress and decreased survival.

Agricultural crops may require substantial inputs of water, fertilizer, and pesticides to thrive. Nutrients (e.g., phosphates, nitrates), insecticides, and herbicides are typically elevated in streams draining agricultural areas, reducing water quality and affecting fish and other aquatic organisms (Omernik 1977; Waldichuk 1993). These changes in water quality can cause ecosystem alterations that affect many biological components of aquatic systems including vegetation within streams, as well as the composition, abundance, and distribution of macroinvertebrates and fishes. These changes can affect the spawning, survival, food supply, and the health of salmon (Stober et al. 1979; NPPC 1986). Though currently used pesticides are not as persistent as previously used chlorinated hydrocarbons, most are still toxic to aquatic life. However, where biocides are applied at recommended concentrations and rates, and where there is a sufficient riparian buffer, the toxic effects on aquatic life may be minimal (Spence et al. 1996).

Chemicals such as some pesticides, phosphorus, and ammonium are transported while adsorbed to sediment. Changes in the aquatic environment, such as a lower concentration of chemicals in the overlying waters or the development of anaerobic conditions in the bottom sediments, can cause these chemicals to be released from the sediment. Phosphorus transported by the sediment may not be immediately available for aquatic plant growth but does serve as a long-term contributor to eutrophication, a condition in which excess nutrients lead to algal blooms and decreased oxygen levels as the algae decompose (EPA 1993).

Groundwater is susceptible to nutrient contamination in agricultural lands composed of sandy or other coarse-textured soil (Franco et al. 1994). Nitrate, a highly soluble form of nitrogen, can leach rapidly through the soil and accumulate in groundwater, especially in shallow zones (Jordan and Weller 1996; Brady and Weil 1996). This groundwater can be a significant source of nutrients in surface waters when discharged through seeps, drains, or by direct subsurface flow to water bodies (Lee and Taylor 2000).

Agricultural practices may also include stream channelization, LWD removal, installation of rip-rap and revetments along stream banks, and removal of riparian vegetation (Spence et al. 1996). Natural channels in easily eroded soils tend to be braided and meander, creating channel complexity as well as accumulations of fallen trees, which help create large, deep, relatively permanent pools, and meander cutoffs. These complex channel habitats create important spawning and rearing habitat by trapping sediment, nutrients, and organic matter, sorting gravels, providing cover and hydrologic heterogeneity (Harmon et al. 1986; Abbe and Montgomery 1996; Bilby and Bisson 1998).

Confined animal facilities (e.g., feed lots) may also adversely affect salmon habitat if the concentrated animal waste, process water (e.g., from that of a milking operation), and the feed, bedding, litter, and soil which comes intermixed with the fecal and urinary wastes is not properly contained and managed. If not properly treated, storm water run-off water and process water can carry nutrients, sediment, organic solids, salts, as well as bacteria, viruses, and other microorganisms into salmon habitat (EPA 1993). These pollutants can cause oxygen depletion, turbidity, eutrophication and other effects on the habitat quality for salmon.

Potential conservation measures for agriculture

The establishment of properly functioning riparian conditions and achieving instream water quality standards should be the goal of restoration and management projects on agricultural lands. Agricultural activities should strive to protect riparian vegetation and water quality through conservation practices and management plans.

The 2008 reauthorization of the Farm Bill (the "Food, Conservation, and Energy Act") included several conservation programs that provide potential benefit to EFH. They are the Environmental Quality Incentives Program, the Wetlands Reserve Program, and the Conservation Reserve and Enhancement Programs. These programs provide farmers assistance for idling erosion-prone land, preserving wetlands, and undertaking land management conservation practices. Land owners are encouraged to contact their local agricultural extension agents to find out further information about these programs.

Below are measures that can be undertaken by the action agency on a site-specific basis to conserve, enhance, or restore salmon EFH adjacent to agricultural lands that have the potential to be adversely affected by agricultural activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to or during the EFH consultation process, and communicated to the appropriate agency. The options listed below represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from EPA (1993).

- Maintain riparian management zones of appropriate width on all permanent and ephemeral streams that include or influence EFH. The riparian management zones should be wide enough to restore and support riparian functions including shading, LWD input, leaf litter inputs, sediment and nutrient control, and bank stabilization functions.

- Reduce erosion and run-off by using practices such as contour plowing and terracing, no till agriculture, conservation tillage, crop sequencing, cover and green manure cropping and crop residue, and, by maximizing the use of filter strips, field borders, grassed waterways, terraces with safe outlet structures, contour strip cropping, diversion channels, sediment retention basins and other mechanisms including re-establishment of vegetation.
- Participate in and benefit from existing programs to encourage wetland conservation and conservation reserves, avoid planting in areas of steep slopes and erodible soils and avoid disturbance or draining of wetlands and marshes.
- Incorporate water quality monitoring as an element of land owner assistance programs for water quality. Evaluate monitoring results and adjust practices accordingly.
- Minimize the use of chemical treatments within the riparian management zone. Review pesticide use strategies to minimize impact to EFH. Reduce pesticide application by evaluating pest problems, past pest control measures and following integrated pest management strategies. Select pesticides considering their persistence, toxicity, runoff potential, and leaching potential.
- Optimize the siting of new confined animal facilities or the expansion of existing facilities to avoid areas adjacent to surface waters containing EFH or in areas with high leaching potential to surface or groundwater. Use appropriate methods to minimize discharges from confined animal facilities (for both wastewater and process water).
- Where water quality is limited from nutrients or where leaching potential is high, avoid land application of manure or other fertilizer unless appropriate management measures are in place to assure that sediment and nutrient input to surface water is controlled. Observe best management practices (BMPs) to assure that application and timing measures fostering high nutrient utilization are employed.
- Apply conservation measures for water intake (see Sectin 4.2.2.19 Irrigation Water Withdrawal, Storage, and Management) to agricultural activities where applicable.
- Encourage farmers to take advantage of the conservation programs that were reauthorized in the Food, Conservation, and Energy Act of 2008 (i.e., Farm Bill).

4.2.2.3 Alternative energy development

Marine, estuarine, and freshwater hydrokinetic energy refers to electrical energy that comes from “waves, tides, and currents in oceans, estuaries, and tidal areas; free flowing water in rivers, lakes, and streams; free flowing water in man-made channels; and differentials in ocean temperatures (ocean thermal energy conversion)” (U.S. DOE 2009). For the purpose of considering threats to designated salmon EFH on the West Coast of the United States, this report focuses on nearshore wave energy and tidal turbine energy development because it is the most likely form of hydrokinetic technology to move forward within the next 5-years. Ocean thermal energy and offshore wind development is not considered in this discussion because they are not likely to be proposed off the West Coast of the United States in the near future.

Wave energy conversion devices can be grouped by the design features to capture wave energy, into six main types: point absorbers, attenuators, oscillating wave surge converters, oscillating water column, overtopping devices, and submerged pressure differential devices (U.S.DOE 2009). Tidal turbines are placed on the bottom and can have an exposed or closed blade. Although each design is unique, these devices are typically attached to the seafloor, channel bottom, or some type of structure and deployed at or near the water’s surface or at depth.

In order to develop and operate wave or tidal hydrokinetic projects, there are four phases of activities that can potentially affect salmon EFH. The potential effects of each phase of a hydrokinetic project (preconstruction, construction, operation and maintenance, and decommissioning) need to be considered (Boehlert and Gill 2010; Gill 2005; Kramer et al. 2010; Previsic 2010; U.S.DOE 2009). In addition to the design features and footprint of an individual device, the spatial and temporal scales of a project (single device /short-term; single device /long term; multiple devices /short term; multiple devices /long term) are important considerations when evaluating effects on salmon EFH (Boehlert and Gill 2010). The potential cumulative effects of the spatial arrangement (vertical and horizontal) of multiple devices in the water column also need to be evaluated.

Construction activities typically include: horizontal directional drilling to land cables from the device to the shoreline; laying of subsea transmission cable; foundation/mooring installation; deployment and commissioning of device(s). Operation and maintenance include the mechanical functioning of the devices and appurtenances, as well as inspection and repair of equipment. Decommissioning at the end of the project (typically 5-30 years) involves removal of all equipment in the water column and transmission cables and restoration of the site, if needed.

Related activities that pertain to both the construction and operations phases include installation and maintenance of navigation buoys to mark the deployment area; and reliable port infrastructure to accommodate work vessels as well as delivery and retrieval of large hydrokinetic devices to pier-side for repair and maintenance, if necessary.

Potential adverse impacts from alternative energy development

Because the majority of hydrokinetic renewable energy technologies remain at the conceptual stage and have not yet been developed as full-scale prototypes or tested in the field, there have been few studies of their environmental effects. Currently, identification of the potential environmental effects have been developed from: (1) predictive studies; (2) workshop reports from expert panels; and (3) report syntheses prepared from published literature related to other technologies, e.g., noise generated by similar marine construction activities, measurements of electromagnetic fields (EMFs) from existing submarine cables, environmental monitoring of active offshore wind farms in Europe, and turbine passage injury reduction mechanisms employed in conventional hydropower turbines.(Boehlert and Gill 2010; Kramer et al. 2010; Nelson et al. 2008; U.S. DOE 2009).

The majority of potential effects on salmon EFH are from the presence and operation of a wave energy convertor device or turbine. Although all phases of an individual project will alter the physical marine environment, the types and duration of those changes are varied. Numerous reviews (Kramer et al. 2010; U.S.DOE 2009) have identified the following potential effects of the wave energy converter devices, all of which may affect the quality and quantity of salmon EFH: (1) alteration of current and wave strengths and directions; (2) alteration of substrates and sediment transport and deposition; (3) interference with animal movements and migrations, including fish (prey and predators) and invertebrate attraction to subsurface components of device, concentration of displaced fishing gear; (4) presence of rotor blades or other moving parts; and attraction and concentration of predators on surface components of device; (5) alteration of habitats for benthic organisms; (6) sound and vibration in water column during construction and operation; (7) generation of EMFs by electrical equipment and transmission lines; (8) release into water column of toxic chemicals from paints, lubricants, antifouling coatings, as well as spills of petroleum products from service vessels. These potential effects on salmon EFH apply to tidal turbines as well.

Presence of subsurface structures may affect water movements, as well as sediment transport, erosion, and deposition at a local scale. During construction and decommissioning, the installation and removal of the foundations, anchors, and transmission cables will disturb and suspend sediments, and may mobilize contaminants, if present. Disturbances to the benthic habitat will occur during temporary anchoring of construction vessels; clearing, digging and refilling trenches for power cables; and installation of permanent anchors, pilings, and other mooring devices. Prior to installation of a buried cable, any debris is typically cleared from the cable route using a ship-towed grapnel (Carter et al. 2009). Cables are buried using a ship mounted plow, whereas buried cables are usually exposed and reburied using a water-jetting technique when needing repair (Carter et al. 2009). Water quality will be temporarily affected by: (1) increased suspended sediments and resultant increased turbidity and decreased water clarity; (2) localized reduction of dissolved oxygen where anoxic sediments are suspended; and (3) mobilization of anoxic or buried contaminated sediments during cable route clearing and installation of cables.

The physical structures associated with ocean and tidal energy operations could potentially interfere with the migration and rearing habitat functions for juvenile and adult salmonids (U.S.DOE 2009). The floating and submerged structures, mooring lines, and transmission cables may create complex structural habitat that could act as a fish aggregating/attraction device (FAD), as well as provide substrate for attachment of invertebrates (considered biofouling where unwanted). Salmonids may be attracted to the physical structure itself, and/or to forage fish attracted to the structure. Floating offshore wave energy facilities could potentially (1) create artificial haul-out sites for marine mammals (pinnipeds) and roosting of seabirds; and (2) trap floating vegetation (e.g., kelp, eelgrass, large wood), and lost fishing gear (e.g., nets, traps, and crab pots). Aggregation of predators (e.g., fish, marine mammals, sea birds) near FADs may reduce the safe passage attribute of a migration corridor by subjecting juvenile or adult salmonids to increased predation. Drifting nets and other fishing gear that may become entangled on mooring lines or the devices may decrease the quality of salmon migration routes due to capture from passive fishing of gear. Deposition of organic matter from biofouling on the structure can change the chemical properties and biological communities near the structures. There will be new lighted, fixed surface structures (devices and navigation buoys marking the project area) in the marine environment which may attract prey and predators of juvenile and adult salmonids.

Depending on the frequency and amplitude of the sound of the moving parts of the device, as well as how far the sound waves propagate, the operational sounds of the devices may affect rearing and migration corridor habitat. There is limited information on sound levels produced during construction (e.g., offshore pile driving) and operation of ocean energy conversion devices, as well as the spatial extent of any altered acoustic environment. Turbines with exposed rotor blades may impede or entrained salmon.

Migrating adult and juvenile salmonids may be exposed to EMFs generated at a project site, which may affect the movement of salmon. The electric current in the cables will induce a magnetic field in the immediate vicinity (U.S.DOE 2009). During transmission of produced electricity, the matrix of vertical and horizontal cables will emit low-frequency EMFs. The source and effects of EMFs in the marine environment are limited and uncertain (Gill 2005).

Accidental, but acute, release of chemicals from leaks or spills (e.g., hydraulic fluids from a wave energy conversion device, drilling fluids during horizontal drilling) could have adverse effects on water quality. Anti-fouling coatings inhibit the settling and growth of marine organisms, and chronic releases of dissolved metals or organic compounds could occur from these compounds (U.S.DOE 2009). The cumulative effects on salmon and their prey from decreased water quality associated with the release of toxic chemicals could vary substantially depending upon the number of units deployed, type of antifouling coating used, and the maintenance frequency of the coating.

Potential conservation measures for alternative energy development

Structural and operational mitigation options are often unique to the technology or issue of concern.

- Locate and operate devices at sites and times of the year, to avoid salmon migration routes and seasons, respectively.
- Schedule the noisiest activities, i.e., pile driving, at times of the year to minimize exposure of juvenile and adult salmon.
- Schedule transmission cable installation to minimize overlap with salmon migration seasons.
- Conduct pre-construction contaminant surveys of the sediment in excavation and scour areas.
- To avoid concentration of predators, above water structures could have design features to prevent or minimize pinniped haul-out and bird roosting.

- Sheath or armor the vertical transmission cable to reduce transmission of EMF into the water column.
- Bury transmission cables on the sea floor to minimize benthic and water column EMF exposure.
- Align transmission cables along the least environmentally damaging route. Avoid sensitive habitats (e.g., rocky reef, kelp beds) and critical migratory pathways.
- Use horizontal drilling where cables cross nearshore and intertidal zones to avoid disturbance of benthic and water column habitat.
- Design the mooring systems to minimize the footprint by reducing anchor size, and cable/chain sweep.
- Develop and implement a device/array maintenance program to remove entangled derelict fishing gear and other materials that may affect passage.
- Use non-toxic paints and lubricating fluids where feasible.
- Limit the number of devices and size of projects until effects are better understood and minimization measures tested.

4.2.2.4 Artificial Propagation of Fish and Shellfish

Public and private hatcheries, acclimation sites, and net pens producing Pacific salmon (coho salmon, Chinook salmon, chum, pink, kokanee, sockeye, steelhead, and cutthroat), trout (Atlantic salmon, brown, rainbow, and golden), char (eastern brook, and lake trout), sturgeon, and several species of warmwater fish operate in and adjacent to salmon EFH in fresh and sea water (NRC 1996; WDFW 1998). Additionally, captive breeding of threatened or endangered stocks of sockeye and spring Chinook salmon occurs in Idaho, Oregon, and Washington, and of endangered winter Chinook salmon and coho salmon in California (Flagg et al. 1995; Sturm et al. 2009). Shellfish culture in salmon EFH consists primarily of oyster culture, although clams, mussels, and abalone are grown as well. Geoduck culture is the fastest growing segment of shellfish culture located in salmon EFH.

Currently, there are several hundred public facilities (Federal, tribal, and state-operated) producing Pacific salmonids for release into fresh and sea water salmon EFH (NRC 1996). In addition, hundreds of private hatcheries in salmon EFH produce various salmon and trout species, as well as catfish and tilapia, for commercial sale.

The artificial propagation of native and nonnative fish in or adjacent to salmon EFH has the potential to adversely affect that habitat by altering water quality, modifying physical habitat, and creating impediments to passage. Artificial propagation of finfish may also adversely impact EFH by predation of native fish by introduced hatchery fish, competition between hatchery and native fish for food and habitat, exchange of diseases between hatchery and wild populations, the release of chemicals in natural habitat, and the establishment of nonnative populations of salmonids and nonsalmonids. Many of these potential adverse effects have been summarized by Fresh (1997). These concerns have led to revision of many hatchery policies to eliminate or reduce impacts on wild fish (USFWS 1984; ODFW 1995; WDF 1991; NWIFC/WDFW 1998).

Various methods of shellfish culture and harvest also have the potential to adversely impact salmon EFH, such as mechanical harvest in eelgrass beds, harrowing, off-bottom culture, and raft and line culture. Typically, the greatest impacts are temporary and are realized during mechanical harvest or harrowing, which involved physical disturbance of the benthic zone. Recovery time after disturbance to seagrass varies with seagrass species, disturbance size, disturbance intensity, and sediment characteristics (Dumbauld et al. 2009). Mechanical harvest or harrowing typically follows a 3-5 year (depending on species cultured) growth period. Mechanical harvest and harrowing are only applicable for on-bottom culture methods. The use of chemicals to control burrowing organisms detrimental to oyster culture may also adversely affect EFH for both salmon and non-salmonids. To control burrowing shrimp, for example, Washington State has used the pesticide carbaryl since 1963. About 800 acres are treated with carbaryl annually in Grays Harbor and Willapa Bay, with a given oyster bed sprayed about every 6 years. Nontarget effects of carbaryl use include short-term decreases in the density of prey species for salmon as well as the mortality of nontarget benthic invertebrates and nonsalmonid fish (Pozarycki et al. 1997; Simenstad and Fresh 1995). Concerns over such potential adverse impacts have led to the development of regulations for the use of chemicals in natural habitat and policies for offsetting losses to eelgrass beds (WDF 1992).

On a positive note, some methods of mollusk culture have been shown to create beneficial habitat for salmonids (Johnson 1998, pers. comm.). Geoduck culture has been shown to support species richness significantly higher than control sites (Brown and Theusen, 2011). Dumbauld et al. (2009) found that structure provided by aquaculture appears functionally similar to eelgrass for small benthic infauna and mobile epibenthic fauna.

Treated wood structures in salmon EFH (e.g., creosote, chromated copper, arsenate) used for docks, pilings, raceway separators, fish ladders etc., and other structures can release toxic heavy metals and persistent aromatic hydrocarbons into the aquatic environment (see Section 4.2.2.14 Estuarine Alteration).

Potential conservation measures for artificial propagation of fish and shellfish

The following lists the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be adversely affected by the artificial propagation of fish and shellfish. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat.

- Minimize the use of biocides and wood preservatives. Promote the use of plastic building materials. Treated wood should be certified as produced in accordance with the most current version of “Best Management Practices for Treated Wood in Western Aquatic Environments” (WWPI et al. 2011). Treated materials containing copper compounds should not be installed when migrating salmon are present.
- Manage shellfish culture activities to provide levels of salmon prey production, cover, and habitat complexity for both salmon smolts and returning adults which are similar to, or better than, levels provided by the natural environment.
- Any gravel used for shellfish bed preparation should be washed prior to placement.
- Unsuitable material (e.g., trash, debris, car bodies, asphalt, tires) should not be discharged or used as fill (e.g., used to secure nets, create berms, or provide nurseries).
- A Pacific herring spawn survey should be conducted prior to undertaking the activities listed below if any of these activities will occur outside the approved work window for the project area’s Tidal Reference Area, which is [insert work window]. The activities requiring a spawn survey are: 1) mechanical dredge harvesting, 2) raking, 3) harrowing, 4) tilling or other bed preparation activities, 5) frosting or applying oyster shell on beds, 5) geoduck harvesting, net removal, or tube removal. Vegetation, substrate, and aquaculture materials (e.g., nets, tubes) should be inspected for Pacific herring spawn. If Pacific herring spawn is present, these activities are prohibited in the areas where spawning has occurred until such time as the eggs have hatched and Pacific herring spawn is no longer present. The Corps encourages the permittee to complete a training class on identifying Pacific herring spawn with the Washington Department of Fish and Wildlife (WDFW). A map showing the Tidal Reference Areas and a table with the approved work windows for Pacific herring can be found at the Corps, Seattle District, Regulatory Branch website. You should maintain a record of Pacific herring spawn surveys, including the date and time of surveys; the area, materials, and equipment surveyed; results from the survey; etc. The record of Pacific herring spawn surveys should be made available upon request.

- Avoid or minimize impacts to eelgrass. New aquaculture activities (new or expanded farms) should not occur within a buffer distance of 25-30 feet from existing native eelgrass beds.
- Newly positioned[5] shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) in existing plots should not be placed within 10 horizontal feet of eelgrass or kelp.
- Newly positioned shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) should not be placed above the tidal elevation of +7 feet Mean Lower Low Water if the area is documented as surf smelt spawning habitat
- Newly positioned shellfish culturing (e.g., culturing by rack and bag, raft, long-line, ground methods) should not be placed above the tidal elevation of +5 feet Mean Lower Low Water if the area is documented as Pacific sand lance spawning habitat.
- Tidelands waterward from the line of mean higher high water should not be used for storing aquaculture gear (e.g., bags, racks, marker stakes, rebar, nets, tubes) for a consecutive period of time exceeding 7 days.
- All pump intakes (e.g., for geoduck harvest, washing down gear) that use seawater should be screened in accordance with NMFS criteria.
- Land vehicles (e.g., all-terrain, trucks) and equipment should not be washed within 150 feet of any stream, waterbody, or wetland. All wash water should be treated before being discharged to any stream, waterbody, or wetland.
- Land vehicles should be stored, fueled, and maintained in a vehicle staging area placed 150 feet or more from any stream, waterbody, or wetland.
- All vehicles operated within 150 feet of any stream, waterbody, or wetland should be inspected daily for fluid leaks before leaving the vehicle staging area. Repair any leaks detected in the vehicle staging area before the vehicle resumes operation.
- At least once every three months beaches in the project vicinity should be patrolled by crews who will retrieve aquaculture debris (e.g., anti-predator nets, tubes, tube caps, stakes) that escapes from the project area. Within the project vicinity, locations should be identified where debris tends to accumulate due to wave, current, or wind action, and after weather events these locations should be patrolled by crews who will remove and dispose of aquaculture debris appropriately.
- Ensure area nets (e.g., anti-predator nets) are tightly secured to prevent them from escaping from the project area.
- Vessels used for shellfish culturing should not ground in eelgrass beds.

4.2.2.5 Bank Stabilization and Protection

The alteration of riverine and estuarine habitat from bank and shoreline stabilization, and protection from flooding events can result in varying degrees of change in the physical, chemical, and biological characteristics of existing shoreline and riparian habitat. The use of dikes and berms can also have long-term adverse effects in riparian, tidal marsh and estuarine habitats. Tidal marshes are highly variable, but typically have freshwater vegetation at the landward side, saltwater vegetation at the seaward side, and a gradient of species in between that are in equilibrium with the prevailing climatic, hydrographic, geological, and biological features of the coast. These systems normally drain through highly dendritic tidal creeks that empty into the bay or estuary. Freshwater entering along the upper edges of the marsh drains across the surface and enter the tidal creeks. Structures placed for bank stabilization and coastal shoreline protection include, but are not limited to, concrete or wood seawalls; rip-rap revetments (sloping piles of rock placed against the toe of the dune or bluff in danger of erosion from wave action); dynamic cobble revetments (natural cobble placed on an eroding beach to dissipate wave energy and prevent sand loss); vegetative plantings; sandbags; and other bioengineering techniques.

5 “Newly positioned” is defined as being placed within a portion of the project area where aquaculture is not currently located and has not previously occurred.

Potential adverse effects of bank stabilization and protection

Human activities removing riparian vegetation, armoring, relocating, straightening and confining stream channels and along tidal and estuarine shorelines influences the extent and magnitude of stream bank erosion and down-cutting in the channel (Gerstein and Harris 2005). In addition, these actions have reduced hydrological connectivity and availability of off-channel habitat and floodplain interaction. Dikes, levees, ditches, or other water controls at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing freshwater flushing and annual flushing, annual renewal of sediments and nutrients, and the formation of new marshes. Water controls within the marsh proper intercept and carry away freshwater drainage, block freshwater from flowing across seaward portions of the marsh, increase the speed of runoff of freshwater to the bay or estuary, lower the water table, permit saltwater intrusion into the marsh proper, and create migration barriers for aquatic species. In deeper channels where reducing conditions prevail, large quantities of hydrogen sulfide are produced that are toxic to marsh grasses and other aquatic life. Acid conditions of these channels can also result in release of heavy metals from the sediments.

Long-term effects on the tidal marsh include land subsidence (sometimes even submergence), soil compaction, conversion to terrestrial vegetation, greatly reduced invertebrate populations, and general loss of productive wetland characteristics. Loss of these low-salinity environments reduces estuarine fertility, restricts suitable habitat for aquatic species, and creates abnormally high salinity during drought years. Low-salinity environments form a barrier that prevents the entrance of many marine species, including competitors, predators, parasites and pathogens.

Armoring of shorelines to prevent erosion and maintain or create shoreline real estate simplifies habitats, reduces the amount of intertidal habitat, and affects nearshore processes and the ecology of a myriad of species (Williams and Thom 2001) and reduces recruitment of crucial spawning gravel (PFMC 1988). Hydraulic effects on the shoreline include increased energy seaward of the armoring, reflected wave energy, dry beach narrowing, substrate coarsening, beach steepening, changes in sediment storage capacity, loss of organic debris, and downdrift sediment starvation (Williams and Thom 2001). Installation of breakwaters and jetties can result in community changes from burial or removal of resident biota; changes in cover and preferred prey species; and predator attraction (Williams and Thom 2001). As with armoring, breakwaters and jetties modify hydrology and nearshore sediment transport as well as movement of larval forms of many species (Williams and Thom 2001).

Bank stabilization and in-stream structures can be misapplied and used often in restoration projects to create what is perceived as “good habitat”. The physical, chemical and biological processes driving the riverine ecosystem are not correctly considered in designs (Beechie et al. 2010). Frequently, bank stabilization and shoreline protection techniques do not consider alteration of stream flows and temperatures and effectiveness on restoring salmon habitat for and potential changing climate remains a concern (Beechie et. al 2012).

The use of chemicals (creosote, chromated copper arsenate, and copper zinc arsenate) on bulkheads or other wood materials used for bank stabilization is of concern. These chemicals can introduce toxic substances into the water, injure or kill prey organisms and salmonids, or concentrate in the food chain (WMOA 1995). Use of these chemicals is generally prohibited. In freshwater copper concentrates have been observed to have a numerous potential adverse effects on salmonid behavior, development, navigation and mortality in a range of species and life stages (Baldwin et al. 2003; Sandahl et al. 2007; Hetcht et al. 2007; McIntyre et al. 2012).

Potential conservation measures for bank stabilization and protection

- Minimize the loss of riparian habitats as much as possible.

- The diking and draining of tidal marshlands and estuaries should not be undertaken unless a satisfactory compensatory mitigation plan is in effect and monitored.
- Determine the cumulative effects of existing and proposed bio-engineered or bank hardening projects on salmon EFH, including prey species before planning new bank stabilization projects.
- Bank erosion control should use vegetation methods or "soft" approaches (such as beach nourishment, vegetative plantings, and placement of LWD) to shoreline modifications whenever feasible. Hard bank protection should be a last resort and the following options should be explored (tree revetments, stream flow deflectors, and vegetative riprap.
- Re-vegetate sites to resemble the natural ecosystem community, using vegetation management to limit livestock grazing and maintain an appropriate riparian buffer zone.
- Develop design criteria based on site-specific geomorphological, hydrological and sediment transport processes appropriate for the stream channel for any stabilization, protection and restoration projects.
- Include efforts to preserve and enhance EFH by providing new gravel for spawning areas; removing barriers to natural fish passage; and using weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.
- Construct a low-flow channel to facilitate fish passage and help maintain water temperature in reaches where water velocities require armoring of the riverbed.
- Replace in-stream fish habitat by providing root wads, deflector logs, boulders, rock weirs and by planting shaded riverine aquatic cover vegetation.
- Avoid or minimize the use of wood treated with creosote or copper-based chemicals in aquatic habitats there is low flow circulation, and where there is known salmon habitat.
- Use an adaptive management plan with ecological indicators to oversee monitoring and ensure mitigation objectives are met. Take corrective action as needed.

4.2.2.6 Beaver Removal and Habitat Alteration

Historically, beaver were an integral component of wetland and low-gradient stream systems throughout North America (Burchsted et al. 2010). Beaver are of particular importance within West Coast watersheds because of the habitat benefits they provide to salmon (Westbrook et al. 2006). Historical population estimates for beaver range from 60-400 million (Seton 1929), with current beaver populations thought to be at 2 to 20 percent of historic levels (Naiman 1988). Beavers and the dams they create fundamentally alter the physical condition of stream ecosystems, supporting numerous other species (Gurnell 1998, Pollock et al. 2003, Burchsted et al. 2010). Observed physical benefits include increased streamflow, raised water tables, lower stream temperatures, and increased floodplain connectivity and habitat complexity, including an expansion of riparian and wetland habitat (Rosell et al. 2005, Westbrook et al. 2006, Pollock et al. 2007). Observed biological benefits of beaver dams include increases in biological diversity and productivity for suites of taxa such as plants, mammals, birds, herpetofauna, and fishes (Pollock et al. 1998, Pollock et al. 2003, Pollock et al. 2004, Burchsted et al. 2010). The positive relationships between beaver salmonid fishes been particularly well studied. Habitats created by beaver have been shown to be important rearing areas for coho salmon, sockeye salmon, steelhead trout and cutthroat trout (Collen and Gibson 2000, Pollock et al. 2003).

Beaver can have a number of impacts to human infrastructure and land use including localized flooding, removal of riparian vegetation. Because of this they are sometimes targeted for removal in agricultural and urban landscapes. The removal of beaver has, unfortunately, substantially reduced the functionality and quality of thousands of miles of stream, wetland, and riparian habitat in Pacific Coast watersheds and elsewhere. Historical accounts of stream ecosystems in alluvial valleys describe entire valley bottoms as saturated, with numerous wetlands, multi-threaded streams, dense riparian vegetation, abundant beaver dams and continuously flowing water (Walter and Merritts 2008, Cluer and Thorne 2013). This contrasts with the current condition of streams throughout the west, where the removal of beaver, channel straightening and riparian vegetation removal have contributed to the creation of downcut streams that are confined within a narrow trench below former floodplains; the extent and quality of stream, riparian and wetland habitat are greatly diminished or altogether eliminated (Darby and Simon 1999). Stream incision has been particularly problematic because it causes long-term stream degradation resulting in lowered water tables, loss of groundwater storage, loss of perennial stream flow, and a reduction in water availability for both commercial and conservation purposes.

Throughout the Pacific Coast states and elsewhere, there is rapidly growing interest in the use of beaver to restore degraded stream ecosystems. This is because past and current land use practices have caused widespread degradation of streams and climate change threatens to further degrade these ecosystems (Beechie et al. 2010, Roni and Beechie 2013). Encouraging beaver recolonization through the use of artificial beaver dams and riparian enhancements provides an inexpensive, yet effective method to restore degraded stream and wetland systems (Pollock et al. 2012). The observed positive effects of beaver dams on groundwater storage and streamflow have broadened the appeal of beaver dams beyond conservationists to water users such as ranchers and farmers, some of whom have realized improved crop production after reintroducing beaver, and to entities seeking to replace developed wetlands. Thus there is growing recognition from diverse interests that beaver can be used not only as a "habitat conservation tool", but also as a "water conservation tool" to address current and future water shortages. Using beaver as a restoration tool is relatively inexpensive approach compared to traditional restoration techniques that involve engineering, permitting, construction, and maintenance costs. Reintroducing beaver and facilitating their successful establishment through the use of artificial beaver dams and lodges, along with food supplementation, is extremely cost effective (Pollock et al. 2012).

Potential conservation measures for beaver removal and habitat alteration

Following are the types of measures that should be undertaken by action agencies for the purpose of encouraging the use of beaver to create and restore habitat that is generally beneficial to salmonids and numerous other species. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat and were derived, in part, from consultation with NMFS personnel involved in the development of recovery plans for ESA-listed coho salmon and steelhead.

Develop integrated beaver management strategies

Develop an integrated beaver management strategy so that when beaver produce unwanted effects on private land or public infrastructure, there is a mandatory sequence of integrated actions (The "Educate-Mitigate-Relocate" approach) that should be followed by landowners, habitat restoration groups, government agencies (e.g. Departments of Transportation and Public Works) and individuals as outlined below:

- Educate: Use educational materials developed to educate landowners, agencies and other affected parties about the benefits beaver provide by leaving them in place undisturbed. To this end; (1) develop programs to educate landowners and the public in general about the benefits of beaver to the health of our ecosystems, with a focus on benefits to salmonids, and (2) develop a program of outreach and technical assistance to habitat restoration groups about the benefits of including beaver and potential beaver habitat into restoration projects. Include a description of restoration techniques designed to entice beaver to colonize an area. Also include techniques for construction of beaver dam analogues that will simulate the effects of beaver dams both for the purposes of creating habitat suitable for beaver and for creating the beneficial effects of beaver dams in locations that beaver are unlikely to occupy in the near future.

- Mitigate: If the landowner, agency or other affected parties still believe there is a conflict, manage beaver in place with such techniques as tree cages, fencing, flow devices, and (fish passable) culvert exclusion devices. Implementation of this step should also include a synthesis, description and publication of existing mitigation techniques.
- Relocate: Only if all other methods to keep beavers in place fail to resolve the conflict, relocate beaver within the range of coho salmon to an acceptable, priority stream. This step should also include a synthesis, description and publication of existing relocation techniques, and possible identification or licensing of individuals who are qualified to translocate beaver.
- Develop procedures to identify and rank watersheds and stream reaches where beaver reintroduction or relocation would most likely be successful and where it would be of most benefit coho salmon.
- Within the coastal province of Oregon, Burnett et al. (2007) identified the intrinsic habitat potential for coho salmon based on physical factors such as stream flow, valley constraint and stream gradient. A similar approach should be applied to identifying the intrinsic habitat potential of streams for beaver. Identifying areas of high intrinsic potential for both salmonids and beaver for all Pacific Coast watersheds would help to focus restoration efforts using beaver to areas where they would be most useful.

4.2.2.7 Coal Export Terminal Facilities

The construction, maintenance, and operation of coal export facilities can include many non-fishing activities that are already described here, including activities causing high intensity underwater acoustic or pressure waves, construction/urbanization, dredging, estuarine alteration, over-water structures, road building and maintenance, vessel operations, wastewater/pollutant discharge, and wetland and floodplain alteration. All applicable effects associated with these activities should be considered as potential adverse effects from the development, presence, and operations of coal export facilities.

Other potential effects are specific to the exportation of coal and are not described under other non-fishing activities. Although limited, the available information on the effects of coal export facilities documents physiological effects to salmonids and describes physical pathways for coal dust and associated products to enter and remain in the aquatic environment.

Campell and Devlin (1997) describe sublethal effects of coal dust on juvenile Chinook salmon. These include findings that coal dust affects the expression of the L5 and CYP1A1 genes which encode proteins that are crucial to cellular metabolism. In addition, they found that polyaromatic hydrocarbons which leach from coal dust into sea water contained procarcinogens such as benzopyrene, which can be converted in active carcinogens by the CYP1A1 gene. Herbert and Richards (1963) found that coal and coal byproducts reduce growth rates in trout, although it is not clear whether those findings would apply to other salmonids.

The persistence of coal dust and coal byproducts in the aquatic environment should be considered during EFH consultation. Johnson and Bustin (2005) examined the fate of coal dust in the marine environment by assessing sediments adjacent to the Roberts Bank coal terminal in Delta, British Columbia, Canada. They found that over a 22-year time period (1977 – 1999) the concentration of coal dust particles increased substantially, from 1.8 percent in 1975 to 3.6 percent in 1999. The spatial extent of coal dust particles did not increase, decreasing with greater distance from the coal terminal, but the concentration did increase.

<u>*Potential conservation measures for coal export terminal facilities*</u>

Conservation measures that apply to the following activities should also apply to coal export terminal facilities: Construction/urbanization, dredging and dredged spoil disposal, estuarine alteration, introduction/spread of IAS, over-water structures, road building and maintenance, vessel operations, wastewater/pollutant discharge, and wetland and floodplain alteration.

Conservation measures specific to coal export terminal facilities should focus on the potential for release of coal and coal dust into the aquatic environment. The design and function of coal facilities is variable, and conservation measures should be tailored to each facility. What works at one facility may not work at another. Examples of measures that could be employed, but are not limited to the following:

- Cover or enclose conveyors when practicable, to contain the coal and coal dust
- Employ coal dust suppression system on open stockpiles, using automatic sprinklers or other mechanisms
- Utilize other active or passive control systems as appropriate
- Have an emergency response plan in place, to address accidental release of coal or coal dust, fuel spills, and other emergency situations

4.2.2.8 Construction/Urbanization

Activities associated with urbanization (e.g., building construction, utility installation, road and bridge building, storm water discharge) can significantly alter the land surface, soil, vegetation, and hydrology and adversely impact salmon EFH through habitat loss or modification. Effects of urbanization on stream ecology are second only to agriculture, even though urban areas occupy significantly less land surface than farmlands (Paul & Meyer 2001). Construction in and adjacent to waterways can involve dredging and/or filling activities, bank stabilization (see other sections), removal of shoreline vegetation, waterway crossings for pipelines and conduits, removal of riparian vegetation, channel re-alignment, and the construction of docks and piers. These alterations can destroy salmon habitat directly or indirectly by interrupting sediment supply that creates spawning and rearing habitat for prey species (e.g., sand lance, surf smelt, herring), by increasing turbidity levels and diminishing light penetration to eelgrass and other vegetation, by altering hydrology and flow characteristics, by raising water temperature, and by re-suspending pollutants (Phillips 1984).

Projects in or along waterways can be of sufficient scope to cause significant long-term or permanent adverse effects on aquatic habitat. However, most waterway projects and other projects associated with growth, urbanization, and construction within the region are small-scale projects that individually cause minor losses or temporary disruptions and often receive minimal or no environmental review. The significance of small-scale projects lies in the cumulative and synergistic effects resulting from a large number of these activities occurring in a single watershed.

Construction activities can also have detrimental effects on salmon habitat through the run-off of large quantities of sediment, as well as nutrients, heavy metals, and pesticides. Due to the intermittent nature of rainfall and runoff, the large variety of pollutant source types, and the variable nature of source loadings, urban runoff is difficult to control (Safavi 1996). The National Water Quality Inventory (EPA 2002) reports that runoff from urban areas is the leading source of impairment to surveyed estuaries and the third largest source of impairment to surveyed lakes. Oxygen deficits associated with high biological oxygen demand during and after storms are common (Faulkner et al. 2000; Ometo et al. 2000). Run-off of petroleum products and oils from roads and parking lots and sediment, nutrients, and chemicals from yards as well as discharges from municipal sewage treatment plants and industrial facilities are also associated with urbanization (EPA 1993). Urbanized areas also alter the rate and intensity of stormwater run-off into streams and waterways. Inorganic and organic contaminants in urban runoff can cause acute, chronic and sub-lethal effects in aquatic species.

Similarly, effects on run-off rates can be much greater than in any other type of land use, because of the amount of impervious surfaces associated with urbanization. Buildings, rooftops, sidewalks, parking lots, roads, gutters, storm drains, and drainage ditches, in combination, quickly divert rainwater and snow melt to receiving streams, resulting in an increased volume of runoff from each storm, increased peak discharges, decreased discharge time for runoff to reach the stream, and increased frequency and severity of flooding (EPA 1993). Flooding reduces refuge space for fish, especially where accompanied by loss of instream structure, off-channel areas, and habitat complexity. Flooding can also scour eggs and young from the gravel. Increases in streamflow disturbance frequencies and peak flows also compromises the ability of aquatic insects and fish life to recover (May et al. 1997).

The amount of impervious surfaces also can influence stream temperatures. Summer time air and ground temperatures in impervious areas can be 10-12°C warmer than in agricultural and forested areas (Metro 1997). In addition, the trees that could be providing shade to offset the effects of solar radiation are often missing in urban areas. The alteration in quantity and timing of surface run-off also accelerates bank erosion and the scouring of the streambed, as well as the downstream transport of wood. This results in simplified stream channels and greater instability, all factors harmful to salmon (Spence et al. 1996). The lack of infiltration also results in lower stream flows during the summer by reducing the interception, storage, and release of groundwater into streams. This affects habitat availability and salmonid production, particularly for those species that have extended freshwater rearing requirements (e.g., coho salmon). Generally, it has been found that instream functions and value seriously deteriorate if the levels of impervious surfaces reach 10 percent of a sub-basin (WDFW 1997).

Potential conservation measures for construction/urbanization

Existing urban and industrial sites, highways, and other permanent structures will prevent restoration of riparian zones in heavily developed areas. In these areas, generally along major river systems, buffers will not be continuous, and riparian areas will remain fragmented. Habitat improvement plans will need to identify locations of healthy riparian zones and opportunities for re-establishing corridors of riparian vegetation between them, so that nodes of good quality habitat can be maintained and managed in ways that protect salmon habitat (Sedell et al. 1997).

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by construction and urbanization activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process, and communicated to the appropriate agency. The EPA (1993) publication "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters" extensively describes BMPsfor control of runoff from developing areas, construction sites, roads, highways and bridges affecting salmon EFH. In addition to the previous guidelines, the options following represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from Metro (1997), Oregon Department of Fish and Wildlife (ODFW) (1989), and EPA (1993).

- Protect existing, and wherever practicable, establish new riparian buffer zones of appropriate width on all permanent and ephemeral streams that include or influence EFH. Establish buffers wide enough to support shading, LWD input, leaf litter inputs, sediment and nutrient control, and bank stabilization functions.

- Plan development sites to minimize clearing and grading and cut-and-fill activities.

- During construction, temporarily fence setback areas to avoid disturbance of natural riparian vegetation and maintain riparian functions for EFH.

- Use BMPs in building as well as road construction and maintenance operations such as avoiding ground disturbing activities during the wet season, minimizing the time disturbed lands are left exposed, using erosion prevention and sediment control methods, minimizing vegetation disturbance, maintaining buffers of vegetation around wetlands, streams and drainage ways, and avoiding building activities in areas of steep slopes with highly erodible soils. Use methods such as sediment ponds, sediment traps, or other facilities designed to slow water run-off and trap sediment and nutrients.

- Where feasible, remove impervious surfaces such as abandoned parking lots and buildings from riparian areas, and re-establish wetlands.
- Implement Low Impact Development construction practices to the maximum extent possible.

4.2.2.9 Culvert construction

Culvert construction, maintenance, and replacement are common activities occurring in Pacific Coast salmon habitat, typically—but not always—associated with roads. Culverts convey water from upslope portions of terrain to downslope areas, thereby minimizing the risk of flooding, erosion, and undesired impacts to infrastructure and habitat. In the past, however, many culverts were constructed too small to convey large flow events, too steep to allow adequate fish passage, or without other physical characteristics to avoid the impacts to habitat and species that are now recognized to be significant problems.

Regulatory requirements under the ESA and MSA, as well as best practices developed by states, counties, tribes, and Federal agencies, have established a suite of construction, maintenance, and replacement actions to minimize adverse impacts to habitats and species. Habitat restoration programs have provided support for installation of "fish friendly" culverts, and the state of the art culvert is typically an open-bottom arched culvert that is designed to better mimic a natural stream bed.

Potential adverse Effects from culvert construction

The physical and chemical components to culvert construction that lead to potential adverse habitat impacts include slope, jump height, lack of instream structure, contaminants, and water velocity. These can lead to compromised fish passage, lethal and sublethal effects on individuals, and loss of ecological connectivity (Castro 2003; NMFS 2008b). Culverts may pose significant barriers to migration in salmon habitat. Road crossings are a common bottleneck to migrating adult salmon, as many employ faulty or poorly designed culverts (Chestnut 2002). For example, if a culvert is too small compared to the surrounding river, water velocities will increase rapidly via a Venturi effect. Debris will not readily flow through the culvert, eventually clogging it and making fish passage even more difficult. This blockage also prevents woody debris from reaching lower stretches of the stream, removing valuable fish habitat.

The slope of a culvert can affect fish passage directly by providing conditions that lead to excessive water velocity. This can create a passage barrier to upstream migrating fish. Velocities greater than one foot per second (fps) can create a barrier for juvenile salmon, regardless of the culvert length. For adult passage, velocities can range between two and six fps, depending on culvert length (NMFS 2001).

Excessive water velocity also can cause scouring at the downstream end of a culvert leading to a "perched" culvert requiring migrating fish to jump just to access the culvert. A perched situation can also occur when a culvert is simply placed too high and dries out during periods of low flow, or is placed too far above the stream at the outflow, thereby preventing fish from accessing it or safely exiting (Sylte 2002; Flanders 2000). NMFS (2008a) states that there should ideally be no difference in water height between water inside a culvert and water in the adjacent stream; and offers criteria for maximum jump heights.

Culverts can also impact a stream's geomorphology by trapping sediment above the culvert and increasing erosion below through a process called downcutting (Castro 2003; Wheeler et al. 2005). Downstream scour of stream bed and banks often occurs when large flow events through inadequately- sized culverts create a fire hose effect, mobilizing sediment and potentially eroding stream banks. This situation not only introduces excess sediment into the stream (potentially smothering redds), but also can remove riparian vegetation, a vital component of salmonid habitat. These physical changes can impact the entire lotic system, particularly harming macroinvertebrates that are prey for salmon (Vaughan 2002).

Numerous other effects resulting from the presence of culverts have been identified. These include loss of ecological connectivity, loss of (or excessive) transport of sediment and woody debris downstream, loss of spawning or rearing habitat, and effects on benthic invertebrates and aquatic vegetation (Bates et al. 2003). It is important to remember that various culvert characteristics can act synergistically, even when one factor alone isn't enough to adversely affect habitat. For example, a too-steep slope can be mitigated by the presence of instream structure that allows for resting pockets and serves to slow water velocity. However, a too-steep slope plus lack of instream structure can make a culvert less passable for fish than if only one of those conditions existed.

The cumulative effects of multiple culverts in a stream system and multiple adverse elements associated with each culvert can increase the physiological stress of migrating salmon and may lower the probability of successful passage and subsequent adult spawning.

Potential Conservation Recommendations for Culvert Construction

NMFS (2001), Bates et al. (2003), and NMFS (2008a) offer design criteria that address the effects listed above. These criteria are often incorporated into conservation recommendations for individual projects, in ESA and EFH consultations, and could be used to develop a general suite of conservation recommendations germane to culvert construction.

- In instances where culverts are used to bridge stream crossings, specific engineering care should be given to maintain the stream's ecological function including use of alternative designs such as Active Channel Design, Stream Simulation Design and Hydraulic Design.
- Where applicable, baffles, weirs, and resting pools should be established to create hydraulic refuges for upstream migrating fish.
- Water velocities and jump heights should not exceed the swimming performance of critical life stages for Pacific salmon (adult or juvenile) or be increased beyond NMFS's culvert specific passage criteria.
- Regular maintenance should be conducted to ensure culverts remain clear of debris, operable, and have suitable hydraulic conditions.
- Where applicable, alternatives to culverts (such as bridges) should be explored.

4.2.2.10 Dam Construction/Operation

Dams built to provide power, water storage, and flood control have significantly contributed to the decline of salmonids in the region. Potential adverse effects include impaired fish passage (including blockages, diversions), alterations to water temperature, water quality, water quantity, and flow patterns, the interruption of nutrients, LWD, and sediment transport which affect river, wetland, riparian, and estuarine systems, increased competition with nonnative species, and increased predation and disease.

The construction of dams without fish passage facilities has blocked salmon from thousands of miles of mainstream and tributary stream habitat in the Columbia River basin, Sacramento-San Joaquin system, and other streams throughout the western United States (PFMC 1988). While technology exists for providing fish passage around dams, it has not always been successful, and migration delays and increased mortality may still occur at some projects under certain water temperatures and flows. Poorly designed fishways, or fishways that are improperly operated and maintained, can inhibit movement of adults upstream causing migration delays and unsuccessful spawning. Additionally, the fallback of adult salmon through spillways and turbines contribute to migration delays and increased mortality. Increased vulnerability to predation is also an impact of dams and fish passage structures.

Dams are also a barrier to downstream passage of juveniles. In general, reservoirs and water diversions (see Section 4.2.2.19 Irrigation Water Withdrawal, Storage, and Management)) reduce water velocities and change current patterns, resulting in increased migration times (Raymond 1979), exposure to less favorable environmental conditions, and increased exposure to predation. At dams, injury and mortality to juveniles occurs as a result of passage through turbines, sluiceways, juvenile bypass systems, and adult fish ladders. Encounters with turbine blades, rough surfaces, or solid objects can cause death or injury. Changes in pressure within turbines or over spillways also can result in death or injury. Juveniles, frequently stunned and disoriented as they are expelled at the base of the dam, are particularly vulnerable to predation (PFMC 1988). Dams also result in changes in concentrations of dissolved oxygen and nitrogen. Above the dams, slow-moving water has lower dissolved oxygen levels than faster, turbulent waters, a factor that may stress fish (Spence et al. 1996). Below hydroelectric facilities, nitrogen supersaturation may also negatively affect migrating as well as incubating or rearing salmon by causing gas-bubble disease. Gas bubble disease increases in years of high flow and high spill.

Hydrologic effects of dams include water-level fluctuations, altered seasonal and daily flow regimes, reduced water velocities, and reduced discharge volume. These altered flow regimes can affect the migratory behavior of juvenile salmonids. Water-level fluctuations associated with hydro power peak operations may reduce habitat availability, inhibit the establishment of aquatic macrophytes that provide cover for fish, and in some cases strand fish or allow desiccation of spawning redds. Drawdowns reduce available habitat area and concentrate organisms, potentially increasing predation and transmission of disease (Spence et al. 1996). Drawdown in the fall for flood control produces high flows during spawning which allow fish to spawn in areas which may not have water during the winter and spring, resulting in loss of the redds.

Impoundments may also change the thermal regimes of streams causing effects on salmon. Temperatures may increase in shallow reservoirs to the detriment of salmon. Below deeper reservoirs that thermally stratify, summer temperatures may be reduced, but fall temperatures tend to increase as heated water stored during the summer is released. These changes in water temperatures affect development and smoltification of salmonids, decreasing survival. Water temperatures also can affect adult migration (Spence et al. 1996). Water temperature changes also influence the success of predators and competitors and the virulence of disease organisms. Additionally, in winter, drawdown of impoundments may facilitate freezing, which diminishes light penetration and photosynthesis, potentially causing fish kills through anoxia (Spence et al. 1996).

In watersheds where temperatures and flows may limit salmon production, dams can sometimes be operated to have positive benefits such as lowering water temperatures during the summer and providing stable flows and temperatures which may benefit both salmonid spawning and rearing, and invertebrate production.

Dam impoundments alter natural sediment and LWD transport processes. Water storage at dams may prevent the high flows that are needed to scour fine sediments from spawning substrate and move wood and other materials downstream. Behind dams, suspended sediments settle to the bottoms of reservoirs, depriving downstream reaches of needed sediment inputs, leading to the loss of high-quality spawning gravels (as substrate becomes dominated by cobble unsuitable for spawning) as well as to changes in channel morphology (Spence et al. 1996).

Dams can also affect the health and extent of downstream estuaries. Reservoir storage can alter both the seasonal pattern and the characteristics of extremes of freshwater entering the estuary. Flow damping has also resulted in a reduction in average sediment supply to the estuary. Except for times of major floods, residence time of water in estuaries has increased with decreasing salinity. Estuaries have also been converted into a less-energetic microdetritus-based ecosystem with higher organic sedimentation rates. Detritus and nutrient residence has increased; vertical mixing has decreased, likely increasing primary productivity in the water column, and enhancing conditions for detritivorous, epibenthic, and pelagic copepods (Sherwood et al. 1990). The effects of these changes have not been evaluated as yet, though there are concerns about possible effects on fish and other resources which depend on a highly co-evolved and biologically diverse estuarine environment (NRC 1996).

Potential conservation measures for dam construction/operation

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by dam construction and operation activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from Spence et al. (1996) and NMFS (1997a).

- Operate facilities to create flow conditions adequate to provide for passage, water quality, proper timing of life history stages, avoid juvenile stranding and redd dewatering, and maintain and restore properly functioning channel, floodplain, riparian, and estuarine conditions. Specific flow objectives have been developed for the Columbia and Snake river and Sacramento bay/delta river systems and other systems with federally operated facilities where there are species listed under the ESA, through FERC orders, through specific legislative acts (e.g., the Central Valley Water Improvement Act, the Bay-Delta Accord), water quality orders, and through legal settlement agreements. Federal projects are operated within the context of the projects' authorized purposes, applicable state water laws, and contractual commitments.
- Provide adequate designing and screening for all dams, hydroelectric installations, and bypasses to meet specific passage criteria developed by the Columbia Basin fish managers.
- Develop water and energy conservation guidelines and integrate them into dam operation plans and into regional and watershed-based water resource plans.
- Provide mitigation (including monitoring and evaluation) for unavoidable adverse effects on salmon EFH operation.

4.2.2.11 Debris Removal

Organic Debris

Natural occurring flotsam such as LWD and macrophyte wrack (i.e., kelp) is often removed from streams, estuaries, and coastal shores. This debris is removed for a variety of reasons including dam operations, irrigation levee protection, aesthetic concerns, and commercial and recreational uses. Because the debris affects habitat function and provides habitat for aquatic and terrestrial organisms, removing it may change the ecological balance among riverine, estuarine, and coastal ecosystems.

Potential Adverse effects from organic debris

LWD and macrophyte wrack promote habitat complexity and structure to various aquatic and shoreline habitats. The structure provides cover for managed species, creates habitats and microhabitats (e.g., pools, riffles, undercut banks, side channels), and retains gravels and can maintain the underlying channel structure (Abbe and Montgomery 1996; Montgomery et al. 1995; Ralph et al. 1994; Spence et al. 1996) in riverine systems. Its removal reduces these habitat functions. Reductions in LWD input to estuaries have reduced the spatially complex and diverse channel systems that provide for productive salmon habitat (NRC 1996). Woody debris also plays a significant role in salt marsh ecology (Maser and Sedell 1994). Reductions in woody debris input to the estuaries may affect the ecological balance of the estuary. LWD also plays a significant role in benthic ocean ecology, where deep-sea wood borers convert the wood to fecal matter, providing terrestrial based carbon to the ocean food chain (Maser and Sedell 1994). Dams and commercial in-river harvest of LWD have dwindled the supply of wood, jeopardizing the ecological link between the forest and the sea (Collins et al. 2002; Collins et al. 2003; Maser and Sedell 1994).

Species richness, abundance, and biomass of macrofauna (e.g., sand crabs, isopods, amphipods and polychaetes) associated with beach wrack are higher compared to beach areas with lower amounts of wrack or that are groomed (Dugan et al. 2000). The input and maintenance of wrack can strongly influence the structure of macrofauna communities including the abundance of sand crabs (*Emerita analoga*) (Dugan et al. 2000), an important prey species to some EFH managed species. Beach grooming can substantially alter the macrofaunal community structure of exposed sand beaches (Dugan et al. 2000). In addition, there are concerns that beach grooming efforts to remove wrack may also harm the eggs of the grunion (Leuresthes tenuis), an important prey item of EFH managed species.

Potential conservation measures for organic debris removal

- Remove woody debris only when it presents a threat to life or property. Leave LWD wherever possible. Reposition, rather than remove woody debris that must be moved.
- Encourage appropriate Federal, state, and local agencies to add secured engineered LWD log jams to river systems that are lacking in LWD and have maintenance constraints.
- Encourage appropriate Federal, state, and local agencies to prohibit or minimize commercial removal of woody debris from rivers, estuaries, and beaches.
- Encourage appropriate Federal, state, and local agencies to aid in the downstream movement of LWD around dams, rather than removing it from the system.
- Educate landowners and recreationalists about the benefits of maintaining LWD.
- Localize beach grooming practices and minimize it whenever possible.
- Conduct beach grooming only above the semilunar high tide as soon as the grunion spawning period begins in the spring, and continue 2 weeks after the last grunion spawning runs are observed in the summer.
- Familiarize beach maintenance staff with the importance of such practices.

Inorganic Debris

Marine debris is a problem along much of U.S. coastal waters, littering shorelines, fouling estuaries, and creating hazards in the open ocean. Marine debris consists of a huge variety of man-made materials such as general litter, dredged materials, hazardous wastes, and discarded or lost fishing gear. It enters waterways either indirectly through rivers and storm drains or by direct ocean dumping. Marine debris can have serious negative effects on EFH. Although several legislative laws and regulatory programs exist to prevent or control the problem, marine debris continues to severely impact our waters.

Congress has passed numerous legislative acts intended to prevent the disposal of marine debris in U.S. ocean waters. These include the Marine Protection, Research, and Sanctuaries Act, Titles I and II (also known as the Ocean Dumping Act), The Federal Water Pollution Control Act (Clean Water Act), and the Comprehensive Environmental Response, Compensation, and Liability Act. The International Convention for the Prevention of Pollution from Ships, commonly known as MARPOL Annex V (33 CFR 151), is intended to protect the marine environment from various types of garbage by preventing ocean dumping if the ship is less than 25 nautical miles from shore. Dumping of unground food waste and other garbage is prohibited within 12 nautical miles from shore, and ground non-plastic or food waste may not be dumped within 3 nautical miles of shore. The Ocean Dumping Act implements the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention) for the United States. Section 311 of the Federal Water Pollution Control Act makes it unlawful for any person to discharge any pollutant into the waters of the United States except as authorized by law. The Comprehensive Environmental Response, Compensation, and Liability Act stipulates that releases of hazardous substances in reportable quantities must be reported, and the release must be removed by the responsible party. Regulations implementing these acts are intended to control marine debris from ocean sources, including galley waste and other trash from ships, recreational boaters and fishermen, and offshore oil and gas exploration and facilities.

Land-based sources of marine debris account for about 80 percent of the marine debris on beaches and in our waters. Debris from these sources can originate from combined sewer overflows and storm drains, storm-water runoff, landfills, solid waste disposal, poorly maintained garbage bins, floating structures, and general littering of beaches, rivers and open waters. Typical debris from these land-based sources includes raw or partially treated sewage, litter, hazardous materials, and discarded trash. Legislation and programs that address these land-based sources of pollution include the BEACH Act, the National Marine Debris Monitoring Program (NMDMP), the Shore Protection Act of 1989, and the Clean Water Act. The BEACH Act authorizes the EPA to fund state, territorial, Tribal, and local government programs that test and monitor coastal recreational waters near public access sites for microbial contaminants and to assess and monitor floatable debris. The NMDMP is a 5-year study designed to provide statistically valid estimates of marine debris affecting the entire U.S. coastline and to determine the main sources of the debris. The Shore Protection Act contains provisions to ensure that municipal and commercial solid wastes are not deposited in coastal waters during vessel transport from source to the waste receiving station. The Clean Water Act requires the EPA to develop and enforce regulations that treat storm water and combined sewer overflows as point source discharges requiring National Pollution Discharge Elimination System (NPDES) permits that prohibit non-storm water discharges into storm sewers.

Potential adverse impacts from inorganic debris

Land- and ocean-based marine debris is a very diverse problem and adverse effects on EFH are likewise diverse. Floating or suspended trash can directly affect fish that consume or are entangled in the debris. Toxic substances in plastics can kill or impair fish and invertebrates that use habitat polluted by these materials which persist in the environment and can bioaccumulate through the food web. Once floatable debris settles to the bottom of estuaries, coastal, and open ocean areas, it may continue to cause environmental problems. Plastics and other materials with a large surface area can cover and suffocate immobile animals and plants, creating large spaces devoid of life. Currents can carry suspended debris to underwater reef habitats where the debris can become snagged, damaging these sensitive habitats. The typical floatable debris from combined sewer overflows includes street litter, sewage containing viral and bacterial pathogens, pharmaceutical by-products from human excretion, and pet wastes. It may contain condoms, tampons, and contaminated hypodermic syringes, all of which can pose physical and biological threats to EFH. Suspended organic matter has a high biological oxygen demand, and its reduction can cause algal blooms and anoxia that are detrimental to productive marine habitats.

Potential conservation measures for inorganic debris

- Encourage proper trash disposal in coastal and ocean settings.
- Advocate and participate in coastal cleanup activities.
- Encourage enforcement of regulations addressing marine debris pollution and proper disposal.
- Provide resources and technical guidance for development of studies and solutions addressing the problem of marine debris.

- Provide resources to the public on the impact of marine debris and guidance on how to reduce or eliminate the problem.

4.2.2.12 Desalination

Global population growth continues to place high demand on available supplies of potable water, and areas with limited supplies of this essential resource are turning to desalination (Roberts et al. 2010). Recent estimates suggest that up to 24 million cubic meters of desalinated water are produced daily (Latterman and Hoepner 2008). Expansion of desalination capacity can be found in the U.S., Europe, China, and Australia. California is leading the way in the U.S., with projections that up to 20 new desalination plants, with a capacity of 2 million cubic meters per day, will be constructed by 2030. Desalination plants have a strong potential to detrimentally impact the ecology of marine habitats from water extraction and discharge of effluent. The following discussion is taken, unless otherwise cited, from a recent critical review by Roberts et al. (2010) of the available, peer-reviewed literature on the effects of effluent discharge.

Desalination of seawater to produce potable water uses one of two basic processes: thermal distillation such as multi-stage flash (MSF) distillation, and reverse osmosis (RO). Both of these methods have a saltwater intake and an effluent discharge. The effluent is water remaining after desalination and the concentrated salts from the seawater, commonly referred to as "brine". The brine also may contain various chemicals used in the desalination process, heavy metals from the machinery, and concentrated contaminants that were in the seawater. RO plants are increasingly common compared to the MSF plants.

The potential effects are largely concerned with intake of seawater, which can entrain and impinge marine organisms, and discharge of the brine, which can affect the physiochemistry, and therefore the ecology, at the discharge site and beyond. The effects from intake of seawater are similar to those described under Section 4.2.2.25 Power Plant Intakes, and will not be discussed here.

The discharge of brine can affect the salinity, temperature, and contaminant loading of the receiving body. Changes to salinity have been the most studied of these potential effects. Depending on the desalination method used, the design of the plant, and the salinity of the intake water, the salinity of the brine can range from as low as 37.3 parts per thousand to as high as 75 ppt. In general, for an RO plant, the salinity of the brine will be roughly double that of the intake water. Published research shows that the extent of the brine plume – the area where the salinity is elevated – varies greatly, from 10s of meters, to 100s of meters, or in extreme cases, to several kilometers from the discharge point. The extent of the plume depends on a variety of factors, including the capacity of the plant, the salinity of the brine, the location of the discharge, the design of the diffuser, and local hydrologic conditions. However, in most cases studied, the intensity of the plume diminishes rapidly with distance from the outfall, and is usually no greater than 2 ppt above background salinity within 20 m of the outlet.

Brine is usually denser than seawater and will, therefore, sink to the bottom and extend farther along the seafloor than at the surface. Where prevailing currents carry the plume further alongshore than offshore, the coastal fringe may be especially susceptible to impacts. During times of high tide, the brine may be concentrated around outfalls. Thus, the area impacted by the plume is likely to be both spatially and temporally variable.

A number of studies have shown that discharge of brine can lead to detectable ecological impacts to seagrass habitats, phytoplankton, invertebrate and fish communities. The effects on seagrasses are the most widely studied. However, the results of these studies are highly variable. Several studies on the Mediterranean seagrass *Posidonia oceana* showed clear adverse effects, with significant increases in mortality and leaf necrosis at increases of only 1-2 ppt. Others found no significant effects, even six years after plant operations began. A study on eelgrass (*Zoster marina*) from marine and estuarine waters of the Netherlands found increased mortality at salinities 30 ppt and 25 ppt respectively, which are at the upper end of the salinity range in these habitats (van Katwijk et al. 1999). This suggests that eelgrass, a species of particular importance to Pacific Coast salmon (Fresh 2007), is sensitive to salinity changes and could be at risk if exposed to a brine plume.

Infaunal and epifaunal invertebrate communities were found to be impacted by the brine plume in several studies. Close to the outfall, nematodes dominated the community and reduced diversity of other taxa up to 400 meters from the outfall. The diversity and abundance of benthic diatoms may also be reduced near the outfall. These communities are an important part of the food web upon which juvenile and adult salmon depend, and could be at risk from exposure to brine plumes. In contrast, other studies found no change in the macrobenthic organisms where the brine dissipated within 10 m from the outfall. Some of the studies that showed changes to the benthic community were associated with older plants that discharged excessive levels of copper, an issue that is largely avoidable.

Salinities of 55 ppt or higher were found to be acutely toxic to juvenile sea bream and larval flounder. The implications of this to Pacific Coast salmon are not clear, but suggest that brine discharge could affect their survival, depending on the location of the outfall. Salmon entering the estuarine and marine environment are undergoing smoltification, the adaptation to saltwater. During this time, they gradually adapt to full-strength seawater, and are under considerable physiological stress. Exposure to a concentrated brine plume at this sensitive life stage could increase this already high level of physiological stress and reduce their chances of survival.

Depending on the design of the plant, the brine may be warmer than the receiving waters. This is primarily limited to MSF plants, while RO plants tend to result in ambient temperature plumes. Because RO plants are becoming more common, relative to the MSF plants, this is a lesser problem than in the past. MSF plants can produces brines that are 10-15 degrees C warmer than the receiving waters. However, most studies have found that the thermal impacts dissipate quickly and typically diminish to background levels within tens of meters of the outfalls. The extent and severity of the thermal plume is dependent upon a variety of factors, such as the temperature of the discharge and receiving waters, the plant capacity, and local hydrologic conditions. Given the potentially high water temperatures in the immediate vicinity of the plume, there is a potential for salmon, particularly juveniles, to be affected. Mesa et al. (2002) found that exposure to increased temperature did not increase mortality or predation in juvenile Chinook salmon, but there was clear evidence of increased physiological stress.

Desalination can clearly impact the ecology of the receiving waters, but the extent of those effects depend on a variety of factors, such as plant capacity, discharge location and design, temperature and salinity differences between effluent and receiving water, and hydrologic conditions at the discharge site. Such variables should be considered when assessing the effects of these plants.

Potential conservation measures for desalination plants

The following conservation measures for desalination plants are modified from "Guidelines for Desalination Plants in the Monterrey Bay National Marine Sanctuary" (NOAA 2010).

- Entrainment and Impingement:
  - Desalination plants should be designed and sited to avoid and minimize impingement and entrainment to the extent feasible. Desalination project proponents should investigate the feasibility of using subsurface intakes as an alternative to traditional intake methods. Other options for consideration should include, but may not be limited to: vertical and radial beach wells, horizontal directionally drilled and slant-drilled wells, seabed filtration systems and other sub-seafloor structures. Where feasible and beneficial, subsurface intakes should be used. It must be ensured however, that they will not cause saltwater intrusion to aquifers, negatively impact

coastal wetlands that may be connected to the same aquifer being used by the intake, and they must address the likelihood of increased coastal erosion in the future. Subsurface intakes have the potential to minimize or eliminate impingement and entrainment impacts and improve the performance and efficiency of a desalination project by providing a certain level of pretreatment.

- In cases where it has clearly been determined that sub-surface intakes are not feasible and that an open ocean intake is necessary, the use of appropriately sited existing pipelines of acceptable structural integrity should be investigated and if feasible, pursued, to minimize impacts to the seafloor. If a new pipeline is necessary, sub- seafloor placement should be evaluated to minimize disturbances to biological resources and to recreational and commercial activities.
- When it is necessary to use an open ocean intake, other methods to minimize impingement and entrainment should be evaluated and pursued. These should include design alternatives such as placement of the intake structure to avoid sensitive habitat or highly productive areas, screening the intake ports, if feasible, increasing the number of intake ports, or decreasing the intake velocity. The project proponent should determine expected entrainment and impingement impacts associated with various intake velocities and screen mesh sizes, based upon long-term monitoring data from the area, including diurnal and seasonal variations in planktonic abundance and location.
- Any impacts to EFH and the biota it supports that cannot be avoided through project design or operations should require mitigation. The necessary level of mitigation should be determined through the use of a biologically based model, such as the habitat production foregone method, in order to account for all “non-use” impacts to affected biota. Mitigation projects should attempt to directly offset the impacted species or habitat (in-place, in-kind mitigation).

- Brine Discharge
  - Desalination project proponents should investigate the feasibility of diluting brine effluent by blending it with other existing discharges. The proponent should evaluate the use of measures to minimize the impacts from desalination plant discharges including discharging to an area with greater circulation or at a greater depth, increasing in the number of diffusers, increasing the velocity while minimizing the volume at each outlet, diluting the brine with seawater or another discharge, or use of a subsurface discharge structure.
  - The project proponent should provide a detailed evaluation of the projected short- term and long-term impacts of the brine plume on marine organisms based on a variety of operational scenarios and oceanographic conditions. Modeling should address different types of seasonal ocean circulation patterns, including consideration of “worst case scenarios”.
  - Results of accepted plume models should be included, to illustrate how the plume will behave during variable oceanographic conditions. The plume model should estimate salinity concentrations at the discharge point, as well as where and when it would reach ambient ocean concentrations. The extent, location, and duration of the plume where the salinity is 10 percent above ambient salinity should also be provided.
  - The project proponent should provide information on the physical and chemical parameters of the brine plume including salinity, temperature, metal concentrations, pH, and oxygen levels. These water quality characteristics of the discharge should conform to California Ocean Plan requirements and should be as close to ambient conditions of the receiving water as feasible.
  - A continuous monitoring program should be implemented to verify the actual extent of the brine plume, and to determine if the plume is impacting EFH. If it is, then mitigation for the EFH impact should be required.

- Use of Chemicals for Treatment and Cleaning
  - The project proponent should provide a complete list of all chemicals that may be used for the desalination plant as well as how these will be stored and disposed. They should also include an evaluation of the potential for these chemicals to cause impacts to local marine organisms.

- The project proponent should identify and quantify all procedures and chemicals to be used for cleaning and maintaining the outfall and intake structures, filter membranes, and all other aspects of the plant. This should also include a detailed spill prevention and response plan for chemicals stored at project site.
- The project proponent should evaluate the feasibility of using alternative pretreatment techniques such as ozone pretreatment, subsurface intakes, and membrane filtration, aimed at reducing the use of chemicals.

- Plant Site Selection and Structural and Engineering Considerations:
  - Desalination plant intakes should be sited to avoid sensitive habitats. For open-water intakes, areas of high biological productivity, such as upwelling centers or kelp forests or other dense beds of SAV should be avoided, since the entrainment and impingement impacts of a desalination plant are in large part dictated by the biological productivity in the vicinity of that intake.
  - Desalination plant intakes and discharges should not be located in or near HAPCs.
  - Areas with limited water circulation such as enclosed bays or estuaries, which can "trap" the brine discharge, should be avoided. Instead, brines should be discharged in areas with strong tidal currents to achieve more rapid dilution of the brine by the receiving waters.
  - Intake and discharge pipelines should be placed and configured to avoid sensitive biological areas.

4.2.2.13 Dredging and Dredged Spoil Disposal

Dredging is associated with improving river navigation for commercial and recreational activities and for maintaining the navigation channels of ports and marinas. Dredging may also be carried out during the construction of roads and bridges and the placement of pipe, cable, and utility lines. Dredging is also conducted to maintain channel flow capacity for flood control purposes.

Potential adverse effects from dredging and dredged spoil disposal

Dredging results in the temporary elevation of suspended solids emanating from the project area as a turbidity plume. Excessive turbidity can affect salmon or their prey by abrading sensitive epithelial tissues, clogging gills, decreasing egg buoyancy (of prey), and affects photosynthesis of phytoplankton and submerged vegetation leading to localized oxygen depression. When suspended sediments subsequently settle, they can destroy or degrade benthic habitats (NMFS 1997).

The removal of bottom sediments during dredging operations can disrupt the entire benthic community and eliminate a significant percentage of the feeding habitat available to fish for a significant period of time. The rate of recovery of the dredge area is temporally and spatially variable and site specific. Recolonization varies considerably with geographic location, sediment composition, and types of organisms inhabiting the area (Kennish 1997). Dredging may also affect the migration patterns of juvenile salmonids as a result of noise, turbulence, and equipment (FRI 1981).

The suspended sediments dredged from estuarine and coastal marine systems are generally high in organic matter and clay, both of which may be biologically and chemically active. Dredged spoils removed from areas proximate to industrial and urban centers can be contaminated with heavy metals, organochlorine compounds, polyaromatic hydrocarbons, petroleum hydrocarbons, and other substances (Kennish 1997) which may be released into the water column during the dredging operation. Sediments in estuaries downstream from agricultural, or urban/suburban residential, areas may also contain herbicide and pesticide residues (NMFS 1997).

Dredging and subsequent sediment deposition poses a potential threat to the eelgrass and other aquatic vegetation in estuaries and nearshore marine ecosystems, which provide important structural habitat and prey for salmon (see Section 4.2.2.14 Estuarine Alteration). Dredging not only removes plants and reduces water clarity, but can change the entire physical, biological, and chemical structure of the ecosystem (Phillips 1984). Dredging also can reverse the normal oxidation/reduction potential of the sediments of an eelgrass system, which can reverse the entire nutrient-flow mechanics of the ecosystem (Phillips 1984).

Concomitant with dredging is spoil disposal. Dredged material disposal has been used in recent years for the creation, protection and restoration of habitats (Kennish 1997). When not used for beneficial purposes, spoils are usually taken to marine disposal sites and this in itself may create adverse conditions within the marine community. When contaminated dredged sediment is dumped in marine waters, toxicity and food-chain transfers can be anticipated, particularly in biologically productive areas. The effects of these changes on salmon are not known.

Potential conservation measures for dredging and dredged spoil disposal

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon habitat in spawning redds, eelgrass beds, and other EFH areas of particular concern, that have the potential to be affected by dredging/spoil disposal activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from NMFS (1997), NMFS (1997d), and Meyer (1997 pers. comm.).

- Explore collaborative approaches between material management planners, pollution control agencies, and others involved in watershed planning to identify point and nonpoint sources of sediment and sediment pollution; to promote the establishment of riparian area buffers to help reduce sediment input, and to promote use of best management measures to control sediment input.
- Avoid dredging in or near spawning redds, eelgrass beds, and other EFH areas of particular concern; especially where the areal extent of the dredging could affect the prey base for emigrating juvenile salmon.
- Monitor dredging activities especially contaminated sediments and regularly report effects on EFH. Reevaluate activities based on the results of monitoring.
- Employ best engineering and management practices for all dredging projects to minimize water column discharges. Avoid dredging during juvenile emigration through estuaries. Where avoidance is not fully possible, area and timing guidelines should be established in consultation with local, state, tribal, and Federal fish biologists.
- When reviewing open-water disposal permits for dredged material, identify direct and indirect effects of such projects on EFH. Consider upland disposal options as an alternative. Mitigate all unavoidable adverse effects and monitor mitigation effectiveness.
- Test sediments for contaminants prior to dredging and dispose of contaminated sediments at upland facilities.
- Determine cumulative effects of existing and proposed dredging operations on EFH.
- Explore the use of clean dredged material for beneficial use opportunities.

4.2.2.14 Estuarine Alteration

Estuaries represent transitional environments coupling land and sea water. The dominant features of estuarine ecosystems are their salinity variances; typically shallow areas; high biological productivity and diversity; which, in turn are governed by the tides and the amount of freshwater runoff interacting with coastal topography. These systems present a continuum along a fresh-brackish-salt water gradient as a river system empties into the sea. There is a very large range of sizes of estuary systems from the mouth of a small coastal stream to Puget Sound or Chesapeake Bay. The combination of mixed salinity and sediment deposition within shallow coastal waters results in areas of high and uneven advection from winds and currents, forming diverse structures and ecological processes. Estuarine ecosystems, containing a large diversity of species that reflect the great structural diversity and resultant differentiation of niches, may be characterized as:

- Unique hydrological features by which fresh water slows and flows over a wedge of heavier intruding tidal salt water resulting in suspended terrestrial and autochthonous products settling into the inflowing salt water or into bottom sediments.
- Shallow nutrient-rich environments resulting in an enormously productive vegetative habitat and detrital food chain for many organisms, such as crustaceans and juvenile fish.
- Critical nursery habitats for m any aquatic o organisms, particularly anadromous fish and ecotones for shore birds and waterfowl.
- Contributing to the "trapping" and recycling of nutrients: a n area w here an accumulation of nutrients such as potassium and nitrogen are concentrated and recycled – a repeating interactive process by which the incoming tidal water re-suspends nutrients at the fresh-salt water interface while moving them back up the estuary, and the land-based sources of nutrients move towards the sea.
- Depending on the depths, timing and volumes of marine inflows, estuarine conditions may be influenced to a large degree by constituents of the marine waters. For example, more acidic and cooler waters in Puget Sound are mostly the result of marine inflows.
- Accumulating fine sediments transported in by tides and rivers, further enhancing productivity by being adsorptive surfaces for nutrients.

In Oregon where there are relatively few estuarine wetlands because of the steep topography of the shore, it is estimated that between 50 percent and 90 percent of the t tidal marsh s systems in estuaries have been lost in the past century (Frenkel and Morlan 1991). The estuarine environment benefits salmon by providing a food rich environment for rapid growth, physiological transition between fresh and salt water environments, and refugia from predators (Simenstad 1983). Estuarine eelgrass beds, macroalgae, emergent marsh vegetation, marsh channels, and tidal flats provide particularly important estuarine habitats for the production, retention, and transformation of organic matter with in the estuarine food web as well as a direct source of food for salmon and their prey. Additionally, estuarine marsh vegetation, overhanging riparian vegetation, eelgrass beds, and shallow turbid waters of the estuary provide cover for predator avoidance. As noted by Salo (in Groot and Margolis 1991), "the food web supporting juvenile salmonids in the estuarine habitat appears to be detritus-based." Since estuarine detritus comes from mostly local marine and riparian plants, the food web relies on actions that sustain and protect plant production in-water and along shorelines. Estuaries provide enough habitat variety to allow the numerous species and stocks of salmonids to segregate themselves by niche.

Chinook salmon fry, for example, prefer protected estuarine habitats with lower salinity, moving from the edges of marshes during high tide to protected tidal channels and creeks during low tide (Healey 1980; 1982; Levy and Northcote 1981; 1982; Kjelson et al. 1982; Levings 1982). As the fish grow larger, they are preying on fishes and increasingly found in higher salinity waters and increasingly utilize less -protected habitats, including delta fronts or the edge of the estuary before dispersing into marine waters. As opportunistic feeders, Chinook salmon consume larval and adult insects and amphipods when they first enter estuaries, with increasing dependence on larval an d juvenile fish such a s anchovy, smelt, herring, and stickleback as they grow larger (Sasaki 1966; Dunford 1975; Birtwell 1978; Levy et al. 1979; Northcote et al. 1979; Healey 1980;1982; Kjelson et al. 1982; Levy and Northcote 1981; Levings 1982; Gordon and Levings 1984; Myers 1980; Reimers 1973).

For juvenile coho salmon, LWD is an important element of estuarine habitat (McMahon and Holtby 1992).

During their residence time in estuaries, small coho salmon consume large planktonic or small nektonic animals, such as amphipods, insects, mysids, decapod larvae, and larval juvenile fishes (Myers and Horton 1982; Simenstad et al. 1982; Dawley et al. 1986; McDonald et al. 1987). In estuaries, larger salmon smolts prey on fishes that inhabit intertidal and pelagic habitats with deep marine-influenced habitats often preferred (Pearce et al. 1982; Dawley et al. 1986; McDonald et al. 1987). The estuarine residence time of juvenile coho salmon is highly variable, ranging from days to months, and is probably correlated with age of emigration, with younger fish spending more time in the estuary than older fish (Powers et al. 2006).

Although pink salmon generally pass directly through the estuary en route to nearshore areas, populations that do reside in estuaries for one to two months utilize shallow, protected habitats such as tidal channels and consume a variety of prey items, such as copepods, amphipods, and larvae and pupae of various insects (Heard and Salo, in Groot and Margolis, 1991).

There are four general categories of impacts on estuarine ecosystems: *enrichment* with excessive levels of organic materials, inorganic nutrients, or heat; *physical alterations* which include hydrologic changes, removal of natural woody material, dredging to deepen for navigation, and filling to convert marine to uplands; *introduction of toxic materials*; *introduction of exotic species* leading to direct changes in species composition and food web dynamics.

Progressive *enrichment* of estuarine waters with inorganic nutrients, organic matter, or heat leads to changes in the structure and processes of estuarine ecosystems. Nutrient enrichment can lead to excessive algal growth, increased metabolism, and changes in community structure, a condition known as eutrophication.

Jaworski (1981) discusses sources of nutrients and scale of eutrophication problems in estuaries. Addition of excessive levels of organic matter to estuarine waters results in elevated pathogens and lowered dissolved oxygen concentrations which then results in concomitant changes in community structure and metabolism. Inorganic nutrients from mineralization of the organic matter can stimulate dense algal blooms and lead to another source of excessive organic matter. The source of high levels of organic matter is normally stormwater or sewage waste water, and high levels historically resulted from seafood processing wastes and industrial effluents (Weiss and Wilkes 1974). Impacts from thermal loading include interference with physiological processes, behavioral changes, disease enhancement, and impacts from changing gas solubilities. These impacts may combine to affect entire aquatic systems by changing primary and secondary productivity, community respiration, species composition, biomass, and nutrient dynamics (Hall et al. 1978). (Note the references from 1974 to 1981 refer to conditions common at those times. The seriousness of those conditions does not reflect widespread compliance with NDPES permits etc. in the past 30 years. The degree that eutrophication of estuaries remains a major issue varies widely over the US.)

Local *physical alterations* in estuarine systems include such activities as filling and draining of wetlands, construction of deep navigation channels, bulkheading, and canal dredging through wetlands. Two major types of impacts resulting from these activities are estuarine habitat destruction and hydrologic alteration. For example, canals and deep navigation channels can alter circulation, increase saltwater intrusion, and promote development of anoxic waters in the bottoms of channels. Upstream changes in rivers can also have pronounced effects on estuaries into which they discharge. Construction of dams, diversion of fresh water, and groundwater withdrawals lower the amount and change the delivery timing of fresh water, nutrients, and suspended input -- all important factors in estuarine productivity (Day et al. 1989).

The measurable consequences of anthropogenic disturbances in the Columbia River estuary have been dramatic since the initial comprehensive surveys and contemporaneous initiation of dredging, diking, shipping, groin and jetty construction, and riverflow diversion between the 1870s and the end of the twentieth century. Thomas (1983) documented a 30 percent loss (142 square kilometers) of the surface area of the estuary, although some 45 square kilometers have been changed from op en water to shallows. Thomas (1983) also reported a 43 percent loss of tidal marshes and a 76 percent loss of tidal wetlands. The loss of shallow estuarine areas can shift the estuarine prey composition from benthic crustaceans and terrestrial insects, the preferred food of most salmon smolts, to water-column dwelling zooplankton. These zooplankton are favored by species such as herring, smelt, and shad (Sherwood et al. 1990).

Toxic materials include such compounds as pesticides, heavy metals, petroleum products, and exotic byproducts of industrial activity near estuaries. Such contaminants can be acutely toxic, or more commonly, they can cause chronic or sublethal effects. Toxins can also bioaccumulate in food chains. The same processes that lead to the trapping of nutrients, and thereby to the productivity of the estuary, also lead to the trapping and concentrating of pollutants. Fine sediments not only retain phosphorous and other nutrients, but also petroleum and pesticide residues. Odum (1971) noted that estuarine sediments can concentrate dichlorodiphenyltrichloroethane over 100,000 times higher than in the water of the estuary. Such pesticides residues enter the food chain via detritus-eating invertebrates and are further concentrated. The same features of water circulation in the estuary that concentrate nutrients also concentrate and disperse pollutants such as mercury and lead, heavy metals from sewage, industrial and pulp m ill effluents. Estuarine food chains are extremely complex and sensitive to alterations in the physical and chemical range of stresses. Loss or disruption of one element can have a cascading effect on species presence and productivity.

Introduction of exotic species has the potential to change species composition and food web dynamics. See Section 4.2.2.18 Introduction/Spread of Invasive Alien Species for further detail.

Note that predation can also be an issue. Changes to food webs or physical conditions from any of the four general categories of impacts can result in elevated or different risks from predators.

<u>Potential conservation measures for estuarine alteration</u>

The following suggested measures are adapted from NMFS (1997), NMFS (1997d), Lockwood (1990), and Meyer, (1997 pers. co mm.).

In addition to the relevant conservation measures listed for "Dredging and Dredged Spoil Disposal," "Irrigation Water Withdrawal, Storage, and Management," "Bank Stabilization, Wastewater/Pollutant Discharge," "Artificial Propagation of Fish and Shellfish," "Offshore Oil and Gas Exploration, Drilling and Transportation," and the "Introduction and Spread of Nonnative Species," the following are suggested to minimize potential adverse effects of estuarine alteration activities.

- Minimize alteration of shallow estuarine habitat in areas of salmon EFH, including eelgrass beds, tidal channels, and estuarine and tidally-influenced marshes. Minimize effects through appropriate site design, engineering, best management practices, and mitigate all unavoidable adverse effects (See EPA 1993; Metro 199 7; SCS Enginners 1989).
- Utilize BMPs for controlling pollution from marina operations, boatyards, and fueling facilities.
- Design appropriate restoration and mitigation performance objectives for properly functioning conditions and values of EFH and monitor achievement of these objectives. Restoration of shallow water habitat is paramount.
- Utilize the placement of woody debris as a part of marsh and estuary enhancement and mitigation work; avoid scavenging logs from estuarine areas; re-position, rather than remove, logs that are hazardous to navigation within river or estuary; and maximize removal of dikes where possible.
- Promote awareness and use of the U.S. Department of Agriculture's (USDA's) Wetland Reserve Program to encourage restoration of estuarine habitat.
- Maximize maintenance of freshwater inflow to estuaries. Ideally peak flows could also be provided to sustain and recover natural processes.

- Design culvert replacements and repairs in EFH to increase fish passage for both adult and juvenile fish.

4.2.2.15 Flood control maintenance

The protection of riverine and estuarine communities from flooding events can result in varying degrees of change in the physical, chemical, and biological characteristics of existing shoreline and riparian habitat. Land surrounding rivers is in high demand for agricultural and developmental purposes, prompting creation of artificial structures that improve flood control (SRSRB 2006). These structures include levees, weirs, channels, and dikes.

Potential adverse effects from flood control and maintenance

Managing flood flows with these structures can disconnect a river from its floodplain eliminating off-channel habitat important for salmon (WSCC 2001b) Floodplains serve as a natural buffer to changes in water flow: they retain water during periods of higher flow and release it from the water table during reduced flows (Ziemer and Lisle 2001). These areas are typically well vegetated, lowering water temperatures, regulating nutrient flow and removing toxins. Juvenile salmon use these off channel areas because their reduced flows, greater habitat complexity and shelter from predators may increase growth rates and their chance of survival.

Artificial flood control structures have similar effects on aquatic habitat, as do bank stabilization efforts and woody debris removal. Riverbanks are artificially steepened, eliminating much of the inshore, shallow-water habitat used by larval and juvenile salmonids. Channel complexity is also lost, reducing naturally formed pool-riffle sequences (NMFS 2008c). Pools provide deepwater habitat for larger fish, as well as thermal and spatial refugia during low flow periods. Riffles support benthic invertebrates and juvenile fishes (Thompson 2002). The woody debris that provides shelter and helps structure heterogeneous flows is also lost (USFWS 2000). As a result, water moves at a uniform, increased rate, thereby decreasing spawning habitat and altering sediment dynamics. Sediment size distribution is important for providing habitat to salmonid prey items such as stoneflies and mayflies (NMFS 2009a). In addition, the routing of water through specific flood channels may isolate or strand migrating salmon. Earthen levees can be prone to failure due to cracks caused by rooting plants, and may thus be periodically cleared or stripped of vegetation, leaving denuded banks and barren riparian zones. This leads to decreased shading, higher water temperatures, less LWD recruitment, reduced filtering of overland nutrients, sediment, and toxics, and a loss of bank stability.

The use of dikes and berms can also have long-term adverse effects in tidal marsh and estuarine habitats. Dikes, levees, ditches, or other water controls at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing freshwater flushing and annual flushing, annual renewal of sediments and nutrients, and the formation of new marshes. Water controls within the marsh proper intercept and carry away freshwater drainage, block freshwater from flowing across seaward portions of the marsh, increase the speed of runoff of freshwater to the bay or estuary, lower the water table, permit saltwater intrusion into the marsh, and create migration barriers for aquatic species. In deeper channels where reducing conditions prevail, large quantities of hydrogen sulfide are produced that are toxic to marsh grasses and other aquatic life. Acid conditions of these channels can also result in release of heavy metals from the sediments.

Long-term effects on the tidal marsh include land subsidence (sometimes even submergence), soil compaction, conversion to terrestrial vegetation, greatly reduced invertebrate populations, and general loss of productive wetland characteristics. Loss of these low-salinity environments reduces estuarine fertility, restricts suitable habitat for aquatic species, and creates abnormally high salinity during drought years. Low-salinity environments form a barrier that prevents the entrance of many marine species, including competitors, predators, parasites and pathogens.

Potential conservation measures for flood control and maintenance

- Minimize the loss of riparian habitats as much as possible.
- The diking and draining of tidal marshlands and estuaries should not be undertaken unless a satisfactory compensatory mitigation plan is in effect and monitored.
- Wherever possible, “soft” approaches (such as beach nourishment, vegetative plantings, and placement of LWD) to shoreline modifications should be utilized.
- Include efforts to preserve and enhance EFH by providing new gravel for spawning areas; removing barriers to natural fish passage; and using weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.
- Construct a low-flow channel to facilitate fish passage and help maintain water temperature in reaches where water velocities require armoring of the riverbed.
- Replace in-stream fish habitat by providing rootwads, deflector logs, boulders, and rock weirs and by planting shaded riverine aquatic cover vegetation.
- Use an adaptive management plan with ecological indicators to oversee monitoring and ensure mitigation objectives are met. Take corrective action as needed.
- Retain trees and other shaded vegetation along earthen levees.
- Screen inappropriate flood control channels.
- Ensure adequate inundation time for floodplain habitat that activates and enhances near-shore habitat for juvenile salmon.
- Ramp and convey flood flows appropriately to reduce stranding events.
- Reconnect wetlands and floodplains to channel/tides.

4.2.2.16 Forestry

Forest practices can affect salmon habitat in several ways. Construction, reconstruction, maintenance, and use of roads associated with forestry can block fish access to streams, and can increase sediment delivery to streams and reduce stream substrate functions for fish and their prey. Tree felling, yarding, and site preparation, particularly if near the stream or on unstable slopes, can also increase sediment delivery, can cause loss of large wood for stream channel structure, can reduce shade and increase stream temperature, and can alter instream nutrients and hydrology (Beschta et al. 1987; Bisson et al. 1987; Chamberlin et al. 1991; Spence et al. 1996; Grant et al. 2008). The effects of forest practices are summarized below in terms of their effects on these salmon habitat elements: stream substrate, water temperature, other water quality components, wood and stream channel complexity, hydrology, habitat connectivity and beaver habitat.

Stream Substrate
Certain forest management activities including tree felling and yarding in riparian areas and on unstable slopes, and particularly road construction, increase sediment delivery to streams through increased surface erosion and mass wasting (Furniss et al. 1991; FEMAT 1993; Spence et al. 1996; Lee et al. 1997; McClelland et al. 1997). Tree felling, log yarding, and site preparation (e.g., prescribed burning and scarification prior to planting) adjacent to streams or with narrow buffers between the activities and streams can deliver sediment directly to streams (Chamberlin et al. 1991; Murphy 1995; Rashin et al. 2006). Streamside buffer strips of 75 to100 feet in width are adequate to filter out most upslope sediment (King 1979; Megahan and Ketcheson 1996); buffers as small as 30 feet in width are adequate in some cases, depending on slope, soil type, amount of disturbance, etc. (Rashin et al. 2006). Road construction, maintenance, and use (particularly during wet weather) deliver sediment to streams mainly through road surfaces, road-side ditches, and road intersections with streams (Reid and Dunne 1984). Those channelized sources are not effectively mitigated by no-cut buffers. Erosion rates decline after completion of road

construction; however, unpaved road surfaces continually erode fine sediments and add significant amounts of sediment to streams (Reid and Dunne 1984; Swanston 1991; Croke and Hairsine 2006; Cover et al. 2008). Also, road construction or improper road maintenance on unstable slopes can greatly increase landslide rates and deliver large pulses of sediment to streams (Swanson and Dryness 1975; Swanston and Swanson 1976; Furniss et al. 1991; McClelland et al. 1997; Robison et al. 1999; Jakob 2000). Road culverts and associated fills can also be a source of sediment pulses, especially if culverts become plugged or fail (Furniss et al. 1991; Murphy 1995; Beechie et al. 2005).

Increased sediment delivery to streams causes sedimentation of stream substrates. This reduces habitat availability for aquatic invertebrates on which juvenile salmon feed, and also reduces exchange of oxygenated water in spawning gravels, which decreases survival of salmon eggs and embryos (Bjornn and Reiser 1991; Murphy 1995). Sedimentation-induced reduction in habitat quality for invertebrates causes reduction in food supply for, and growth rates of juvenile salmonid fishes (Waters 1995; Shaw and Richardson 2001; Suttle et al. 2004). Sedimentation also degrades spawning substrates for eggs and embryos, and reduces the quality of pool habitat and overwintering habitat for juvenile salmonid fishes (Platts et al. 1989; Furniss et al. 1991; Waters 1995; Gucinski et al. 2001; Suttle et al. 2004; Cover et al. 2008).

Water Temperature

Forest management can increase stream temperatures by reducing the density of the riparian vegetative canopy and stream shade, and thereby increasing the amount of solar radiation reaching streams (Brown 1970; Brown and Krygier 1970; Brazier and Brown 1973; Steinblums 1977; Steinblums et al. 1984; Brosofske et al. 1997; Johnson and Jones 2000; Kiffney et al. 2003; 2004; Moore et al. 2005a; Pollock et al. 2009; Groom et al. 2011). The amount of stream shade following clearcut tree felling is related to the width of no-cut buffers (Brazier and Brown 1973; Steinblums 1977; Steinblums et al. 1984; Kiffney et al. 2003; Gomi et al. 2005; Moore et al. 2005a; Fleuret 2006), but the relationship is quite variable, depending on site-specific factors such as stream size, stream channel aspect, topography, forest structure and forest species composition (Moore et al. 2005a). The thermal responses of streams to reductions in riparian canopy density also are variable, and are affected by the geomorphic and hydrologic conditions within the subject stream reaches (Story et al. 2003; Johnson 2004; Moore et al. 2005b; Janisch et al. 2012). In some instances (such as narrow streams with dense, overhanging streamside vegetation, or stands on the north sides of streams with an east-west orientation), no-cut buffers as narrow as 30 feet adjacent to clearcut units can maintain stream shade (Brazier and Brown 1973). Other studies indicate that buffers of 100 feet or greater in width are needed in some circumstances to protect streams from temperature increases due to adjacent clearcuts (Steinblums et al. 1984; Kiffney et al. 2003).

Forest thinning can increase the amount of solar radiation penetrating through no-cut buffers, depending on the intensity of thinning (Chan et al. 2004). Although the available published studies on effects of thinning are not sufficient to establish quantitative relationships, reductions in stream shade due to thinning are likely to increase stream temperatures in some situations.

Forest management can also affect stream temperatures by altering factors internal to the stream such as width/depth ratios and the connectivity of streams with floodplains (Beschta et al. 1987; Bisson et al. 1987; Bilby and Bisson 1998; Johnson and Jones 2000; Pollock et al. 2009). Increases in sedimentation generally increase the width and reduce the depth of streams, and such streams are more prone to warming by sunlight (Poole and Berman 2001; Poole et al. 2001a; 2001b). Constructing roads or logging on unstable slopes can increase the rate of landslides that propagate downstream as debris flows, which reduce riparian vegetation, stream shade and the amount of woody material in streams (Johnson and Jones 2000; Pollock et al. 2009). Without this wood, affected streams collect less of the gravel that allows for hyporheic exchange of water, which can exert a significant cooling effect during the warm part of the day (Poole et al. 2001a; Story et al. 2003; Johnson 2004). The construction of road fills and the cutting of road side slopes can intercept groundwater (Furniss et al. 1991) that in some situations otherwise would cool stream segments.

Documented adverse effects on Pacific salmon from warm water temperature include: (1) delay or blockage of adult migration (Sauter et al. 2001); (2) increased adult mortality and reduced gamete survival during pre-spawn holding, and reduced spawning success (Berman 1990; McCullough et al. 2001; Marine 1992); (3) reduced growth of alevins or juveniles (McCullough et al. 2001; Marine 2004); (4) reduced competitive success relative to non-salmonid fishes (Reeves et. al. 1987; Sauter et al. 2001); (5) out-migration from unsuitable areas and truncation of spatial distribution (Dunham et al. 2001); (6) increased disease virulence, and reduced disease resistance (McCullough et al. 2001); and (7) potentially harmful interactions with other habitat stressors (Materna 2001).

Other Water Quality Components

Suspended Sediment – Increased yield of fine sediments caused by forestry activities (primarily roads but also activity-induced landslides and other sources of erosion) can increase suspended sediment in streams (Reid and Dunne 1984; Beschta 1990; Waters 1995; Hassan et al. 2005). Increases in suspended sediment can kill or injure fish. Exposures to very high concentrations of suspended sediment can kill fish (Newcombe and Jensen 1996). Sublethal effects include physiological stress and reduced feeding and growth (Redding et al. 1987; Gregory and Northcote 1993; Waters 1995; Newcombe and Jensen 1996; Wingfield et al. 1997; Shaw and Richardson 2001; Shrimpton et al. 2007) and reduced resistance to disease or toxicants (Redding et al. 1987; Waters 1995). Concentrations of suspended sediment that are below levels causing physiological harm can, however, provide increased cover and protection from predators (Gregory and Levings 1998).

Nutrients/Productivity – Although tree removal can increase water temperature and have the negative effects on salmon habitat noted above, it also can positively affect fish habitat. Decreasing shade increases the amount of photosynthetically active radiation reaching streams (Brosofske et al. 1997; Hetrick et al. 1998; Kiffney et al. 2003), and thereby increases primary (e.g., algal) and secondary (e.g., macroinvertebrate) productivity, provided that nutrients are not limiting (Kiffney et al. 2003; Kiffney et al. 2004; Mallory and Richardson 2005; Kiffney 2008). Tree removal and reduced uptake of soil nutrients by trees may increase nutrient levels in streams (Webster et al. 1990; McClain et al. 1998; Danehy et al. 2007); however, increases in nitrogen and phosphorous concentrations are either very small or short-lived (Megahan 1980; Hicks et al. 1991a; Salminen and Beschta 1991; Brown and Binkley 1994; Gravelle et al. 2009). Application of fertilizers to promote tree growth can result in drift, overland flow, or ephemeral stream transport of nutrients into streams (Norris et al. 1991), which also can increase primary productivity. Increases in primary productivity can increase the biomass of macroinvertebrate organisms, some of which are prey for juvenile salmon, although the diversity of macroinvertebrates may be reduced (Hicks et al. 1991a; Kiffney et al. 2005; Compton et al. 2006; Richardson 2008).

Dissolved Oxygen/Litter Fall – Increases in water temperature and primary productivity, and changes in delivery of organic matter due to logging can affect the concentration of dissolved oxygen in salmon habitats. Inputs of leaf litter and other organic matter may reduce dissolved oxygen through respiration by micro-organisms; however, those inputs also provide nutrients and food for aquatic invertebrates. Logging practices that introduce large quantities of organic debris in streams can greatly decrease dissolved oxygen concentration (Hall and Lantz 1969; Brown and Binkley 1994). Keeping logging debris out of stream channels is typically required under current forest practices, and therefore, changes in inputs of organic matter (and by association, dissolved oxygen) mainly relate to changes in riparian vegetation. Logging initially reduces the amount of organic matter input to streams (Webster et al. 1990; Bilby and Bisson 1992; Hetrick et al. 1998; Richardson and Danehy 2007), and then changes the composition of organic matter, as herbaceous plants and broadleaf shrubs replace conifers along the stream (Bonin et al. 2000; Piccolo and Wipfli 2002; Volk et al. 2003; Hart 2006). A recent study found that the effect of logging on total litter input was transient, with litter inputs in logged areas becoming similar after 7 years to unlogged control streams (Kiffney and Richardson 2010).

Increases in stream temperature alone can reduce dissolved oxygen concentrations by lowering saturation levels. However, where forest practices retain shade or allow rapid shade recovery such that temperatures are sufficiently low for oxygen saturation levels to remain above 8 parts per million, there may be little negative effect of temperature increase on dissolved oxygen in streams (Hynes 1960; Leitritz and Lewis 1980; Bjornn and Reiser 1991).

Rivers, estuaries, and bays were the primary means of transporting and storing logs historically in the Pacific Northwest. Log storage within the bays and estuaries remains an issue in several Pacific Northwest bays. Using estuaries, bays, and nearby uplands for storage of logs is common in Alaska, with most of Alaska's log transfer facilities (LTFs) in southeast Alaska, and a few in Prince William Sound.

An LTF is a facility which is constructed in whole or part in waters of the United States and which is utilized for the purpose transferring commercially harvested logs to or from a vessel or log raft, including the formation of a log raft (EPA 2000). LTFs may include a crane, an A-frame structure, conveyor, slide or ramp, and are used move logs into the water. Logs can also be placed in the water by helicopters and barges. The physical adverse effects of these structures on EFH are similar in many ways to those of floating docks and other "over-water" structures. Accumulation of bark debris is unique to LTFs. After the logs have entered the water, they are usually bundled into rafts and hooked to a tugboat for shipment. In the process, bark and other wood debris can pile up on the bottom of the waterway. The piles can smother clams, mussels, and some types of submerged vegetation, with the bark sometimes remaining for decades. Accumulation of bark debris in shallow and deep water environments has resulted in locally decreased richness and abundance of epifaunal macrobenthic invertebrate organisms (Jackson 1986; Kirkpatrick et al. 1998), which can reduce the availability of food for some species and life stages of groundfish.

Stored logs may release soluble, organic compounds. This can degrade groundfish EFH by significantly increasing biological oxygen demand within the area of accumulation (PNPCC 1971). High oxygen demand can lead to an anaerobic zone where toxic sulfide compounds are generated, particularly in brackish and marine waters. Leaching of soluble organic compounds also leads to reduced visibility and predation efficiency for EFH species. Reduced dissolved oxygen concentrations, anaerobic conditions, and the presence of toxic sulfide compounds thereby likely reduce the production of salmon and their forage organisms. Anaerobic areas also reduce available habitat. Soils at onshore facilities where logs are transferred often are contaminated with gasoline, diesel fuel, solvents, etc., from trucks and other machinery. These contaminants can leach into adjacent EFH.

The physical, chemical, and biological impacts of LTF operations can be substantially reduced by adherence to appropriate siting and operational constraints. In 1985, the Alaska Timber Task Force (ATTF) developed guidelines to "delineate the physical requirements necessary to construct a log transfer and associated facilities, and in context with requirements of applicable law and regulations, methods to avoid or control potential impacts from these facilities on water quality, aquatic and other resources." Since 1985, the ATTF Guidelines have been applied to new LTFs in Alaska through the requirements of NPDES permits and other state and Federal programs (EPA 1996). Adherence to guidelines such as the ATTF operational and siting guidelines and BMPs in the NPDES general permit for Alaska is likely to reduce the 1) amount of bark and wood debris that enters estuarine and marine EFH, 2) the potential for displacement or harm to aquatic species, and 3) accumulation of bark and wood debris on the substrate of waterways. The conservation measures for LTFs reflect these documents.

Toxic Chemicals – The use of herbicides, insecticides, fire retardants, and spill or leaching of petroleum products from forest roads can kill invertebrates that are food sources for fish can kill or injure fish. Herbicides applied directly to surface waters or entering by wind drift or leaching from near-stream soils can kill aquatic invertebrates (Hartman and Scrivener 1990). Forestry related doses of herbicides that are lethal to salmonid fishes (Reid 1993) would be unlikely except in the case of spills; however, sublethal doses are more likely; related sublethal adverse effects include reduced growth, altered behavior, and reduced resistance to physiological stress (Beschta et al. 1995; Spence et al. 1996). Norris et al. (1991) concluded that insecticides generally have shorter term effects on stream ecosystems than herbicides, but that initial negative effects on aquatic invertebrates can be dramatic. Documentation of the effects of upslope application of fire retardants on streams is scarce; however, when applied directly to streams, fire retardants can kill fish (Hakala et al. 1971; Norris and Webb 1989; Schullery 1989). Petroleum-based products (e.g., fuel, oil, hydraulic fluids) are moderately to highly toxic to fish and other aquatic organisms, depending on concentration and exposure time (Neff 1985). Free oil and emulsions can adhere to gills and interfere with respiration, and heavy concentrations of oil can suffocate fish. Evaporation, sedimentation, microbial degradation, and hydrology determine the fate of fuels entering fresh water (Saha and Konar 1986) and exposures of aquatic invertebrates and fish. Forest practices that avoid fueling near streams and include measures/equipment to avoid and contain spills (e.g., from log hauling and fuel trucks) can minimize the risk of exposure of fish to lethal concentrations of petroleum products. Practices that avoid leakage from logging machinery and transport trucks can reduce chronic inputs of petroleum products from forest road surfaces to streams, and reduce the risk of sublethal adverse effects on fish.

Synthesis of Effects on Water Quality

Roads constructed and used for forestry are a source of suspended sediment as well as substrate sedimentation, and thus have mostly detrimental effects on salmon and their habitat (Spence et al. 1996; Shrimpton et al. 2007). Logging that reduces canopy cover sufficiently to increase water temperature can cause physiological, behavioral, and ecological stresses on salmon, but also can increase primary production, invertebrate biomass, and fish biomass (Murphy and Hall 1981; Nislow and Lowe 2006). Increases in stream nutrient levels from tree removal and/or application of fertilizers can add to productivity; however, such increases are typically small and short duration (Salminen and Beschta 1991; Brown and Binkley 1994). Current forest practices tend to reduce organic inputs through litter fall initially, but these effects may also be short-lived (Kiffney and Richardson 2010). Increases in stream temperature, photosynthetically active radiation, primary productivity, and nutrients can reduce dissolved oxygen; however, these effects appear to be counterbalanced by positive effects on food production.

The competing effects of increased temperature on salmon behavior, physiology, and ecological interactions (negative) and increases in their prey base (positive) may be relatively short in duration, especially in small streams, where shade tends to become substantially re-established within a 10 years of logging (Moore et al. 2005a). Temperature increases in streams that have been subject to debris flows may be more persistent due to changes in channel form (Pollock et al. 2009). The overall significance of these changes to individual stream reaches can only be understood by using basin-scale analysis that examines the cumulative effects of short-term, localized temperature increases (Beschta et al. 1987; Brosofke et al. 1997). Loss of shade from logging along larger streams may have more enduring, although somewhat lesser effects on stream temperature, fish, and their food webs due to higher flows and greater dilution of added heat. While it is possible that logging can temporarily stimulate fish production through temperature and light-related mechanisms, chronic sedimentation of substrate from roads and the loss of instream wood (see discussion of channel complexity below) will tend to negate and outlast those potential positive effects and be detrimental to both prey organisms and physical habitat features important for spawning, incubation, and rearing of salmon (Murphy et al. 1986; Spence et al. 1996).

LTFs can reduce water quality through accumulation of bark debris and leaching of soluble organic compounds, which increases biological oxygen demand.

Wood and Stream Channel Complexity

In-stream wood regulates sediment and flow routing, influences stream channel complexity and stability; increases pool volume and area; retains non-woody organic matter, allowing it to be biologically processed prior to downstream export as dissolved and particulate nutrients; delays surface water passage, allowing it to be cooled by mixing with ground water; provides a substrate for organic matter development and benthic invertebrates (Coe et al. 2009); and provides hydraulic refugia and cover within streams for fish (Bilby

1984. Bisson et al. 1987; Sullivan et al. 1987; Gregory et al. 1991; Hicks et al. 1991; Ralph et al. 1994; Bilby and Bisson 1998). Instream wood also retains salmon carcasses (Cederholm and Peterson 1985), a major source of nitrogen, phosphorus and carbon in stream ecosystems (Bilby et al. 1996).

Logging near streams reduces the amount of wood that falls into streams over time (Murphy et al. 1986; Bisson et al. 1987; 1992; Ralph et al. 1994). In mature conifer forests in western North America, approximately 50 percent of total wood recruited to streams from streamside areas comes from within 10 to 12 m of the streams, 75 percent of the wood comes from within 17 to 25 m, and 100 percent comes from within 50 to 60 m (McDade et al. 1990; Welty et al. 2002; Meleason et al. 2003). In hardwood riparian forests, the trees are considerably shorter than conifer trees, and more than 50 percent of total wood delivered to streams originates within 5 m of streams and 100 percent originates within 25 m.

Landslides, and debris flows that propagate landslides downstream, sometimes contribute substantial amounts of wood to streams inhabited by salmon. This phenomenon is well documented in the Oregon Coast Range, where wood transported in this manner may constitute one-half or more of the wood recruited to downstream reaches (McGarry 1994; Reeves et al. 1995; May and Gresswell 2003; Reeves et al. 2003). Because of this, logging on unstable slopes and near along debris flow-prone streams likely reduces the potential recruitment of wood to salmon habitat (Reeves et al. 1995; May and Gresswell 2003; Reeves et al. 2003).

Decreased in-stream wood due to logging reduces the number, area, and volume of pools in streams (e.g., Bilby and Ward 1989; Ralph et al. 1994; Montgomery et al. 1995; Beechie and Sibley 1997). Pools are important as rearing and pre-spawning holding habitat for Pacific salmon (Hicks et al. 1991a). Reductions in wood also decrease that retention of gravel that is used for spawning and incubation by Pacific salmon (Bilby and Ward 1989; Buffington and Montgomery 1999).

Hydrology

Total water yield typically increases after logging due to reduced evapotranspiration by live trees (Harr et al. 1975; Keppler and Zeimer 1990; Jones 2000), and stream flows appear to respond to the increase in water yield in proportion to the acreage logged (Bosch and Hewlett 1982; Keppler and Zeimer 1990; Stednick 1996). Tree removal generally increases summer low flows for the first 5-10 years after logging; however, this effect may be fairly quickly countered by new plant growth and increased evapotranspiration within a few years after harvest (Hicks et al. 1991b). The projected gains and losses of base flow from tree removal and subsequent plant regrowth will tend to be small percentages of the overall stream flow, except in small watersheds where a substantial portion of the land is logged.

A review of the effects of logging on peak flow showed that peak flow tended to increase as a function of logged area, but also showed that increased peak flow tends to be manifested only for relatively frequent (less than 5-year recurrence interval) flood events (Grant et al. 2008) . However, the ability to detect logging-induced changes in flow becomes more difficult with increasing magnitude of flood events. It is somewhat unclear how much of the peak flow increases for the frequent flood events are attributable to logging and how much to water routing by roads. Roads appear to be either the primary factor (Megahan 1972; Wemple et al. 1996) or at least a demonstrable contributor in proportion to the amount of road network linkages to streams (Grant et al. 2008). While logging and roads may increase peak flows of less than 5-year floods, peak flows that scour stream substrate sufficiently to reduce salmon survival (particularly the egg-to-fry stage) have so far only been documented for greater than 5-year floods (Beamer et al. 2005). Available evidence suggests that forestry-caused changes in peak flow may have little or no effect on salmon habitat and populations.

Habitat Connectivity

Forest roads and culverts that eliminate or restrict fish access to streams can have a profound effect on distribution and abundance of salmon at the population scale (Kiffney et al. 2009). For example, in two watersheds in northwestern Washington, impassable culverts reduced juvenile coho salmon rearing capacity by 30-58 percent (Beechie et al. 1994; Roni et al. 2002; Pess et al. 2003). Roads along streams can also reduce or eliminate floodplain habitats such as alcoves, groundwater channels, and side channels. Basin-scale studies examining total habitat losses from all land uses indicate that approximately 40 percent of the losses were attributable to loss of floodplain channels (Beechie et al. 1994; Beechie et al. 2001). Reduction of those off-channel rearing areas caused by roads that constrict floodplains will tend to reduce survival of juvenile fish and thus reduce overall productivity of salmon populations.

Beaver Habitat
Beaver feeding may reduce standing woody riparian vegetation, but also increases the input of wood to streams. Beaver ponds often fill with sediments and become wetlands, but they retard erosion upstream and reduce sedimentation downstream. The ponds supplement summer low flows and provide important low-velocity over wintering habitat for salmonid fishes. Beaver ponds may also provide a sink for nutrients from tributary streams, thereby enhancing pond productivity and increasing nutrient retention. Overall, the reduction in beaver populations since European settlement has caused fundamental changes in ecosystem structure and function (Spence et al. 1996; Pollock et al. 2003). Summer habitat for coho salmon in ponds within the Stillaguamish River basin in Washington has been reduced by 88 percent, and winter habitat capacity has been reduced by 93 percent, compared with pre-settlement conditions (Pollock et al. 2004). Where coho salmon production is limited by pool availability and where conditions are suitable, allowing or encouraging beaver to build dams may be more cost-effective and appropriate as a restoration technique than adding wood to streams (Pollock et al. 2004).

Beaver often are removed by land managers to protect culverts from being plugged and to protect roads from flooding. Land managers also sometimes remove beaver dams to reduce the risk of dam break floods. Beavers may also be displaced if riparian vegetation, particularly alders, is removed. Removal or displacement of beaver eliminates the beneficial effects of beaver activity on EFH that are described above.

Potential Conservation Measures for Forestry

Forest Roads:

- Avoid construction or reconstruction of roads in riparian areas, and on potentially unstable slopes that can deliver sediment to EFH or tributary streams, unless alternative options for road construction would likely cause greater damage to aquatic habitats or riparian functions.
- Use temporary roads and stream crossings where practicable.
- Mitigate for riparian functions altered by new road segments.
- Ensure that new, reconstructed, and existing roads will not impair hydrological connections between stream channels, ground water, and wetlands; will not increase sedimentation to aquatic systems; will have adequate drainage and surfacing; and will not discharge drainage water into streams or onto potentially unstable land forms (e.g. concave hollows or headwalls on steep hills).
- Require stream crossings to provide adequate fish passage for both adults and juveniles, accommodate a 100-year flood without over-topping the road, and pass adequate woody material. Refer to Chapter 7 (Culverts and Other Road Crossings) in NMFS (2011a), for design criteria and guidelines.
- Apply BMPs for log hauling, recreational use, and seasonal closure to minimize erosion and sediment generation.

Tree Felling and Log Transportation:

- Apply no-cut buffers and limits on tree felling in partial logging zones on all sizes and categories of streams that are adequate to ensure maintenance of wood recruitment, stream shade, stream bank stability, sediment filtration, and connectivity of streams with floodplains and groundwater sources in EFH. Consider both streamside and upstream/upslope sources of wood when designing buffers and limits on tree felling. Use models and published relationships to determine acceptable buffer widths and limits on tree felling.

- Identify potentially unstable slopes and debris flow paths at the plan and project scales using topographic slope stability models and site-specific geologic evaluations. Limit or preclude tree felling on potentially unstable slopes and along debris-flow paths that are likely to deliver wood to EFH.
- Apply buffers on streams and minimize the width of yarding corridors to avoid and minimize sedimentation from machinery use and construction of log yarding corridors.
- Apply seasonal restrictions to avoid and minimize erosion and sedimentation during wet periods.

Toxic Chemicals:

- Develop a fuel transport, storage and spill contingency plan.
- Complete staging, cleaning, maintenance, refueling, and fuel storage for wheeled and tracked machinery in a staging area placed 150 feet or more from any stream or stream-associated wetland, or in areas that are hydrologically disconnected from streams and wetlands.
- Inspect all wheeled and tracked machinery that will be operated within 150 feet of any stream, water body or wetland daily for fluid leaks before leaving the vehicle staging area. Repair any leaks detected in the vehicle staging area before resuming operation.
- Ensure that any forest chemical applications (herbicides, insecticides, fertilizers) comply with EPA label guidelines, and that chemicals are not applied to surface waters, dry ephemeral channels, and other sites where rain would wash them directly or indirectly into streams.

Beaver Habitat:

- Work with state and Federal (i.e., Animal and Plant Health Inspection Service) wildlife agencies to minimize removal of beavers (both commercial and recreational) in areas important to fish.
- Avoid silvicultural activities harmful to beavers (e.g. alder conversion) where it would conflict with beneficial beaver activity.
- Replace culverts with bridges where there are chronic culvert plugging problems that induce beaver removal, or install culvert protective devices that do not impede passage of juvenile and adult salmon.
- Undertake only partial removal of beaver dams using mechanical means, under the guidance of a fishery biologist, where action is necessary due to severe flooding hazards.

Cumulative Effects:

- As part of forest planning, use watershed analysis to analyze the cumulative effects of past and current forest management activities on EFH as indicated in watershed analyses.
- Consider the likely impacts of cumulative effects on EFH when designing future forest management activities.

Log Transfer Facilities and In-water Log Storage:

- Restrict or eliminate storage and handling of logs where the activities are preventing attainment of state or Federal water quality standards.
- Minimize potential impacts of log storage by employing effective bark and wood debris controls, collection, and disposal methods at log dumps, raft building areas, and mill-side handling zones; avoiding the free-fall dumping of logs; using easy let-down devices for placing logs in the water; and bundling logs prior to water storage (bundles should not be broken except on land or at the mill).
- Do not store logs where they will ground at any time or shade aquatic vegetation.
- Avoid siting log storage areas and LTFs in sensitive habitat areas important to species of interest. [not sure if you want make this into EFH language]
- Site log storage areas and LTFs in areas with substantial currents and tidal exchanges.
- Recommend land-based storage sites with the goal of eliminating in-water storage of logs.

4.2.2.17 Grazing

Livestock grazing represents the second most dominant land use in the Pacific Northwest (after timber production), occupying about 41 percent of the total land base. An aspect of grazing is the impact it imparts on riparian ecosystems.[6]

Potential adverse effects from grazing

Numerous symposia and publications have documented the detrimental effects livestock grazing can have on stream and riparian habitats (Johnson et al. 1985; Menke 1977; Meehan and Platts 1978; Cope 1979; AFS 1980; Platts 1981; Peek and Dalke 1982; Ohmart and Anderson 1982; Kauffman and Krueger 1984; Clary and Webster 1989; Gresswell et al. 1989; Kinch 1989; Chaney et al. 1993). These publications describe a series of additive effects that can result when cattle over-graze or impact riparian areas. Over time, woody and hydric herbaceous vegetation along a stream can be reduced or eliminated and livestock trampling causes streambanks to collapse. Without vegetation to slow water velocities, hold the soil, and retain moisture, flooding causes more erosion of streambanks; the stream becomes wider and shallower and in some cases downcut; the water table drops; and hydric, deeply rooted herbaceous vegetation dies out and is replaced by upland species with shallower roots and less ability to bind the soil. The resulting instability in water volume, increased summer water temperature, loss of pools and habitat adjacent and connected to streambanks, and increased substrate fine sediment and cobble-embeddedness.

Riparian areas provide a critical link between aquatic and terrestrial ecosystems. Sustained grazing of these areas can affect substantially fish and aquatic habitats. The riparian zone contributes over 90 percent of the plant detritus which supports the entire aquatic biological food chain in upper tributaries (Cummins and Spengler 1974). Even in larger downstream waters, the riparian zone provides over half (54 percent) of the organic matter ingested by fish. Management efforts to enhance the riparian zone for one species will generally have positive impacts on many other organisms within this biotype.

The quality and persistence of the riparian zone is a function of its fragility. A large body of research and monitoring indicates that overgrazing by domestic livestock has damaged riparian and stream ecosystems (Armour et al. 1994; Mosely 1997) resulting in decreased production of salmonids (Platts 1991). An additional threat to EFH from livestock is the trampling of salmon redds when livestock enter salmon spawning habitat (Gregory and Gamett 2009).

Impacts to the riparian zone vary. Livestock grazing can affect the riparian environment by changing, reducing, or eliminating vegetation and actually eliminating riparian areas through channel widening, channel aggrading, or lowering of the water table (Platts 1991). Soil compaction by trampling can result in a reduction in water infiltration by 40-90 percent (Rauzi and Hanson 1966; Berwick 1976). Streams modified by improper livestock grazing are also wider and shallower than normal (Duff 1983) leading to pool loss by elevating sediment delivery (MacDonald and Ritland 1989). In addition, removal of riparian vegetation along rangeland streams can result in increased solar radiation and thus increased summer temperatures (Li et al. 1994).

Livestock presence in the riparian zone can affect bank stability (Beschta et al. 1993), increase sediment transport rates by increasing both surface erosion and mass wasting (Marcus et al. 1990), and shift vegetative growth to less productive, often exotic plants when Kentucky bluegrass, timothy, and orchard grass replace the native sedges, rye and bunch grasses. Streamside shrubs and trees are also eliminated as the sprouts are browsed by livestock. Regeneration is prevented and the even-aged stands of aspen, willow, cottonwood and associates eventually age, die and disappear (Berwick 1978). Increased sediment in aquatic

6 Riparian ecosystems can best be defined as "…those assemblages of plant, animal, and aquatic communities whose presence can be either directly or indirectly attributed to factors that are stream-induced or related" (Kauffman 1982).

systems can increase turbidity, reduce light penetration, smother fish spawning areas and food supplies, clog the filtering capacity of filter feeders, clog and harm the gills of fish, interfere with feeding behaviors, and significantly lower overall biological productivity.

Because riparian areas are favored by cattle, nutrients consumed elsewhere are often excreted as waste in riparian zones (Heady and Child 1994; Myers and Whited 2010). Pollutants contained in manure and associated bedding materials can be transported into freshwater and marine environments by runoff and process wastewater from rangelands, pastures, or confined animal facilities. These pollutants may include oxygen-demanding substances such as nitrogen, phosphorus, and organic solids; salts; bacteria, viruses, and other microorganisms, as well as sediments that increase organic decomposition. Runoff of animal wastes can cause fish kills due to ammonia, and solids deposited into the aquatic environment and can reduce productivity over extended periods of time due to the accelerated effects of cultural eutrophication. Runoff can be accelerated by grazing processes that remove or disturb riparian vegetation and soils.

Finally, a major grazing-related historical impact to riparian functions has been (and remains) the clearing of hundreds of thousands of acres of riparian bottoms of willow, mountain maple, cottonwood, and other vegetation which sequestered, pumped, and transpired enormous amounts of water. Ranchers convert meadows to hay pastures of introduced timothy, orchard grass and clover harvested for winter forage throughout the west, often in close functional relationship to salmonid EFH.

Potential conservation measures for grazing

- Utilize focused monitoring, management, and grazing regimes or special mitigation activities that allow recovery of degraded areas and maintain streams, wetlands, and riparian areas in properly functioning condition.
- Establish proper streambank alteration move triggers and grazing season of use endpoint indicators to:
  - reduce the amount streambank damage and allow banks to stabilize over time;
  - reduce the amount of the fine sediment introduced into streams; and
  - reduce the amount of damage to streambanks which will also assist in retaining important undercut streambanks, LWD, and overhanging vegetation that provide cover.
- Utilize upland grazing management that minimizes surface erosion and disruption of hydrologic processes. Where range is not in properly functioning condition, forage species composition is altered, productivity reduced, and trends are down, select demonstrably restorative grazing regimes or minimize grazing activity until vegetation has recovered. Once conditions have improved, adjust the grazing strategies to account for all herbivory (e.g., including wildlife) at proper use levels to minimize deterioration of range conditions in the future (Spence et al. 1996).
- Chinook salmon use various stream features such as undercut streambanks, LWD, boulders, and overhanging vegetation to provide cover. The removal of riparian vegetation can reduce overhead cover. Streambank alteration by livestock can eliminate undercut banks and improperly managed grazing can suppress the recruitment of LWD. The introduction of fine sediments can increase substrate embeddedness, reducing the number of hiding places between cobbles and boulders.
- Determine cumulative effects of past and current grazing operations on EFH when designing grazing management strategies.
- Minimize application of chemical treatments within the riparian management zone.
- Utilize innovative grazing practices such as variants of rest-rotation grazing systems, late season riparian grazing systems, winter grazing and management of stocking rates (Heady and Child 1994; Bryant 1985; Davis 1982; Claire and Storch in Kauffman 1982; Hayes 1978; Valentine 1970; and Hedrick in Heady and Child 1994; Pond 1961).
- Minimize livestock access to stream reaches containing salmon redds during spawning and incubation periods (McCullough and Espinosa 1996) by utilizing grazing and vegetation management schemes that promote grazing in other areas and by locating water facilities away from the stream channel and

riparian zone wherever feasible. Excluding livestock from riparian zones has been shown to reduce bank erosion (O'Neal et al. 2010) and decrease salmon redd trampling (Gregory and Gamett 2009).

- Encourage livestock owners to take advantage of The Conservation of Private Grazing Land Program (CPGL) and the Conservation Reserve Enhancement Program (CREP). CPGL and CREP are voluntary programs that help owners and managers of private grazing land address natural resource concerns while enhancing the economic and social stability of grazing land enterprises and the rural communities that depend on them. Technical assistance is provided by the Natural Resource Conservation Service.
- Establish proper streambank alteration move triggers and endpoint indicators in combination with the other management measures intended to reduce the amount of time livestock spend in riparian areas to reduce the amount of the fine sediment introduced into streams.

4.2.2.18 Habitat Restoration Projects

Habitat loss and degradation are major, long-term threats to the sustainability of fishery resources (NOAA Fisheries 2002). Viable coastal and estuarine habitats are important to maintaining healthy fish stocks. Good water quality and quantity, appropriate substrate, ample food sources and substantial hiding places are needed to sustain fisheries. Restoration and/or enhancement of coastal and riverine habitat that supports managed fisheries and their prey will assist in sustaining and rebuilding fisheries stocks and recovering certain threatened or endangered species by increasing or improving ecological structure and functions. Habitat restoration/enhancement may include, but is not limited, to improvement of coastal wetland tidal exchange or reestablishment of historic hydrology; dam or berm removal; fish passage barrier removal/modification; road related sediment source reduction; natural or artificial reef/substrate/habitat creation; establishment or repair of riparian buffer zones and improvement of freshwater habitats that support anadromous fishes; planting of native coastal wetland and SAV; creation of oyster reefs; and improvements to feeding, shade or refuge, spawning and rearing areas that are essential to fisheries.

It is very important that habitat restoration efforts be developed and designed based on a larger planning effort that initially identifies the causes of habitat impairment at a larger scale and then considers active restoration techniques to accelerate habitat recovery that will provide the greatest benefits to the population under consideration (Bisson et al. 1997; Lawson 1997). Restoration efforts should consider a watershed or basin approach. Each project should be adequately designed, carefully monitored and evaluated, and revised if necessary to meet project goals.

The first step to restoration is setting an appropriate goal based on ecosystem function (Zedler 2005). Restoration efforts undertaken without an understanding of hydrogeological and ecological conditions in the watershed may be unsuccessful. For example, while stabilizing an eroding bank may improve local water quality, if placed incorrectly it may deflect water flow and create erosion. Additionally, habitat restoration activities based solely on an individual species without consideration of the immediate ecosystem may not restore habitat function.

Various documents are available to help those involved in habitat restoration efforts. The Environmental Protection Agency (EPA) has produced a watershed assessment primer (http://water.epa.gov/polwaste/nps/handbook_index.cfm) to meet water quality standards and protect water resources, especially in impaired water systems. The California Department of Fish and Wildlife) salmonid stream habitat restoration manual (http://www.dfg.ca.gov/fish/REsources/HabitatManual.asp) provides guidance and forms for habitat assessment, monitoring, and restoration. River RAT is a river project development and evaluation tool that was developed by the US Fish and Wildlife Service (USFWS) and NOAA Fisheries to thoroughly evaluate the impacts of proposed projects on river habitat, particularly for Pacific salmon species listed as threatened or endangered under the ESA (http://www.restorationreview.com/).

Potential adverse effects from restoration projects

The implementation of restoration/enhancement activities may have localized and temporary adverse impacts on EFH. Possible impacts include 1) localized nonpoint source pollution from substances like petroleum products, sediment, or nutrients, 2) interference with spawning, migration or feeding 3) direct effects like crushing from equipment operation or materials placement, and 5) fish handling. Such concerns should be addressed as part of the planning process. For example in-water projects should be allowed only during times of year that minimize interference with spawning, rearing and migration. Areas for staging, maintaining and fuel equipment and supplies should be located far enough from live water to minimize the chance of petroleum product spills and leaks or disturbed sediment reaching live water.

The use of artificial reefs is a popular form of habitat enhancement, but it can also impact the aquatic environment through the loss of habitat upon which the reef material is placed or the use of inappropriate materials in construction. Usually, reef materials are set upon flat sand bottoms and care must be taken to avoid burying or smothering bottom-dwelling organisms or preventing them from utilizing the area as habitat. Some materials may be inappropriate for the marine environment (e.g., automobile tires; compressed incinerator ash) and can serve as sources of toxic releases or physical damage to existing habitat when breaking free of their anchoring systems (Collins et al. 1994).

Potential conservation measures for restoration projects

- Develop and conduct habitat restoration activities on a watershed-scale.
- Design restoration activities as an experiment, using adaptive management to determine project success and modify until the success criteria are achieved.
- Protect habitat-forming processes (e.g., riparian community succession, bedload transport, runoff pattern) that maintain the biophysical structure and function of aquatic ecosystems.
- Use BMPs to minimize and avoid all potential impacts to EFH during restoration activities. This conservation measure requires the use of BMPs during restoration activities to reduce impacts from project implementation. BMPs should include, but are not limited to, the following:
    - Measures to protect the water column such as turbidity curtains, hay bales, and erosion mats should be used.
    - Staging areas should be planned in advance and kept to a minimum size.
    - Buffer areas around sensitive resources such as rare plants, archeological sites, etc., should be flagged and avoided.
    - Invasive species should be removed from the proposed action area prior to commencement of work. Only native plant species should be replanted.
    - Ingress/egress areas should be established prior to restoration activities to minimize adverse impacts from project implementation.
- Avoid restoration work during critical fish windows to reduce direct impacts to important ecological functions such as spawning, nursery, and migration. This conservation measure requires scheduling projects when managed species are not expected in the area. These periods should be determined prior to project implementation to reduce or avoid any potential impacts.
- Provide adequate training and education to volunteers and project contractors to ensure minimal impact to the restoration site. Volunteers should be trained in the use of low-impact techniques for planting, equipment handling, and any other activities associated with the restoration.
- Conduct monitoring before, during, and after project implementation to ensure compliance with project design and restoration criteria. If immediate post-construction monitoring reveals that unavoidable impacts to EFH have occurred, appropriate coordination with NOAA Fisheries should occur to determine appropriate response measures, possibly including mitigation.
- Mitigate fully any unavoidable damage to EFH during project implementation and accomplish within reasonable period of time after the impacts occurred.

- Remove and restore, if necessary, any temporary access pathways and staging areas used in the restoration effort.
- Develop obtainable goals for each restoration project using ecological functions as guidelines.

4.2.2.19 Introduction/Spread of Invasive Alien Species

(IAS) are any species non-native to an ecosystem whose introduction causes or is likely to cause economic or environmental harm, or harm to human health (Executive Order 13112). Under this broad definition, the socioeconomic and ecological damage to the global environment has been conservatively estimated to exceed $US 1.4 trillion annually, or roughly five percent of the global economy (*see* Pimental D. [ed.], 2002). In the U.S. alone, invasive species have been estimated to annually yield $120 billion in economic damage from control and prevention costs and compromised environmental services (Pimental et al. 2004). This recognition has led to a multitude of international agreements to better coordinate IAS introductions through recognized international pathways of introduction (Fisher 2005), and international guidelines have been developed to address such risks (Orr and Fisher 2009). Executive Order 13112 further details requirements of the Federal government to improve coordination of prevention mechanisms and to establish early detection and rapid response control measures among Federal, state and local government entities within the borders of the U.S.

In the U.S., IAS are reported as the second leading cause for the listing of native species as threatened or endangered under the ESA (Pimental et al. 2000). The introduction of nonnative plant and animal species may be either deliberate (e.g., to enhance sport-fishing or control aquatic weeds) or accidental without thought to the consequences (e.g., the dumping of live bait-fish and the seaweeds in which they are packed, aquaculture escapees, the pumping of bilge or ballast water, or releases from aquariums by individuals). The ecological and economic consequences of non-native species introductions depends, in large measure, on the degree to which such species are subsequently shown to exhibit invasive properties, wherein native species are displaced from habitat previously accessible, or where native species' fitness is otherwise compromised through other mechanisms (e.g., predation, parasitism, etc.).

Although the impacts of non-native species introductions to salmon EFH have not been extensively examined, the spread of many nonnative species into salmon EFH has demonstrated their invasive potential. These introductions can potentially alter habitat processes and functions. Introduced fishes can dominate or displace native fish through predation, reproduction impairment, habitat modification, pathogen and/or parasite infection, and/or hybridization (Spence et al. 1996). In the Columbia Basin, introduced predator species including walleye, channel catfish, and smallmouth bass have high predation rates on emigrating salmon smolts. Boyd (1994) reports that the presence of striped bass in a river system near California's San Francisco Bay region resulted in estimated losses of 11 percent to 28 percent of native run fall Chinook salmon. White bass and northern pike introduced into the inland delta of the Sacramento and San Joaquin Rivers prey on salmon and other species (Cohen 1997). In Oregon's coastal lakes and reservoirs, introduced fish species such as striped bass, largemouth bass, smallmouth bass, crappie, bullheads and yellow perch have become established with obvious predation impacts in some basins and negligible impacts in others. For example, nonendemic Umpqua squawfish are voracious predators of juvenile salmonids in Oregon's Rogue River Basin (Satterwaithe 1998; pers. comm.) and the Coos and Umpqua estuaries contain striped bass that prey on salmonids (OCSRI 1997). Introduced grass carp and common carp can destroy beds of aquatic plants which results in concomitant reductions in cover for juvenile fishes, destruction of substrates supporting diverse invertebrate food chain assemblages, and increases in turbidity (Spence et al. 1996). Displacement of salmonids and other cold water species by such non-native invasive species results in a reduced total usable habitat area for spawning and rearing, and thereby a diminished production capability for salmon (McCullough et al. 1996).

Introduced invertebrates in marine and freshwater environments can also lead to habitat alterations, potentially compromising cover and foraging opportunities for species managed under the MSA for which EFH has been established. For example, the colonial ascidian *Didemnum sp.* can coat substrates to such a heavy degree that other benthic organisms are displaced (Bullard et al. 2007). The outcome of such an invasion in salmon EFH could adversely affect the capacity of such habitats to provide sufficient forage for juvenile salmonids. The food webs of San Francisco Bay have been dramatically altered by non-native invertebrate invasions primarily attributed to the ballast water vector (Carlton 1999). To this end, the arrival of an Asian clam has multiplied to such abundance that it can filter all the water over a significant portion of the bay in less than a day, removing bacteria, phytoplankton, and zooplankton in the process and leaving little behind for other organisms (The Resources Agency of California [RAC] 1997). In this same embayment, the introduction of the green crab has raised significant concerns for intercompetition and predation with the native Dungeness crab, whose larvae represent a significant food source for juvenile salmon, and hence, a component of Chinook salmon and coho salmon EFH. Based on effects observed in the Great Lakes ecosystem and their spread elsewhere (Higgins and Vander Zanden, 2010; Ward and Ricciardi, 2010) the potential introduction and spread of the invasive zebra mussels into the Columbia basin would similarly result in drastic and adverse changes to aquatic substrates of salmon EFH with significant consequences. The high risk potential of the ecological consequences to uninvaded aquatic environments such as the Columbia River system from the zebra mussel has required extreme vigilance and resource agency costs to prevent such introductions (Wu et al. 2010).

Biological invasions of introduced macrophytes are also a worldwide problem with implications to EFH. Mechanisms underlying invasive plant impacts on native fish and macroinvertebrate communities are largely related to increased growth rates, allelopathic chemical production, and phenotypic plasticity that allow for the invasive plants to exhibit greater adaptability to the environmental conditions inherent to the invaded environment than the native plants that are outcompeted (Shultz and Dibble 2012). Introduced plants can also have serious detrimental effects on salmon habitat. The exotic aquatic plant egeria (*Egeria densa*) is known to harm coho salmon rearing in coastal lakes (OCSRI 1997). Similarly, the recognition of the potential harm caused by the invasive algae *Caulerpa taxifolia* (Schaffelke and Hewitt, 2007), resulted in a massive and costly rapid response in order to eradicate it from a southern California embayment and address the risks it posed to nearshore biodiversity through further spread.

The spread in estuaries of various species of cordgrass *Spartina* spp. and another grass, the common reed *Phragmites australis*, is also of concern. *Spartina* spp. may affect salmon habitat in a number of ways, many of which appear to be detrimental to salmon and their prey. *Spartina* forms dense uniform stands in the upper intertidal area, traps sediment and raises the elevation of the mudflat, making them inaccessible to salmonids as foraging habitat. The macroinvertebrate population in areas dominated by *Spartina* a*lterniflora* is somewhat different than that in mudflat areas. Nonnative plant invasions may decrease food for some species such as chum salmon that feed on the mudflats, while it may increase resources for Chinook salmon that feed on invertebrates in the water column or on the surface, though the interactions are complicated and are still being studied (Luiting et al. 1997). Other effects from *Spartina* invasion (as well as from *Phragmites*) results from the meadows serving as filters of nutrients and sediments washing off the land. While this may be beneficial in terms of reducing pollution, it can also have negative effects by raising the elevation of the high intertidal area and sequestering nutrients from the estuarine system.

Many of the region’s riparian habitats have also been extensively altered by invasive species (e.g., blackberries, reed canary grass, and scotch broom), deterring the establishment of native species, and altering the habitat (e.g., shading, stream bank stability) and the nutrient cycling characteristics of the area. The effects of these changes are not fully known.

Potential conservation measures for introduction/spread of nonnative species

Watershed management strategies for enhancement and conservation of salmon EFH in many instances will include restoration of water flows and riparian areas, as well as other habitat conditions. These measures should discourage nonnative IAS from establishing or expanding their territories (e.g., colder water will favor salmonids over centrarchids).

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by the introduction of non-native or nonendemic species. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process, and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from Cohen (1997).

- Provide and display educational materials on the potential impacts resulting from the release of nonnative organisms into the natural environment to increase public awareness and engender broad cooperation amongst user groups and stakeholders.
- For the commercial import of plants and animals for aquarium and ornamental plant trades, import those organisms that have been evaluated and determined to be safe for importing through the application of risk assessment guidelines developed through the Aquatic Nuisance Task Force.
- Adopt measures outlined by the International Marine Organization and avoid ballast water exchange in nearshore coastal waters. Use shore-based ballast water treatment systems and ship-board ballast treatment systems as alternatives.
- Inspect all vessels for hull fouling, non-native IAS species prior to introducing the vessels into new waterbodies.
- Conduct vessel hull cleaning outside of water and control run-off from such operations to ensure it does not enter waters not natal to the vessel origin.
- Use native organisms for aquaculture operations whenever possible, and do not transfer native organisms across waterbodies without inspection by qualified agents if the waterbody of export is known to harbor aquatic IAS associated with aquaculture operations that could 'hitch-hike' unintentionally with the aquatic species transfer.
- Develop appropriate early detection and rapid response eradication methods for nonnative IAS plant species and predatory animal species, consistent with Federal guidelines as specified by the National Invasive Species Management Plan (NISC 2009).

4.2.2.20 Irrigation Water Withdrawal, Storage, and Management

Water is diverted from lakes, streams, and rivers for irrigation, power generation, industrial use, and municipal use. Water is also withdrawn from the ocean at offshore water intake structures in California. Ocean water may be withdrawn for cooling coastal power generating stations or as a source of potential drinking water after desalinization.

Potential adverse effects from irrigation water withdrawal, storage, and management

In general, potential effects of freshwater system irrigation withdrawals on salmonid EFH include physical diversion and injury to salmon (see below), as well as impediments to migration, changes in sediment and LWD transport and storage, altered flow and temperature regimes, water level fluctuations, and reduced habitat area. In addition, fish and other aquatic organisms may be affected by the reduced dilution of pollutants in rivers and streams where substantial volumes of water are withdrawn. Alterations in physical and chemical attributes in turn affect many biological components of aquatic systems including riparian vegetation as well as composition, abundance, and distribution of macroinvertebrates and fish (Spence et al. 1996).

In addition, the volume of fresh water diverted and stored for agriculture can be substantial and can affect both the total volume of water available to salmon and to form their requisite habitats. The effects of water withdrawals during the irrigation season are likely to grow more pronounced as a result of climate change. Climate and hydrology models project significant reductions in both total snow pack and low-elevation snow pack in the Pacific Northwest over the next 50 years (Mote and Salathe 2009). Such changes may reduce overall habitat productivity and reduce the ability to conserve diverse salmon life histories.

Returned irrigation water to a stream, lake, or estuary project can substantially alter and degrade habitat (NRC 1989). Generally problems associated with return flows of surface water from irrigation projects include increased water temperature, salinity, pathogens, chemical oxygen demand, increased toxicant concentrations from pesticides and fertilizers, and increased turbidity (NPPC 1986).

Water impoundments can result in raised or lowered summer temperatures and increases in fall and winter temperatures. Increases in fall and winter temperatures can accelerate embryonic development of salmonid emergence, reducing their chances of survival. Low dissolved oxygen can also be a problem in irrigation impoundments that have been drawn down, as is freezing which inhibits light penetration and photosynthesis (Ploskey 1983; Guenther and Hubert 1993). Elevated fall water temperatures from impoundments can also result in disease outbreaks in adult salmon that increase prespawning mortality (Spence et al. 1996).

Irrigation withdrawals and impoundments also change sediment transport and storage. Siltation and turbidity in streams generally increase as a result of increased irrigation withdrawals, because of high sediment loads in return waters (Spence et al. 1996). In some systems, sediments may accumulate in downstream reaches covering spawning gravels and filling in pools that Chinook salmon use for rearing (Spence et al. 1996). In other systems, water withdrawals and storage reservoirs can lead to improved water clarity, because they trap sediment. This can lead to aggradation of the stream channel as the capacity of the stream to transport sediment is reduced. The settling of gravel sediments behind impoundments and the reduced sediment transport capacity can cause downstream reaches to become sediment starved. This results in loss of high quality spawning areas as substrate becomes dominated by cobble and other large fractions not suitable for spawning (Spence et al. 1996).

Water diversions and impoundments also can change the quantity and timing of streamflow. Changes in flow quantity alters stream velocity which affects the composition and abundance of both insect and fish populations (Spence et al. 1996). Changed flow velocities may also delay downstream migration of salmon smolts and result in salmon mortality (Spence et al. 1996). Low flows can concentrate fish, rendering juveniles more vulnerable to predation (PFMC 1988).

Water level fluctuations from impoundment releases/storage can de-water eggs, strand juveniles (PFMC 1988), and, by eliminating aquatic plants along stream bank margins and shorelines, decrease fish cover and food supply (Spence et al. 1996).

The physical means of withdrawing water may adversely affect salmon. For major irrigation withdrawals, water is either stored in impoundments or diverted directly from the river channel at pumping facilities. Individual irrigators commonly construct smaller push-up dams from streambed materials, to divert water into irrigation ditches or to create small storage ponds from which water is pumped. In addition, pumps may be submerged directly into rivers and streams to withdraw water. Effects of these irrigation withdrawals and impoundments on aquatic systems include creating impediments or blockages to migration (for both adults and juveniles), diverting juveniles into irrigation ditches or damage to juveniles as a result of impingement on poorly designed fish exclusion screens (Spence et al. 1996).

Groundwater pumping for irrigation, while providing an alternative to surface water diversion, also can reduce surface flows, especially summer flows which can be derived from groundwater discharges (Spence et al. 1996).

Potential conservation measures for irrigation water withdrawal, storage, and management

Water conservation is one of the most promising means of meeting new and expanding needs for additional water (Gillilan and Brown 1997). For example, Washington State's Water Resources Management Trust Water Rights Program, started in 1991, provides a means of enhancing instream flow. The program allows water that is no longer being used for another purpose to be left instream and protected from further appropriation. Participants in the instream flow protection processes in the states of Washington, Idaho, Oregon, and California include:

California: The state's most potent instream flow protection is a result of administrative activities of the State Water Resources Control Board, which is required to consider the comments of CDFG when making decisions about appropriation and transfer permits. Since 1991, individuals have been authorized to change the purpose of existing rights to instream purposes. Private individuals and organizations have also taken advantage of the opportunity to initiate public trust proceedings.

Idaho: Only the Idaho Water Resources Board is allowed to apply to the Department of Water Resources for an instream water right. State statutes allow the public to petition the Board to apply for instream flow rights, but the Board has interpreted this language to mean that it may accept petitions only from state agencies. Applications approved by the Department of Water Resources must be submitted to the Idaho State Legislature for approval.

Oregon: Only the Oregon Water Resources Department may hold instream water rights. The Water Resource Department considers requests from ODFW, Environmental Quality, and Parks and Recreation agencies. Individuals may acquire existing rights and take responsibility for changing the use to instream purposes in an administrative hearing, but then must turn the right over to the Water Resources Department to be held in trust.

Washington: Washington Department of Ecology (WDOE) establishes minimum flows either at its own initiative or after request from the Department of Fisheries and Wildlife. However, these instream flows were established long after much of the water from many streams had been appropriated for off-stream purposes and thus flows in many streams are often much lower than the established minimum flows. A significant feature of the Trust Water Rights Program is that the water enrolled through the program is protected as equal in seniority to the water right from which is was gleaned.

In 1996, the Bureau of Reclamation released policy guidance on the content of water conservation plans for water districts. Recommended water measures include (1) water management and accounting designed to measure and account for the water conveyed through the districts distribution system to water users; (2) a water pricing structure that encourages efficiency and improvements by water users; (3) an information and education program for users designed to promote increased efficiency of water use; and (4) a water conservation coordinator responsible for development and implementation of the water conservation plan (Bureau of Reclamation 1996).

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by irrigation water withdrawal and storage. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from McCullough and Espinosa, Jr. (1996) and OCSRI (1997).

- Apply conservation and enhancement measures for dams (see Section 4.2.2.9 Dam Construction/Operation) to water management activities and facilities, where applicable.
- Establish adequate instream flow conditions for salmon by using, for example, the Instream Flow Incremental Methodology.
- Undertake efforts to purchase or lease, from willing sellers and lessors, water rights necessary to maintain instream flows in accordance with appropriate state and Federal laws.
- Identify and use appropriate water conservation measures in accordance with state law.
- In accordance with state law, install totalizing flow meters at major diversion points and ensure that the diversions do not exceed legally authorized annual or instantaneous quantities. For water withdrawn from reservoirs, install gauges that identify the water surface elevation range from full reservoir elevation to dead pool storage elevation. Additionally, if the reservoir is located in-channel, install gauges upstream and downstream of the reservoir.
- Screen water diversions on all fish-bearing streams.
- Incorporate juvenile and adult salmon passage facilities on all water diversions.
- Where possible, relocate diversions to larger water bodies that would be less severely affected by the reduced flow volume.

4.2.2.21 Liquefied natural gas projects

Liquefied natural gas (LNG) is expected to provide a large proportion of the future energy needs in the United States. In recent years there has been an increase in proposals for new LNG facilities along the west coast including a number of onshore and offshore facilities in Oregon and California. The LNG process cools natural gas to its liquid form at approximately minus 162 ºC. This reduces the volume of natural gas to approximately 1/600th of its gaseous state volume, making it possible for economical transportation with tankers. Upon arrival at the destination the LNG is either vaporized onshore or offshore and sent out into an existing pipeline infrastructure or transported onshore for storage and future vaporization. The process of vaporization occurs when LNG is heated and converted back to its gaseous state. LNG facilities can utilize open loop, closed loop, combined loop, or ambient air systems for vaporization. Open loop systems utilize warm water for vaporization, and closed loop systems generally utilize a recirculating mixture of ethylene glycol for vaporization. Another type of closed-loop system is submerged combustion vaporization (SCV) which provides a water bath with submerged pipe coils. Combined loop systems utilize a combination of these systems.

Onshore LNG facilities generally include a deepwater access channel, land-based facilities for vaporization and distribution, storage facilities, and a pipeline to move the natural gas. Offshore facilities generally include some type of a deepwater port with a vaporization facility and pipelines to transport natural gas into existing gas distribution pipelines or onshore storage facilities. Deepwater ports and onshore terminals require specific water depths and include an exclusion zone for LNG vessel and/or port facility security.

Potential adverse effects from liquefied natural gas projects

Construction and operation of LNG facilities can affect the habitat of salmonids in a variety of ways. Direct conversion and loss of habitat can occur through dredging and filling, construction of overwater structures, placement of pipelines, and shoreline armoring. Construction-related effects on habitat include generation of underwater noise from pile driving and vessel operations, turbidity, and discharge of contaminants. Long-term degradation of habitat can result from impingement and entrainment at water intakes for vaporization water and ballast and engine cooling water for LNG vessels, discharge of contaminants, discharge of cooled water from open-loop systems, and stranding of fishes by vessel wakes. Short- and long-term habitat degradation can result from accidental spills of LNG and other contaminants. With the exception of the discharge of contaminated water, discharge of vaporization water, and accidental spills of

LNG, these effects are covered under other threats described in this document.

Contaminants can enter aquatic habitats through accidental releases associated with onshore and offshore operations, discharge of water containing biocides used to control fouling of piping systems, and discharges of the condensates from heat exchangers. A rapid phase transition can occur when a portion of LNG spilled onto water changes from a liquid to a gas virtually instantaneously. The rapid change from a liquid to vapor state can cause locally large overpressures ranging from a small pop to a blast large enough to potentially damage structures (Luketa et al. 2008). Because rapid phase transition would occur at the surface of the water it would be unlikely to affect fishes that are several feet under the surface. However, any fish present at or near the surface of the water would likely be killed. Effects on the aquatic environment from an LNG spill include thermal shock from the initial release (cold shock from the cryogenic liquid) and thermal shock from ignition of the vapor (Hightower et al. 2004). Condensates from heat exchanger such as SCV systems are generally acidic and require buffering with alkaline chemicals (FERC 2010). The condensate can include a wide range of metals and other contaminants. These contaminants may include copper, a known disruptor of salmonid olfactory function (e.g., Baldwin et al. 2003). The concentration of these chemicals will vary depending on the water source and facility design.

The operation of LNG facilities can result in the alteration of temperature regimes. Water utilized for the purposes of vaporization could be discharged at temperatures that differ significantly from the receiving waters and can be 5-10 ºC below ambient temperature. Changes in water temperatures can alter physiological functions of marine organisms including respiration, metabolism, reproduction, and growth; alter migration pathways; and increase susceptibility to disease and predation. Thermal effluent in inshore habitat can cause severe problems by directly altering the benthic community or adversely affecting marine organisms, especially egg and larval life stages (Pilati 1976, cited in NMFS 2008; Rogers 1976, cited in NMFS 2008).

Potential conservation measures for liquefied natural gas projects

- Site LNG facilities in areas that minimize the loss of habitat such as naturally deep waters adjacent to uplands that are not in the floodplain.
- Recommend the vaporization systems that do not rely on surface waters as a heat source, such as an ambient air system. This will avoid impingement and entrainment of living resources. If a water-sourced system must be used, recommend closed loop systems over open loop systems. This will minimize water withdrawals and the associated impingement and entrainment of living marine resources.
- Locate facilities that use surface waters for vaporization and engine cooling purposes away from areas of high biological productivity, such as estuaries.
- Design intake structures to minimize entrainment or impingement.
- Regulate discharge temperatures (both heated and cooled effluent) such that they do not appreciably alter the temperature regimes of the receiving waters. Strategies should be implemented to diffuse this effluent.
- Avoid the use of biocides (e.g., aluminum, copper, chlorine compounds) to prevent fouling where possible. The least damaging antifouling alternatives should be implemented.

4.2.2.22 Mineral Mining

The effects of mineral mining on salmon EFH depends on the type, extent, and location of the activities. Minerals are extracted by several methods. Surface mining involves suction dredging, hydraulic mining, panning, sluicing, strip mining, and open-pit mining (including heap leach mining). Underground mining utilizes tunnels or shafts to extract minerals by physical or chemical means. Surface mining probably has greater potential to affect aquatic ecosystems, though specific effects will depend on the extraction and processing methods and the degree of disturbance (Spence et al. 1996).

Potential adverse effects of mineral mining

Water pollution by heavy metals and acid is also often associated with mineral mining operations, as ores rich in sulfides are commonly mined for gold, silver, copper, iron, zinc, and lead. When stormwater comes in contact with sulfide ores, sulfuric acid is commonly produced (West et al. 1995). Abandoned pit mines can also cause severe water pollution problems.

Mining activities can result in substantial increased sediment delivery, although this varies with the type of mining. While mining may not be as geographically pervasive as other sediment-producing activities, surface mining typically increases sediment delivery much more per unit of disturbed area than other activities because of the level of disruption of soils, topography, and vegetation. Erosion from surface mining and spoils may be one of the greatest threats to salmonid habitats in the western United States (Nelson et al. 1991).

Hydraulic mining for gold from streams, flood plains, and hill slopes occurred historically in California, Oregon, and Washington in areas affecting salmon EFH. Though hydraulic mining is not common today, past activities have left a legacy of altered stream channels, and abandoned sites and tailings piles can continue to cause serious sediment and chemical contamination problems (Spence et al. 1996).

Placer mining for gold and associated suction dredging continues to occur in watersheds supporting salmon. Recreational gold mining with such equipment as pans, motorized or nonmotorized sluice boxes, concentrators, rockerboxes, and dredges can locally disturb streambeds and associated habitat. Additionally, mining activities may involve the withdrawal of water from the stream channel. Commercial mining is likely to involve activities at a larger scale with much disturbance and movement of the channel involved (OWRRI 1995). In some cases, water may be completely diverted from the stream bed while gravel is processed.

Commercial operations may also involve road building, tailings disposal, and the leaching of extraction chemicals, all of which may create serious impacts to salmon EFH. Cyanide, sulfuric acid, arsenic, mercury, heavy metals, and reagents associated with such development are a threat to salmonid habitat. Improper or in-water disposal of tailings may cause toxicity to salmon or their prey downstream. On land placement of tailings in unstable or landslide prone areas can cause large quantities of toxic compounds to be released into streams or to contaminate groundwater (NPFMC 1999). Indirectly, the sodium cyanide solution used in heap leach mining is contained in settling ponds from where they might contaminate groundwater and surface waters (Nelson et al. 1991).

Mineral mining can also alter the timing and routing of surface and subsurface flows. Surface mining can increase streamflow and storm runoff as a result of compaction of mine spoils, reduction of vegetated cover, and the loss of organic topsoil, all of which reduce infiltration. Increased flows may result in increased width and depth of the channel.

Mining and placement of gravel spoils in riparian areas can cause the loss of riparian vegetation and changes in heat exchange, leading to higher summer temperatures and lower winter stream temperatures (Spence et al. 1996). Bank instability can also lead to altered width-to-depth ratios, which further influences temperature (Spence et al. 1996).

Potential conservation measures for mineral mining

State and Federal law (i.e., the Clean Water and Surface Mining Control and Reclamation Acts) contain provisions for regulating mining discharges. State and local governments are taking an increasingly active role in controlling irresponsible mining operations (Nelson et al. 1991) and most western states require operators to draw up a mining plan that details potential environmental damage from that operation, and reclamation and performance bonds must be posted (Nelson et al. 1991). A challenge still lies in the reclamation of the thousands of abandoned sites that have or may potentially impact salmon EFH.

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by mining related activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the restoration and maintenance of properly functioning salmon habitat. The following suggested measures are adapted from recommendations in Spence et al. (1996), NMFS (1996b), and WDFW (1998).

- Avoid mineral mining in waters, riparian areas, or flood plains of streams containing or influencing the salmon spawning and rearing habitats.
- Assess the cumulative effects of past and proposed mineral extraction activities and take these into account in planning for mining operations.
- Utilize an integrated environmental assessment, management, and monitoring package in accordance with state and Federal law.
- Minimize spillage of dirt, fuel, oil, toxic materials, and other contaminants into the water and riparian areas. Monitor turbidity during operations. Prepare a spill prevention plan and maintain spill containment and water repellent/oil absorbent clean-up materials on hand.
- Treat wastewater (acid neutralization, sulfide precipitation, RO, electrochemical, or biological treatments) and recycle on site to minimize discharge to streams. Test wastewater before discharge for compliance with the Federal and state clean water standards.
- Minimize mine-generated sediments from entering or affecting EFH. Minimize the aerial extent of ground disturbance (e.g., through phasing of operations), and stabilize disturbed lands to reduce erosion. Employ methods such as contouring, mulching, and construction of settling ponds to control sediment transport.
- Reclaim, rather than bury, mine waste that contains heavy metals, acid materials, or other toxic compounds if leachate can enter EFH through groundwater.
- Restore natural contours and plant native vegetation on site after use to restore habitat function to the extent practicable.

4.2.2.23 Offshore Oil and Gas Exploration, Drilling and Transportation Activities

<u>*Potential adverse effects from offshore oil and gas exploration, drilling, and transportation*</u>

Oil is extracted from offshore platforms in southern California and large amounts of Alaskan crude oil also enter the region on Alaskan tankers bound for refineries. These nearshore oil and gas related activities have the potential to pollute salmon EFH and harm prey resources. Oil exploration/production areas are vulnerable to an assortment of physical, chemical, and biological disturbances resulting from activities used to locate oil and gas deposits such as high energy seismic surveys to actual physical disruptions from anchors, chains, drilling templates, dredging, pipes, platform legs, and the platform jacket. The effects of the underwater sounds produced by seismic surveys are described in Section 4.2.2.1.3 Seismic Surveys. During actual operations, chemical contaminants may also be released into the aquatic environment (NMFS 1997b). Physical alterations in the quality and quantity of local habitats may also occur during the construction and operation of shore-side facilities, tanker terminals, pipelines, and the tankering of oil. These activities may be of concern if they occurred in habitats of special biological importance to salmon stocks or their prey (NPFMC 1999).

Accidents and spills during transport and during oil transfer from ships or pipelines to refineries are the greatest potential threats to salmon EFH. They are likely to affect shallow nearshore areas or sensitive habitats such tidal flats, kelp beds, estuaries, river mouths, and streams.

Although oil is toxic to all marine organisms at high concentrations (parts per million), certain species are more sensitive than others. The type, volume, and properties of the spilled oil (environmental variables such as water density, wave height, currents, wind speed, etc.) and the type of response effort all affect the potential risk to salmon EFH. Oil spills in marine waters probably affect salmon more through their effects on salmon food organisms than on the salmon themselves, because juvenile and adult fish generally are able to avoid oil slicks in open seas. However, if an oil spill reached nearshore areas with productive nursery grounds, such as an estuary, or if a spill occurred at a location where fish were concentrated, a year's production of smolts could be lost (NPFMC 1999).

Injuries to fish and their prey in the surface slick results from both physical coating by oil as well as to the toxicity of the petroleum hydrocarbons and other compounds in the oil. Many low molecular weight aromatic hydrocarbons are soluble in water, increasing the potential for exposure to aquatic resources. Adult fish tolerate much higher concentrations of petroleum hydrocarbons than eggs and larvae. Sublethal effects of oil typically manifested in adult fish are primarily physiological and affect feeding, migration, reproduction, swimming activity, and schooling behaviors (Kennish 1997; Strickland and Chasan 1993).

Clean-up activities for oil residues on beaches, rocky shorelines or sea surface sometimes involve physical or chemical methods such as high pressure hoses, steam, or dispersants. These activities may be more hazardous to plants and animals than the oil itself and may also adversely affect salmon habitat.

Dispersants are also sometimes used to emulsify oil (i.e., reduce the water-oil interfacial tension) so that it can enter the water column rather than remaining on the surface. While reducing the adverse effects on the shoreline, birds, and marine mammals, the dispersants may be toxic themselves to marine organisms and plants as well as make the oil itself more available for uptake by marine organisms and hence more toxic (Falco 1992).

Degradation byproducts of petroleum hydrocarbons have high acute toxicities to fish. Studies of bivalve tissue from beaches heavily oiled by the *Exxon Valdez* incident showed that a complex assemblage of intermediate hydrocarbon oxidation byproducts were bioavailable for uptake in marine organisms for several years post-spill. Thus, oxidation byproducts may be an additional source of chronic exposure and effects on fish populations (NOAA 1996).

Potential conservation measures for offshore oil and gas exploration, drilling, and transportation

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in nearshore and estuarine regions that have the potential to be affected by transportation and onshore support activities associated with oil and gas exploration, drilling, and production. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options listed below represent a short menu of general types of conservation actions that can contribute to the protection and restoration of properly functioning salmon habitat.

- Monitor and enforce double hull standards for all oil tankers doing business in U.S. waters, as well as other pollution prevention measures of the Oil Pollution Act of 1990.

- Utilize adequate spill prevention measures such as tug escorts, speed limits, the use of marine pilots, vessel traffic systems, designated areas to be avoided, traffic separation schemes, rescue/salvage tugs, and compliance with international, national, and state spill prevention standards.
- Utilize the agreement between the ten major oil company members of the Western States Petroleum Association as a catalyst to involve other oil carriers and maximize routing of tankers carrying Alaskan North Slope crude to California ports at least 50 miles seaward of the Pacific coast while transiting the coastline after leaving Prince William Sound.
- Route dry cargo vessels and other vessels carrying significant quantities of oil or hazardous cargo at least 50 miles seaward of the Pacific coast while transiting the coast.
- Avoid national marine sanctuaries and areas designated as areas to be avoided and support efforts to re-evaluate and strengthen precautionary and readiness measures in national marine sanctuaries.
- Apply vessel maintenance, inspection programs, and crew training programs, required for oil tank vessels to dry cargo and other vessels carrying significant quantities of oil.
- Monitor and report water and sediment quality around all oil extraction, bunkering, or transfer facilities, and gather other baseline information to assure better natural resource damage assessments after spill events.

4.2.2.24 Overwater structures

Overwater structures include commercial and residential piers, wharves, marinas, floats and docks, floating breakwaters, barges, rafts, booms, and mooring buoys. In saltwater areas, these structures are typically located in intertidal areas out to about 15 meters below the area exposed by the mean lower low tide (i.e., the shallow subtidal zone). In freshwater areas, they are typically located within 100 feet of ordinary low water. Light, wave energy, substrate type, depth, and water quality are the primary factors controlling the plant and animal assemblages found at a particular site. Overwater structures and associated activities can alter these factors and interfere with key ecological functions such as spawning, rearing, foraging and refugia. Site- specific factors (e.g., water clarity, current, depth) and the type and use of a given overwater structure determine the occurrence and magnitude of these impacts.

Construction and maintenance of overwater structures often involves driving of piles (see Section 4.2.2.1.1 Pile Driving) and dredging of navigation channels (see Section 4.2.2.12 Dredging and Dredged Spoil Disposal). Both activities may also adversely affect EFH. Maintenance also includes the removal of damaged or otherwise unsound piles. Piles can be removed using a variety of methods, including vibratory hammer, direct pull, clam shell grab, or cutting/breaking the pile below the mudline. Vibratory hammers can be used to remove all types of pile, including wood, concrete, and steel. However, old, brittle piles may break under the vibrations and necessitate another method. The direct pull method involves placing a choker around the pile and pulling upward with a crane or other equipment. Broken stubs are often removed with a clam shell and crane. In this method, the clam shell grips the pile near the mudline and pulls it out. In other instances, piles may be cut or broken below the mudline, leaving the buried section in place.

Potential adverse effects of Overwater Structures

The following description of the potential impacts of overwater structures and associated activities on EFH, unless otherwise cited, is taken from a recent, comprehensive literature review by Nightingale and Simenstad (2001). For a more detailed discussion, the reader is directed to this review.

Overwater structures and associated developments may adversely affect EFH in a variety of ways, including construction related impacts, changes in ambient light conditions, alteration of the wave and current energy regime, and through activities associated with the use and operation of the facilities, such as increased vessel traffic and pollutants.

Overwater structures create shade which reduces the light levels below the structure. The size, shape and intensity of the shadow cast by a particular structure depend upon its height, width, construction materials, and orientation. High and narrow piers and docks produce narrower and more diffuse shadows than do low and wide structures. Increasing the numbers of pilings used to support a given pier increases the shade cast by pilings on the under-pier environment. In addition, less light is reflected underneath structures built with light-absorbing materials (e.g., wood) than from structures built with materials that allow light transmission (e.g., glass, steel grates). Structures that are oriented north south produce a shadow that moves across bottom substrate throughout the day, resulting in a smaller area of permanent shade than those with an east-west orientation.

The shadow cast by an overwater structure affects both the plant and animal communities below the structure. Distributions of plants, invertebrates, and fishes have been found to be severely limited in under-dock environments when compared to adjacent, unshaded vegetated habitats. Light is the single most important factor affecting aquatic plants. Under-pier light levels have been found to fall below threshold amounts for the photosynthesis of diatoms, benthic algae, eelgrass, and associated epiphytes and other autotrophs. These photosynthesizers are an essential part of nearshore habitat and the estuarine and nearshore foodwebs that support many species of marine and estuarine fishes. Eelgrass and other macrophytes can be reduced or eliminated, even by partial shading of the substrate, and have little chance to recover.

Fishes rely on visual cues for spatial orientation, prey capture, schooling, predator avoidance, and migration. The reduced-light conditions found under an overwater structure limit the ability of fishes, especially juveniles and larvae, to perform these essential activities. Shading from overwater structures may also reduce prey organism abundance and the complexity of the habitat by reducing aquatic vegetation and phytoplankton abundance (Kahler et al. 2000; Haas et al. 2002). Biotic assemblages on pilings have been demonstrated to differ from natural hard substrate (Glasby 1999a) with these differences attributed to shading effects (Glasby 1999b). Other studies have shown shaded epibenthos to be reduced relative to that in open areas. These factors are thought to be responsible for the observed reductions in juvenile fish populations found under piers and the reduced growth and survival of fishes held in cages under piers when compared to open habitats (Able et al. 1998; Duffy-Anderson and Able 1999).

The shadow cast by an overwater structure may increase predation on EFH managed species by creating a light/dark interface that allows ambush predators to remain in a darkened area (barely visible to prey) and watch for prey to swim by against a bright background (high visibility) (Helfman 1981). Prey species moving around the structure are unable to see predators in the dark area under the structure and are more susceptible to predation. Furthermore, the reduced vegetation (i.e., eelgrass) densities associated with overwater structures decrease the available refugia from predators.

In-water structures (e.g., pilings) also provide perching platforms for avian predators such as double-crested cormorants (*Phalacrocorax auritis*), from which they can launch feeding forays or dry their plumage. Because their plumage becomes wet when diving, cormorants spend considerable time drying out feathers (Harrison 1983) on pilings and other structures near feeding grounds (Harrison 1984).

Placement of structures in shallow water may also disrupt migration of smaller juvenile salmonids that use nearshore areas. Boat activity and the physical presence of the structures may result in juvenile salmonid delaying passage or forcing them into deeper water areas in an attempt to go around the structures. Littoral areas are important for juvenile salmonid migration (Ward et al. 1994).

Wave energy and water transport alterations from overwater structures can impact the nearshore detrital foodweb by altering the size, distribution, and abundance of substrate and detrital materials. Disruption of longshore transport can alter substrate composition and can present potential barriers to the natural processes that build spits and beaches and that provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning.

Pilings can alter adjacent substrates by increasing shell deposition from piling communities and changing substrate bathymetry. Changes in substrate type can alter the nature of the flora and fauna native to a given site. In the case of pilings, native dominant communities typically associated with sand, gravel, mud, and eelgrass substrates are replaced by communities associated with shell hash substrates.

The primary adverse effect of removing piles is the suspension of sediments, which may result in harmful levels of turbidity and release of contaminants contained in those sediments. Vibratory pile removal tends to cause the sediments to slough off at the mudline, resulting in relatively low levels of suspended sediments and contaminants. Vibratory removal of piles is gaining popularity because it can be used on all types of piles, providing that they are structurally sound. Breaking or cutting the pile below the mudline may suspend only small amounts of sediment, providing the stub is left in place and little digging is required to access the pile. Direct pull or use of a clamshell to remove broken piles, however, may suspend large amounts of sediment and contaminants. When the piling is pulled from the substrate using these two methods, sediments clinging to the piling will slough off as it is raised through the water column, producing a potentially harmful plume of turbidity and/or contaminants. The use of a clamshell may suspend additional sediment if it penetrates the substrate while grabbing the piling.

While there is a potential to adversely affect EFH during the removal of piles, many of those removed are old creosote-treated timber piles. In some cases, the long-term benefits to EFH obtained by removing a consistent source of contamination may outweigh the temporary adverse effects of turbidity.

Treated wood used for pilings and docks releases contaminants into saltwater environs. Polyaromatic hydrocarbons (PAHs) are commonly released from creosote-treated wood. PAHs can cause a variety of deleterious effects (cancer, reproductive anomalies, immune dysfunction, and growth and development impairment) to exposed fish (Johnson et al. 1999; Johnson 2000; Stehr et al. 2000). Wood also is commonly treated with other copper-based chemicals such as ammoniacal copper zinc arsenate and chromated copper arsenate (Poston 2001). Copper is a common contaminant in salmon habitat and can increase susceptibility to disease, cause hyperactivity, impair respiration, or disrupt osmoregulation. Moreover, salmon use olfactory cues to convey important information about habitat quality, predators, mates, and the animal's natal stream, and copper can impair olfactory performance. Research has shown that fish behaviors can be disrupted at concentrations of dissolved copper that are at, or slightly above, background concentrations. Therefore, substantial copper-induced loss of olfactory capacity will likely impair behaviors essential for the survival or reproductive success of salmon. These preservatives are known to leach into marine waters for a relatively short period of time after installation, but the rate of leaching is highly variable and dependent on many factors. Concrete or steel, on the other hand, are relatively inert and do not leach contaminants into the water.

Although not the cause of direct introductions, artificial overwater structures and associated substrate may provide increased opportunity for nonnative species colonization and exacerbate the increase in their abundance and distribution (Bulleri and Chapman 2010). Glasby et al. (2007) argue that artificial structures, such as floating docks and pilings, provide entry points for invasion and increase the spread and establishment of non-native species in estuaries. In the San Francisco Estuary, the Smithsonian Institute conducts Rapid Assessment Surveys to determine nonnative species distribution on overwater structures. Of the 294 distinct nonnative taxa observed, 60 percent were found on floating docks, 20 percent on intertidal benthos, and 13 percent from benthic grabs (Cohen et al. 2005). Overwater structures can serve as focal points for nonnative species known to prey on salmon (Kahler et al. 2000) or otherwise alter salmon habitat processes and functions (Nightingale and Simenstad 2001). Given the relative lack of natural hard bottom habitat in estuaries, the addition of artificial hard structures within this type of habitat may prove an invasion opportunity for non-native hard substratum species (Glasby et al. 2007; Wasson et al. 2005; Tyrell and Byers, 2007).

Construction of docks may result in increased vessel traffic. Docks may be built for small marinas (small boats), ferry terminals (ferries), or commercial use. Depending on the size of the boat using the dock, increased vessel traffic may have negligible to significant effects on EFH. Boat traffic creates energy that suspends fine sediments and increases turbidity. Ferry docking and departing may result in multiple propeller wash events per hour (Olson et al. 1997). Ferry propeller wash may cause elevated turbidity, coarsening of sediments underneath ferry terminals (Francisco 1995), and scour pits (Shreffler and Gardiner 1999; Haas et al. 2002). Propeller wash may increase current by up to six times the background current (Olson et al. 1997), which may result in epibenthic meiofauna flushing (Haas et al. 2002). Ferry terminals have been shown to significantly alter epibenthic juvenile salmonid prey during periods of salmon emigration in Washington (Haas et al. 2002).

Wakes from boat traffic may also increase turbidity in shallow waters, uproot aquatic macrophytes in shallow waters, or cause pollution through exhaust, fuel spills, or release of petroleum lubricants (Warrington 1999; McConchie and Tolman 2003). Hilton and Phillips (1982) in their studies on boat traffic and increased turbidity in the River Ant determined that boat traffic definitely had a large effect on turbidity levels in the river. Nordstrom (1989) says that boat wakes may also play a significant role in creating erosion in narrow creeks entering an estuary (areas extensively used by rearing juvenile salmonids). Kahler et al. (2000) indicates that wake erosion results in continuous low level sediment input with episodic large inputs from bank failure.

Dorava (1999) indicates that boat wake erosion was the cause of substantial bank erosion on the Kenaii River, Alaska (whose primary traffic is 10- to 26-foot-long recreational boats) and the reason for substantial bank stabilization measures to arrest that erosion. The result of the erosion in important salmon areas is a reduction in numbers of salmon (Dorava 1999). Dorava (1999) further indicates that juvenile Chinook salmon rearing habitat features are easily altered by boat wake induced streambank erosion and streamside development.

Klein (1997), citing several EPA studies, indicates that boat traffic in waters less than 8.2 feet in depth result in substantial impacts to submerged vegetation and benthic communities. Klein (1997) also indicates that sediment resuspension is substantial if a boat operates in less than 7.2 feet of water and that a slight increase in depth would prevent the resuspension of sediment. Asplund (2000) evaluated the literature on boating effects on the aquatic environment and found that impacts were few in waters greater than 10 feet.

Boating can result in discharges of many pollutants from boats and related facilities, and physical disruption to wetland, riparian and benthic communities and ecosystems through the actions of a boat hull, propeller, anchor, or wakes (USEPA 1993; Carrasquero 2001; Kahler et al. 2000; Mosisch and Arthington 1998). Boats may interact with the aquatic environment by a variety of mechanisms, including emissions and exhaust, propeller contact, turbulence from the propulsion system, waves produced by movement, noise, and movement itself (Asplund 2000). Sediment resuspension, water pollution, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion are the major areas of concern (Asplund 2000).

Boat traffic may adversely affect SAV present in the area. Eelgrass has been shown to be shorter in areas directly affected by boat traffic (Burdick and Short 1999). Propeller wash may erode away the rhizome of seagrasses or cause extensive scarring (Sargent et al. 1995). Boat traffic creates energy that suspends fine sediments and increases turbidity. Ferry docking and departing may result in multiple propeller wash events per hour (Olson et al. 1997). Ferry propeller wash may cause elevated turbidity, coarsening of sediments underneath ferry terminals (Francisco 1995), and scour pits (Shreffler and Gardiner 1999; Haas et al. 2002). Propeller wash may increase current by up to six times the background current (Olson et al. 1997), which may result in epibenthic meiofauna flushing (Haas et al. 2002). Ferry terminals have been shown to significantly alter epibenthic juvenile salmonid prey during periods of salmon emigration in Washington (Haas et al. 2002).

While the effect of some individual overwater structures on EFH may be minimal, the overall impact may be substantial when considered cumulatively. The additive effects of these structures increase the overall magnitude of impact and reduce the ability of the EFH to support native plant and animal communities.

Potential conservation measures for overwater structures

- Use upland boat storage whenever possible to minimize need for overwater structures.
- Locate overwater structures in sufficiently deep waters to avoid intertidal and shade impacts, to minimize or preclude dredging, to minimize groundings, and to avoid displacement of SAV, as determined by a pre-construction survey.
- Design piers, docks, and floats to be multi-use facilities in order to reduce the overall number of such structures and the nearshore habitat that is impacted.
- Incorporate measures that increase the ambient light transmission under piers and docks. These measures include, but are not limited to, maximizing the height of the structure and minimizing the width of the structure to decrease shade footprint; grated decking material; using solar tubes to direct light under the structure and glass blocks to direct sunlight under the structure; illuminating the under-structure area with metal halide lamps and use of reflective paint or materials (e.g., concrete or steel instead of materials that absorb light such as wood) on the underside of the dock to reflect ambient light; using the fewest number of pilings necessary to support the structures to allow light into under-pier areas and minimize impacts to the substrate; and aligning piers, docks and floats in north-south orientation to allow arc of sun to cross perpendicular to structure and reduce duration of light limitation.
- Use floating breakwaters whenever possible and remove them during periods of low dock use.
- Encourage seasonal use of docks and off-season haul-out.
- Use waveboards to minimize effects on littoral drift and benthic habitats.
- Locate floats in water far enough offshore as to not impede juvenile fish migration past the structures
- Use mid-water floats or other technology to keep anchor chains from contacting the substrate.
- Conduct in-water work during the time of year when EFH-managed species and prey species are least likely to be impacted.
- Avoid use of treated wood timbers or pilings to the extent practicable. Use of alternative materials such as untreated wood, concrete, or steel is recommended.
- Fit all pilings and navigational aids, such as moorings and channel markers, with devices to prevent perching by piscivorous bird species.
- Orient night lighting such that illumination of the surrounding waters is avoided.
- Mitigate for unavoidable impacts to benthic habitats that is adequately provided, properly monitored, and adaptively managed.
- Elevated turbidity during construction may be avoided with the use of a silt curtain if site conditions allow.
- When removing piles:
  - Remove piles completely rather than cutting or breaking off if the pile is structurally sound.
  - Minimize the suspension of sediments and disturbance of the substrate when removing piles. Measures to help accomplish this include, but are not limited to, the following:
    - When practicable, remove piles with a vibratory hammer, rather than the direct pull or clamshell method.
    - Remove the pile slowly to allow sediment to slough off at, or near, the mudline.
    - The operator should first shake or vibrate the pile to break the bond between the sediment and pile. Doing so causes much of the sediment to slough off the pile at the mudline, thereby minimizing the amount of suspended sediment.
    - Place a ring of clean sand around the base of the pile. This ring will contain some of the sediment that would normally be suspended.

        - Encircle the pile, or piles, with a silt curtain that extends from the surface of the water to the substrate.
    - Complete each pass of the clamshell to minimize suspension of sediment if pile stubs are removed with a clamshell.
    - Fill all holes left by the piles with clean, native sediments if possible.
    - Place old piles on a barge equipped with a basin to contain all attached sediment and runoff water after removal. Creosote-treated timber piles should be cut into short lengths to prevent reuse, and all debris, including attached, contaminated sediments, should be disposed of in an approved upland facility.

4.2.2.25 Pesticide use

Pesticides are a diverse group of chemicals that are broadly used to control unwanted organisms in agriculture and a range of non-agricultural uses (e.g., forestry, rights-of-way, horticulture, outdoor solid waste containers, irrigation ditches, stagnant water, households and domestic dwellings). They include fungicides, herbicides, insecticides, nematicides, molluscicides, rodenticides, fumigants, disinfectants, repellents, wood preservatives, and antifoulants among others. In Willapa Bay and Grays Harbor, two estuaries in Washington State, the insecticide carbaryl is often sprayed into the aquatic habitat to control burrowing shrimps that interfere with shellfish culture. Given this wide-spread use, pesticides are ubiquitous contaminants in the aquatic environment, and are known to adversely affect many types of organisms, including salmonids by either injuring or killing them, or by degrading the habitats upon which they depend.

Pesticides contain “active” ingredients that kill or otherwise affect targeted organisms (listed on the label). There are more than 900 active ingredients, and they must be registered under the Federal Insecticide, Fungicide, and Rodenticide Act. Registered pesticide products, known as formulations, typically contain active ingredients and a variety of “inert” or other ingredients which are generally not assessed for toxicity, although they are released into the environment. Examples may include chemical adjuvants to make pesticide products more efficacious, surfactants to reduce the interfacial, surface tension and increase uptake by the target, solvents, or other chemicals. Many of these ingredients have their own toxic properties that may result in adverse effects on salmon or their prey. Beginning in 2008, NMFS has issued six biological opinions (NMFS 2008b; 2009b; 2010, NMFS 2011b, NMFS 2012a, 2012b) to the EPA on the registration of 27 pesticides, a draft biological opinion on 3 pesticides (NMFS 2013) is scheduled to complete consultation on 7 others. These biological opinions determined that when applied according to the label instructions, many of these pesticides can have severe effects on individual and populations of threatened and endangered Pacific salmonids under NMFS’ jurisdiction. The biological opinions concluded that many of the pesticides analyzed present a limiting factor to the recovery of at least some of the 27 ESUs of Pacific Coast salmonids, and that application according to the labels would jeopardize the continued existence as well as adversely modify designated critical habitats of many of them. The following summary is drawn from the first two biological opinions (NMFS 2008b; 2009b), which covered a total of six of the pesticides: chlorpyrifos, diazinon, malathion, carbaryl, carbofuran, and methomyl.

The risk analyses in the Opinions used existing literature to evaluate the effects of these pesticides on a number of important endpoints (survival, growth, reproduction, swimming, olfactory-mediated behaviors, and prey survival) and found strong evidence of adverse responses at concentrations that would be expected to occur in the habitats used by salmon. In off-channel habitats that are very important to juvenile salmonids, estimates of pesticide concentrations appeared to be especially high. The Opinions concluded the following:

- Direct, acute exposure to pesticides can kill salmonids. Monitoring data and modeling estimates show that some pesticides can reach lethal concentrations in some of the habitats used by salmon, especially in off-channel habitats.

- Acute or chronic exposure to sublethal concentrations of some active ingredients can lead to lower feeding success and likely results in reduced growth. Survival of juvenile salmonids has been correlated with growth rates, where lower growth rates result in lower survival.
- Salmonid prey are highly sensitive and affected by real-world exposures to many of the pesticides and mixtures of pesticides, particularly, neurotoxic insecticides. Aquatic habitats that are routinely exposed to certain pesticides showed reductions in the abundance and species diversity of the prey community, and reduced growth rates in juvenile salmon have been associated with low prey abundance.
- Exposure to real-world sublethal concentrations of some pesticides has been shown to impair swimming behavior in salmonids. Swimming speed, distance swam, and acceleration can be reduced after such exposure. The ecological consequences of aberrant swimming behavior are impaired feeding that translates into reduced growth, interrupted migratory patterns, survival, and reproduction.
- Definitive evidence supports that olfaction can be impaired by some pesticides at concentrations that are expected to occur in salmon habitats. Juveniles with impaired olfactory functions have been shown to more susceptible to predation, while adult spawning migration and mate detection can be affected by impaired olfaction.
- Mixtures of pesticides, including the ”inert/other” ingredients, can act in combination to increase the potential adverse effects on salmon and salmon habitat compared to exposure to a single ingredient

It is important to note that the potential for pesticides to adversely affect EFH depends on a variety of factors, and not every application will result in an adverse effect. The specific pesticide being applied, the application method and concentration, the distance from salmon habitat that the pesticide is applied, and the general pattern of pesticide use in the area will all affect the pesticide concentrations in the aquatic habitat. In addition the time of year and the species and life stages present are important considerations.

Potential conservation measures for pesticide use

The conservation measure implemented will vary depending on the specific pesticide being applied, the species and life stage in the area, and the time of year. In general, they include:

- Avoid the use of pesticides near aquatic habitats, if possible.
- Implement measures that reduce the need to apply pesticides, such as planting pest-resistant crops.
- Use less toxic alternatives to pesticides.
- Establish a minimum no-application buffer width.
- Install or establish a minimum non-crop vegetative buffer where no pesticides are applied.
- Maintain healthy riparian zones alongside salmon-bearing waters.
- Restrict applications under certain environmental conditions, such as during periods of high wind, rain, or wet soils.

4.2.2.26 Power plant intakes

The withdrawal of water for power plant cooling purposes is termed once-through cooling (OTC). Withdrawal of cooling water removes billions of aquatic organisms every year (CEC 2005). Discharges of heated and/or chemically-treated discharge water may also occur. Adverse impacts to EFH from OTC and subsequent discharges may adversely affect EFH in the source or receiving waters via 1) entrainment, 2) impingement, 3) discharge, 4) operation and maintenance, and 5) construction-related impacts.

Potential adverse effects from power plant intakes

Entrainment is the withdrawal of aquatic organisms along with the cooling water into the cooling system. OTC indiscriminately entrains phytoplankton, zooplankton, and the eggs and larval stages of fish and shellfish. These entrained organisms are subjected to mechanical stress, heated water, and occasionally biocides. Of primary concern is the entrainment of early life history stages of fish and shellfish. Entrainment of larval stages can have a greater on fish and shellfish species than to phytoplankton or zooplankton due to a shorter spawning season, a more restricted habitat range, and greater likelihood of mortality. Long-term water withdrawal may adversely affect fish and shellfish populations by adding another source of mortality to the early life stage, which often determines recruitment and year-class strength (Travnichek et al. 1993). OTC units utilizing estuarine or marine waters are unlikely to entrain larval Chinook salmon or coho salmon given that spawning and larval development for these species occur in freshwater environments. Pink salmon are likely to be more susceptible to impingement and entrainment than the other two species because they typically enter the estuarine and marine habitats immediately after emergence and are, therefore, much smaller. Entrainment studies at power plants located in coastal lagoons and embayments have demonstrated that a large percentage of entrained larvae are composed of resident fishes that serve as a forage base for other species (EPRI 2007). Thus, entrainment may reduce the forage base for salmon species that may utilize the various coastal lagoons and embayments in which OTC units operate. Power plants utilizing OTC in open coastal environments have far less potential for population-level effects on fish populations than power plants located in coastal lagoons and embayments (EPRI 2007). However, localized reductions in forage opportunities may still occur near open coast OTC units.

Impingement occurs to organisms that are too large to pass through in-plant screening devices and instead become stuck or impinged against the screening device or remain in the forebay sections of the system until they are removed by other means (Grimes 1975; Hanson et al. 1977; Moazzam and Rizvi 1980; Helvey 1985; Helvey and Dorn 1987). The organisms cannot escape due to the water flow that either pushes them against the screen or prevents them from exiting the intake tunnel. Similar to entrainment, the withdrawal of water can entrapped particular species especially when visibility is reduced (Helvey 1985). This condition reduces the suitability of the source waters to provide normal EFH functions necessary for subadult and adult life stages of salmon and/or their prey. Population level impacts have not been observed for individual species.

The ecological implications of entrainment and impingement are complex and difficult to assess. Although population level impacts are not consistently observed, the use of OTC may significantly decrease biological productivity in estuarine and marine systems. With modern entrainment sampling and analyses, a more scientifically robust method of determining appropriate compensation may be done through the use of habitat production foregone analyses. A combined habitat foregone estimate for 13 power plants using OTC in California bays and estuaries was approximately 10,800 acres of wetlands (CEC 2005).

Thermal effluents in inshore habitat may alter the benthic community or kill marine organisms, especially larval fish. Temperature influences biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of marine organisms (Blaxter 1969). Thermal impacts are generally site-specific and depend upon the type of habitat and circulation at the discharge site. The thermal impacts of some West Coast plants have been large when discharge occurs either into bays and estuaries with reduced mixing or into the open coast where heated water quickly contacts rocky habitats (Duke 2004; Schiel et al. 2004; Foster 2005). Significant impacts to sensitive habitats, such as eelgrass and kelp, have been observed with some California power plants. However, heated water discharged offshore on the open coast experiences rapid mixing before touching benthic habitat, which likely results in little impact (CEC 2005). The water clarity of the receiving waters may also be diminished if the intake water is more turbid than that around the discharge structure. Water clarity and quality may also be altered by the increased dead organic matter in the discharge, as well as by scour if discharge occurs on shore (CEC 2005).

Other impacts to aquatic habitats may result from construction related activities, such as dewatering or dredging, as well as routine operation and maintenance activities. The effects of some of these activities are discussed elsewhere. There is a broad range of impacts associated with these activities depending on the specific design and needs of the system. For example, dredging activities may cause turbidity, degraded water quality, noise, and substrate alterations. Power plants using OTC may also periodically use biocides such as sodium hypochlorite and sodium bisulfate to clean the intake and discharge structures. Chlorine is extremely toxic to aquatic life. In addition, heat treatments are frequently used to control fouling organisms in the forebay area of OTC units. This kills the fish that remain in the forebay and the fouling invertebrate organisms along the tunnels and racks.

Potential conservation measures for power plant intakes

- To the extent feasible, power plants should utilize cooling alternatives that avoid or minimize the use of river, estuary, or ocean water for cooling purposes. Alternatives such as dry cooling, closed- cycle wet cooling, utilizing recycled water for cooling water are more benign to EFH.
- Locate facilities that rely on surface waters for cooling in areas other than estuaries, inlets, heads of submarine canyons, rock reefs, or small coastal embayments where EFH species or their prey concentrate. Discharge points should be located in areas that have low concentrations of living marine resources.
- Design intake structures to minimize entrainment or impingement. Velocity caps that produce horizontal intake/discharge currents should be employed, and intake velocities across the intake screen should not exceed 0.5 foot per second.
- Design power plant cooling structures to meet the "best technology available" requirements (BTAs) as developed pursuant to Section 316(b) of the Clean Water Act. Use of alternative cooling strategies, such as closed cooling systems (e.g., dry cooling) should be used to completely avoid entrainment/impingement impacts in all industries that require cooling water. When alternative cooling strategies prove infeasible, other BTAs may include but are not limited to fish diversion or avoidance systems, fish return systems that convey organisms away from the intake, and mechanical screen systems that prevent organisms from entering the intake system, and habitat restoration measures.
- Regulate discharge temperatures (both heated and cooled effluent) such that they do not appreciably alter the temperature in a way that could cause a change in species assemblages and ecosystem function in the receiving waters. Strategies should be implemented to diffuse the heated effluent.
- Avoid the use of biocides (e.g., chlorine) to prevent fouling where possible. The least damaging antifouling alternatives should be implemented.
- Mitigate for impacts related to power plants and other industries requiring cooling water. Mitigation should compensate for the net loss of EFH habitat functions from placement and operation of the intake and discharge structures. Mitigation should be provided for the loss of habitat from placement of the intake structure and delivery pipeline, the loss of fish larvae and eggs that may be entrained by large intake systems, and the degradation or loss of habitat from placement of the outfall structure and pipeline as well as the treated water plume. A habitat production foregone approach or equivalent habitat equivalency analysis should be used for determining mitigation.
- Treat all discharge water from outfall structures to meet state water quality water standards at the terminus of the pipe. Pipes should extend a substantial distance offshore and be buried deep enough to not affect shoreline processes. Buildings and associated structures should be set well back from the shoreline to preclude the need for bank armoring.

4.2.2.27 Road Building and Maintenance

Roads may affect groundwater and surface water by intercepting and re-routing water that might otherwise drain to springs and streams. This increases the density of drainage channels within a watershed and results in water being routed more quickly into the streams (NRC 1996; Spence et al. 1996). Altering the connection between surface and groundwater can affect water temperatures, instream flows, and nutrient availability. These factors can affect egg development, the timing of fry emergence, fry survival, aquatic diversity, and salmon growth (NRC 1996). In some situations, road maintenance perpetuates these effects.

In urban areas, extensive road and pavement can effectively double the frequency of hydrologic events that are capable of mobilizing stream substrates (NRC 1996) (also see Section 4.2.2.7 Construction/Urbanization). This increased scour of gravel and cobble in areas where salmon eggs, alevins, or fry reside can kill salmon directly or indirectly increase mortality by carrying them downstream and away from stream cover. Urban roads can be a major source of sediment input during construction as can the installation of bridges, culverts, and diversions with coffer dams. However, these project impacts seem to be more temporary and less pervasive on sediment input than forest roads (Waters 1995).

In small forested watersheds, streamflow appears to be directly related to the total area of the watershed composed of roads and other heavily compacted surfaces. In larger watersheds, where roads and impermeable areas represent a relatively small area of the basin, little or no effect is seen (Adams and Ringer 1994). Altered hydrology was noted when roads covered 4 percent or more of a drainage area (King and Tennyson 1984).

Road culverts can block both adult and juvenile salmon migrations. Blockage can result from the culvert becoming perched above stream bed level, lack of pools that could allow salmon to reach the culvert, or from high water flow velocities in the culvert. The effect of logging roads on erosion and sedimentation has been well studied. Furniss et al. (1991) concluded that forest roads contribute more sediment than all other forest activities combined on a per-unit basis. Road surfaces can break down with repeated heavy wheel loads of hauling trucks, particularly under wet conditions, resulting in a continual source of fine sediment input (Murphy 1995). However, improvements in road-construction and logging methods can reduce erosion rates (NRC 1996). For additional detail, see Section 4.2.2.15 Forestry.

Conservation Measures for Road Building and Maintenance

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH habitat in areas that have the potential to be affected by road building and maintenance activities. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the protection and restoration of properly functioning salmon habitat. The following suggested measures are adapted from Murphy (1995), Mirata (1998), ODFW (1989), and NMFS (1996b).

- Revegetate cut banks, road fills, bare shoulders, disturbed streambanks, etc. after construction to prevent erosion. Check and maintain sediment control and retention structures throughout the rainy season.
- Minimize riparian corridor damage during construction of roads (and bridges, culverts, and other crossings) and avoid locating roads in floodplains.
- Rehabilitate roads by upgrading problem culverts or replacing with bridges, outsloping road surfaces to drain properly without maintenance, revegetating bare surfaces, and other measures as necessary for stability.
- At a minimum, use state or Federal culvert design guidelines (e.g., NMFS 1996b) for design and installations of culverts.
- Road maintenance practices should be conducted according to the requirements of existing NMFS rules such as the July 2000 ESA 4(d) rule (Protective Regulations) for listed West Coast salmon and steelhead (65 FR 42422; July 10, 2000), Limit 10, covering road maintenance. NMFS has found that doing maintenance under these programs not only avoids causing existing problems to worsen, but protects salmonid habitat to the extent that it contributes to the conservation of the species.

4.2.2.28 Sand and Gravel Mining

Mining of sand and gravel in the region's watersheds is extensive. Mining occurs by several methods. Most common is bar scalping or skimming operations, which use bulldozers, scrapers, and loaders to remove the tops of river gravel bars without excavating below the summer water. The bars are almost always attached to the stream banks and are frequently located on the inside of meander bends. Excavation of floodplain and river terrace deposits adjacent to an active or former channel is another common method for gravel extraction. Gravel extraction in these locations may occur to the level of seasonal flow, or may excavate below the adjacent water level, and require pumping of seepage water or underwater extraction from a pond. As active channels naturally move, the channel may migrate into the excavated area. The chance of this occurring is increased in the event of a flood.

Potential adverse effects of sand and gravel mining

The potential effects of gravel extraction activities on anadromous fishes and their habitats are summarized in NMFS' National Gravel Extraction Policy (Packer et al. 2005) with the following categories of effects:

- Extraction of bed material in excess of natural replenishment by upstream transport causes bed degradation.
- Gravel extraction increases suspended sediment, sediment transport, water turbidity and gravel siltation.
- Bed degradation changes the morphology of the channel.
- Gravel bar skimming significantly impacts aquatic habitat.
- Operation of heavy equipment in the channel bed can directly destroy spawning habitat, and produce increased suspended sediment downstream.
- Stockpiles and overburden left in the floodplain can alter channel hydraulics during high flows.
- Removal or disturbance of instream roughness elements during gravel extraction activities negatively affects both quality and quantity of anadromous fish habitat.
- Destruction of the riparian zone during gravel extraction operations can have multiple deleterious effects on anadromous fish habitat.

The culmination of these effects make the stream channels wider, shallower, and less complex, resulting in decreased suitability as rearing habitat for juveniles. During summer low-flow periods deep complex waters are important for survival. During winter high-flow events slow water on the margins of streams created by complex channels are most important for juvenile survival. Similarly a reduction in pool frequency may adversely affect migrating adults that require holding pools (Spence et al. 1996). Changes in the frequency and extent of bedload movement and increased erosion and turbidity can also remove spawning substrates, scour redds (resulting in a direct loss of eggs and young), or reduce their quality by deposition of increased amounts of fine sediments. Other effects that may result from sand and gravel mining include increased temperatures (from reduction in summer base flows and decreases in riparian vegetation), decreased nutrients (from loss of floodplain connection and riparian vegetation), and decreased food production (loss of invertebrates) (Spence et al. 1996).

Potential conservation measures for sand and gravel mining

The following suggested measures are adapted from the Oregon Sediment Removal Considerations (Federal Interagency Working Group 2006), NMFS National Gravel Policy (NMFS 2005), and OWRRI (1995).

- In all sand and gravel removal projects, include restoration, mitigation, and monitoring plans.
- For in-stream sand and gravel removal:
    - Complete all in-water work during the summer low flow period.

- o Require implementation of a spill prevention and response plan to minimize the potential of a contaminant spill and the size of a spill if one were to occur
  - o Avoid reach level impacts on channel morphology by strictly limiting the cumulative gravel removal quantities to ensure gravel recruitment and accumulation rates are sufficient. To achieve this, an estimate of the volume of sand and gravel recruiting to the reach will be required from a qualified hydrologist or fluvial geomorphologist. Only a portion of that estimate will be available for removal.
  - o Minimize site level impacts by retaining the hydraulic control exerted by bars on the stream channel using the following restrictions:
    - ▪ Head of bar buffer. The operators will protect the upstream third of the bar from any excavation activities.
    - ▪ Lateral buffer. An undisturbed setback area between the low flow channel and the active mining area will be no less than 20 percent of the active channel width.
    - ▪ Excavated backwater length. Not greater than two-thirds of the bar feature, and will include the head slope and side slope of the backwater.
    - ▪ Excavated backwater depth. The maximum depth will be equal to the low flow elevation at the downstream end. The backwater area will be sloped to prevent fish entrapment.
    - ▪ Excavated backwater head slope. No steeper than 10 to 1 (horizontal to vertical).
    - ▪ Excavated backwater side slopes. No steeper than 4 to 1 (horizontal to vertical).
- For floodplain sand and gravel removal:
  - o To minimize the occurrence of juvenile entrapment, floodplain pits should be located outside the 50-year flood elevation.
  - o To minimize the probability of pit capture, floodplain pits should be located outside of the 100-year channel migration belt of all streams.

4.2.2.29 Vessel Operations

Population and income drive the demand for trade, and trade drives the demand for transportation services (COE 2012a). The United States is a maritime nation, with its networks of highways, railways and inland waters connecting America's heartland to inland and coastal ports. The U.S. population is expected to increase from 313.4 million in 2011 to 412.2 million in 2042, an increase of 32 percent (COE 2012a). Populations in west coast states of Washington, Oregon and California are expected to grow by 12.8, 10.5 and 24.3 percent, respectively. Forecasts for bulk and containerized trade expect imports to increase from 17 million in 2011 to 60 million in 2037 and exports to increase from 13 to 52 million over the same time period. As coastal and inland waterway communities grow, so does the demand for increased capacity of marine transportation vessels, facilities, and infrastructure for cargo handling activities, water transportation services, and recreational opportunities. By 2030 post-Panamax vessels will make up 62 percent of total container ship capacity. These ships have the capacity to transport 12,000 containers, have 50-foot drafts, 16-foot beams, and 1,200-foot lengths (COE 2012b).

Potential adverse effects from vessel operations/transportation/navigation

While investments to maintain, improve and expand navigation and intermodal transportation infrastructure are necessary for the US to remain globally competitive, these investments come at a significant environmental and resource cost. The growth of the marine transportation industry is accompanied by land-use changes, including over-water or in-water construction, and loss and degradation of aquatic habitat and wetlands through actions such as filling, dredging, channelization, and diking and damming. Wetlands and open-water environments are disproportionately impacted by ports and waterways, and wetland losses have outdistanced gains (Dahl 2011). Freshwater environments have been significantly impacted by physical, chemical and biological changes (COE 2012a). Although some habitat impacts resulting from some site-specific activities may be minimal, the cumulative effects of these activities over time can have substantial impacts on habitat. Impacts to EFH from navigation infrastructure include: (1) loss, conversion, or impairment of benthic, shoreline, and pelagic habitats; (2) altered light and temperature regimes; (3) contaminant and debris releases; (4) altered tidal, current, and hydrologic regimes; and (5) introduction of invasive or nonnative species. Navigation and transportation infrastructure can also directly and indirectly alter aquatic organism assemblages; alter rearing, spawning, and migration behavior; alter predator-prey relationships and interactions; and result in the mortality or injury through entrainment and propeller strikes. For additional information, refer to the Sections on the Construction and Urbanization, Dredging and Dredge Spoils, Wetland and Floodplain Alteration, Wastewater and Pollutant Discharge, Estuarine Alteration, Overwater Structures, Introduction and Spread of Invasive Species, and Bank Stabilization.

Operation and Maintenance of Vessels

Activities associated with the operation and maintenance of commercial, industrial and recreational vessels can directly and indirectly impact EFH. Impacts from vessel operation can result from hydrodynamics due to vessel-induce wake and wave generation, anchor chain and propeller scour; noise and chemical pollution due to vessel operation and waste discharge; and the inadvertent transport of invasive plant and animal species. Impacts can also result from vessel abandonment and dereliction. The severity of vessel-induced impacts on coastal and inland waterway habitats depends on the geomorphology of the impacted area, current velocity, sediment composition, vegetation type and extent of vegetative cover, as well as vessel type and dimensions, number of vessels, speed, vessel direction, proximity to the shoreline, and timing (Yousef 1974; Holland 1987; Garrad and Hey 1988; Barr 1993; Mazumder et al. 1993). Projected population growth and associated demand for improved and expanded waterborne transportation services that include increased vessel traffic and faster, larger vessels will likely exacerbate vessel-induced impacts (Cook 1985; Holland 1987).

Direct and indirect vessel-induced EFH impacts include: (1) loss or impairment of benthic, shoreline and pelagic habitats; (2) contaminant and debris releases, including vessel abandonment and dereliction; (3) underwater noise pollution; and (4) introduction of invasive or nonnative species. Vessel operations can also directly and indirectly alter aquatic organism assemblages; alter rearing, spawning, migration, and recruitment behaviors; and result in the mortality or injury through stranding, entrainment, and propeller strikes.

Loss or impairment of benthic, shoreline and pelagic habitat

Vessel movement creates wakes/waves and energy, which causes altered velocity and pressure regimes, drawdowns, waves along the shoreline, and increases in turbidity due to erosion and resuspended sediments (Bhowmik et al. 1982; Maynord 1990; Bhowmik 1991; Bhowmik et al. 1991; Bhowmik et al. 1993; Mazumder et al. 1993; Maynord 1996). These disturbances can result in shoreline erosion, disturbed substrate, increased turbidity, damaged aquatic vegetation, and impacts to aquatic organisms (Bouwmeester et al. 1977; Hilton and Phillips 1982; Cook 1985; Nielsen et al. 1986; Garrad and Hey 1988; Bhowmik et al. 1991; Bhowmik et al. 1993; Barr 1993; Johnson 1994; Maynord 2005; Hammack et al. 2008; Kelpšaite et al. 2009; Nagrodski et al. 2012).

The degree of sediment resuspension and entrainment into the water column by vessel activity is complex (Anthony and Downing 2003), but is generally dependent upon the wave energy and surge produced by the vessel, as well as the size of the sediment particles, the water depth, and the number of vessels passing through an area (Barr 1993). Heavy recreational vessel traffic can generate substantial wave activity with detrimental results to shoreline vegetation and bank stability (Johnson 1994; Bhowmik et al. 1991). Wave activity also influences the distribution and species composition of aquatic plant communities (Vermaat and de Bruyne 1993; Stewart et al. 1997). Maynord et al. (2008) noted that the persistent nature of wake erosion during the peak boating season may prevent the colonization of some plant species and may induce elevated turbidity levels in the zone near the bank. Wave activity washes away finer clays and silts, leaving coarser, less fertile sediments behind, and can tear or up-root plants. Chambers (1987) study demonstrated that the minimum depth of macrophyte occurrence is related to the depth of surface wave mixing. Doyle's (2001) study on the effects of vessel-induced waves on submerged plant growth concluded that plants exposed to even modest wave energy grew more slowly and were less resilient to recovery from other forms of disturbance.

Substrate and macrophyte disturbance can also occur through propeller wash resuspension of bottom sediments and direct contact with propellers or vessel hulls through grounding (Barr 1993). Benthic disturbance can also occur from anchor scour. As reported in NMFS (2011c), mooring buoys, when anchored in shallow nearshore waters, can drag the anchor chain across the bottom, destroying submerged vegetation and creating a circular scour hole (Walker et al. 1989 as cited in Shafer 2002). A study by Hastings et al. (1995 as cited in Shafer 2002) in Australia found that up to 18 percent of total seagrass cover was lost to mooring buoy scour.

Vessel-induced sedimentation can lead to persistently- poor water quality; altered phytoplankton productivity through reduced photosynthetic efficiency and macrophyte biomass (Kirk 1985; Asplund and Cook 1997; Uhrin and Holmquist 2003); and suppression of benthic, macrophyte and fish communities (Murphy and Eaton 1983; Anthony and Downing 2003; Wolter and Arlinghaus 2003; Eriksson et al. 2004). Both propeller-induced turbulence and vessel-induced wakes from recreational boat traffic have been correlated to rapid increases in total dissolved solids, soluble reactive phosphorus, total phosphorus (Yousef et al. 1980), and turbidity (Yousef 1974; Yousef et al.1980; Garrad and Hey 1988). Turbidity results in poor light conditions which impacts plant growth (Doyle 1999). Water clarity is important in determining the depth-of-penetration of sunlight within a given water body, and light penetration is especially important for submerged aquatic plants such as seagrasses for photosynthesis (Wilson 2010). Benthic diatoms and other microflora can also experience a significant decrease in primary production as a result of increases in turbidity and sediment from resuspension. Shaffer (1984) found that a thin layer of sediment deposited over a sandflat resulted in a 6.5 fold decrease in net primary productivity. Studies investigating sedimentation impacts on eelgrass have found that experimental burial of 25 percent of the plant height can result in greater than 50 percent mortality (Mills and Fonseca 2003).

The value of nearshore habitats to fish and shellfish is well documented (Bjornn and Reiser 1991; Dethier 2006; Fresh 2006; Gelfenbaum et al. 2006; Mumford 2007; Penttila 2007; AHGP 2010; Tabor et al. 2011). The disturbance of sediments and rooted vegetation decreases habitat suitability for fish and shellfish resources and can affect the spatial distribution and abundance of fauna (Soria et al. 1996; Uhrin and Holmquist 2003; Eriksson et al. 2004; Fullerton et al. 2011; Fresh et al. 2011). Declines in SAV, which provides food, shelter, and protection for many aquatic invertebrate and vertebrate species, will indirectly affect populations of species that depend on it.

Increased suspended sediment levels can also affect predator-prey relationships, food availability, and feeding behavior (Barrett et al. 1992; Lloyd 1987; Bash et al. 2001; Meager et al. 2006; Harvey and White 2008; Carter et al. 2010; Huenemann et al. 2012) and cause physical damage or mortality to eggs, larvae, and older fish (Newcombe and Jensen 1996; Bash et al. 2001) The egg and larval stages of marine and estuarine fish are generally highly sensitive to suspended sediment exposures (Morgan and Levings 1989; Wilber and Clark 2001), and juvenile fish may be susceptible to gill injury when suspended sediment levels are high (Servizi and Martens 1991; Bash et al. 2001).

As fish assemblages in inland navigational waterways become exposed to vessel-induced physical forces such as shear stress, wave turbulence, drawdown, dewatering, backwash, and return currents, susceptibility to stranding in littoral areas increases (Bauersfeld 1977; Adams et al. 1999; Ackerman 2002; Wolter and Arlinghaus 2003; Pearson et al. 2006; Pearson et al. 2008; Pearson and Skalski 2011; Nagrodski et al. 2012). Fish stranding, a function of fish size and swimming performance, tends to be a problem for smolts less than 60 to 70 millimeters fork length (Bauersfeld 1977; Ackerman 2002). The risk of stranding increases as the distance from the drawdown to run-up increases. The risk of stranding also increases with increasing salmon density in the nearshore. Using spatial analysis and sequential screen criteria on how the channel morphology influences ship wake characteristics, Pearson et al. (2008) estimated the number of shoreline reaches in the lower Columbia River that could potentially strand juvenile salmonids. They also concluded that stranding was a function of ship characteristics (mainly size and speed), channel and shoreline geomorphology, and the presence and composition of fish fauna.

Contaminant releases

A variety of substances can be discharged or accidentally spilled into the aquatic environment from vessel operations, maintenance, and repair, such as gray water (i.e., sink, laundry effluent), raw sewage, engine cooling water, fuel and oil, vessel exhaust, sloughed bottom paint, boat wash-down water, that may degrade water quality and contaminate bottom sediments (Stammerjohn et al. 1991; EPA 2001; EPA and MA 2006; WDOE 2009). Boat waste discharges result in local increases in nutrient loading and biological oxygen demand and further impact water quality through the release of disease causing organisms and toxic substances (Thom and Shreffler 1996 as cited in NMFS 2011c; Klein 1997; EPA 1985). Despite laws prohibiting the discharge of untreated wastes into coastal waters, many vessels may not be equipped with marine sanitation devices and on-shore pump-out stations are not common (Amaral et al. 2005). Impacts from vessel waste discharges may be exacerbated in small, poorly flushed waterways where pollutant concentrations can reach unusually high levels (Klein 1997). For additional information, refer to the discussion on Wastewater and Pollutant Discharge.

Metals and metal-containing compounds known to have toxic effects on marine organisms such as arsenic, cadmium, copper, lead, zinc and mercury (EPA 2001; EPA 2006) are released into the environment through various vessel maintenance activities such as bottom washing, paint scraping, and application of antifouling paints (Amaral et al. 2005). Sediment disturbance through physical or biological means can reintroduce toxic compounds into the water column, where they can be ingested by fish or other aquatic organisms and in turn by people (EPA 2001; EPA 2006; Jones and Turner 2010; Turner 2010; Berto et al. 2012). Metals are known to have toxic effects on marine organisms (Tierney et al. 2010). Considerable information is available regarding the effects of copper on aquatic organisms (Eisler 1998; Hecht et al. 2007; EPA 2007; Tierney et al. 2010; Tilton et al. 2011). Hecht et al. (2007) concluded benchmark concentrations (BMC) of dissolved copper ranging from 0.18 (BMC_{10}) to 2.1 (BMC_{50}) micrograms per liter (µg/L) corresponded to an approximately 50 percent reduction in olfactory function of juvenile salmon and a 47 percent reduction in alarm response. Copper may also bioaccumulate in bacteria and phytoplankton (Milliken and Lee 1990; Turner et al. 2009). Bao et al. (2013) determined that at least one of the new generation antifouling booster biocides, Irgarol 1051; works synergistically with copper in antifouling paints.

In addition to biocides, herbicides are also used in some antifouling paints to inhibit the colonization of algae and the growth of seaweeds on boat hulls and intake pipes (Readman et al. 1993). The leaching of these chemicals into the marine environment could affect community structure and phytoplankton abundance (Readman et al. 1993).

Other chemicals used in vessel maintenance, repair, and cleaning that can enter the water column and sediment include solvents used in degreasing agents, varnishes, and paint removers; antifreeze; and acids such as battery acid, cleaning compounds, and detergents (EPA 2001). Solvents, many of which are carcinogens, are insoluble and accumulate on the bottom. Detergents and cleaning agents accumulate at the water surface, creating a barrier to the transfer of dissolved oxygen at the air-surface interface. This results in lowered dissolved oxygen concentrations.

The air-surface microlayer is a sink and source for a range of other pollutants including chlorinated hydrocarbons, organotin compounds, petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) (Wurl and Obbard 2004). Pollutants in this layer can be enriched by up to 500 times relative to concentrations in the underlying water column. Wurl and Obbard (2004) concluded that the total concentration of PAHs in the microlayer generally increases with the size of the port and intensity of shipping traffic. Mastran et al. (1994) concluded that recreational boating was a source of PAHs during periods of high boating activity. Outboard engine pollution, particularly from two-cycle engines, can contribute to the concentrations of hydrocarbons in the water column and sediment.

The presence and effects of PAHs in sediment and aquatic organisms is well studied (Meador et al. 1995; Poston 2001; Johnson et al. 2002; Lebow et al. 2004; Stratus Consulting 2006). Polycyclic aromatic hydrocarbons can cause acute and chronic toxicity in marine organisms (Neff 1985), and can bioaccumulate in the tissue of organisms (Meador et al. 1995; Arkoosh et al. 1998). Because PAHs tend to attach to suspended particles and sediment, they can be ingested by shellfish and other bottom dwelling organisms for years (EPA 2001). Arkoosh et al. (1998) concluded that juvenile Chinook salmon bioaccumulate significant concentrations of chemical contaminants during their relatively short residence time in the estuary, primarily through exposure from their diet. Exposure to PAHs can lead to immunosuppression and increased disease susceptibility in juvenile salmon (Arkoosh et al. 1998). Effects on fish from low-level chronic exposure may increase embryo mortality or reduce growth (Heintz et al. 2000).

Debris releases

Solid waste is also a significant source of contaminants in marine and freshwater (Barnes 2005; UNEP 2005; Barnes et al. 2009; Gregory 2009), and billions of pounds of debris are dumped into the oceans each year (Milliken and Lee 1990; UNEP 2005). Commercial fishing, merchant vessel, cruise ship, and recreational boats are major contributors to marine debris because of accidental loss, routine practices of dumping waste, and illegal dumping activities. Plastics are an especially persistent form of solid waste as the longevity of plastic is estimated to be hundreds to thousands of years (Barnes et al. 2009). They tend to concentrate along coastal areas because they float on the surface and can be transported by ocean currents (Barnes 2005; UNEP 2005; Milliken and Lee 1990; Barnes et al. 2009). Entanglement in or ingestion of this debris can cause fish, marine mammals, and sea birds to become impaired or incapacitated, leading to starvation, drowning, increased vulnerability to predators, and physical wounds (UNEP 2004; Gregory 2009). Marine debris can also cause direct physical damage to habitat features through smothering or physical disturbance, and introduction of aggressive invasive species (UNEP 2005; Gregory 2009).

Vessel Abandonment and dereliction

Also considered marine debris, are the hundreds of thousands of sunken, derelict, abandoned, grounded, or wrecked vessels that can be found in US waters (Zelo et al. 2005). These vessels can cause a variety of environmental impacts, including the release of pollutants and hazardous materials, the physical destruction of habitats, and becoming sources for clandestine dumping, nutrient enrichment, and impediments to navigation (Helton 2003). The most obvious environmental threat of a derelict, abandoned, grounded, or wrecked vessel is the release of oil or other pollutants. These hazardous materials may be part of a vessel's cargo, fuel and oil related to vessel operations, or chemicals contained within the vessel's structure which may be released through decay and corrosion over time (Marshall et al. 2002; Negri et al. 2002; Turner 2010). Abandoned, derelict, and grounded vessels may physically damage, smother, or reduce the complexity of benthic habitats; increase shading effects; and create changes in wave energy and sedimentation patterns leading to increased erosion and bed scour (Precht et al. 2001; Zelo and Helton 2005; Zelo et al. 2005).

Introduction of Invasive or Nonnative Species

Industrial and commercial shipping and recreational boating are significant vectors for the introduction of non-native and invasive species. Vectors include hull and sea chest fouling, and ballast water (Ruiz et al. 2000; Clarke Murray 2012). Invasive and non-native species attached to vessel hulls and sea chests are transported between water bodies or through the release of ballast water from large commercial vessels.

Modern ships can carry 10 to 200 thousand tons of ballast water at a time and transport marine organisms across long distances and in relatively short time periods (Hofer 1998 in NMFS 2008). A 2009 International Union for Conservation of Nature report estimated that 7,000 species are carried around the world in ballast water every day and 10 billion tons of ballast water are transferred globally each year. Arrival of zebra mussels in the Great Lakes in the late 1980s focused initial attention on ballast water as a source of invasive species (Buck 2010). A key vector for zebra mussels is now via recreational boat trailers (Buck 2010; Clarke Murray 2012). Recreational vessels can act as both a primary vector and a secondary vector for the spread of invasive and non-native species (Davidson et al. 2010; Clarke Murray 2011; Clarke Murray 2012). See Section 4.2.2.18 Introduction/Spread of Invasive Alien Species for a description of the potential effects of invasive species and measures to minimize those effects.

Potential conservation measures for vessel operation

- Encourage recreational boats to be equipped with marine sanitation devices (MSDs) to prevent untreated sewage to be pumped overboard.
- Establish no discharge zones to prevent any boat sewage from entering boating waters.
- Utilize appropriate methods for containment of waste water, surface water collection, and recycling to avoid the discharge of pollution during the maintenance and operation of vessels.
- Provide and maintain appropriate storage, transfer, containment, and disposal facilities for liquid material, such as oil, harmful solvents, antifreeze, and paints, and encourage recycling of these materials.
- Dispose of wastes, both solid and liquid, produced by the operation, cleaning, maintenance, and repair of boats in a manner that prevents contamination of surface waters. Proper disposal of these materials can be encouraged through public outreach and education.
- Ensure that commercial ships have oil-spill response plans and all necessary equipment in place to improve response and recovery in the case of accidental spillage.
- Use dispersants that remove oils from the environment rather than dispersants that simply move them from the surface to the ocean bottom.
- Promote the use of oil-absorbing materials in the bilge areas of all boats with inboard engines.
- Promote the use of fuel/air separators on air vents or tank stems of inboard fuel tanks to reduce the amount of fuel and oil spilled into surface waters during fueling of boats.
- Avoid overfilling fuel tanks and provide “doughnuts” or small petroleum absorption pads to patrons to use while fueling.
- Keep engines properly maintained for efficient fuel consumption, clean exhaust, and fuel economy. Follow the manufacturer’s specifications and routinely check for engine fuel leaks.
- Avoid pumping any bilge water that is oily or has a sheen. Promote the use of materials that capture or digest oil in bilges. Examine these materials frequently and replace as necessary.
- Avoid in-the-water hull scraping or any abrasive process done underwater that could remove paint from the boat hull.
- Incorporate BMPs to prevent or minimize contamination from ship bilge waters, antifouling paints, shipboard accidents, shipyard work, maintenance dredging and disposal, and nonpoint source contaminants from upland facilities related to vessel operations and navigation.
- Promote education and signage on all vessels to encourage proper disposal of solid debris at sea.
- Avoid ballast water exchange in nearshore coastal waters. Use shore-based ballast water treatment systems and ship-board ballast treatment systems as alternatives.
- Wash recreational boats and watercraft off after use and before trailering it to other waters to avoid spreading exotic, nonnative species to uninfected waters.
- Locate mooring buoys in deep water to avoid grounding and minimize the effects of propeller wash. Use subsurface floats or other methods to prevent contact of the anchor line with the substrate.

- Minimize ship speeds on rivers to those that do not create ship wakes and drawdowns which strand fish or damage shorelines.
- Vessels should be operated at sufficiently low speeds, especially near the shoreline, to reduce wake energy, and no-wake zones should be designated near sensitive habitats.
- Avoid shallow water areas to avoid stirring bottom sediments. In coastal areas, be aware of low tides when seagrass beds, other delicate vegetation, and bottom organisms are more exposed. Restrict boater traffic in shallow-water and sensitive areas.
- Minimize additional seafloor damage when a derelict vessel has to be dragged across the seafloor to deep water by following the same ingress path. Alternatively, identify the least sensitive, operationally feasible towpath. Dismantling derelict vessels in place when stranded close to shore may cause less environmental impact than dredging or dragging a vessel across an extensive shallow habitat.
- Reduce the risk of a sudden release of the entire cargo when a submerged derelict vessel contains hazardous aqueous solutions that pose limited environmental risks, such as mild acids and bases, by allowing the release of the cargo under controlled conditions. The controlled release plan can include water-quality monitoring to validate the calculated dilution rates and plume distance assumptions. All applicable state and Federal laws and regulations regarding the release of chemicals into the water should be followed.
- Develop a contingency plan for uncontrolled releases during vessel salvage operations. The salvage plan should include a risk assessment to determine the most likely release scenarios and use the best practices of the industry.
- Schedule nonemergency salvage operations while including environmental considerations to minimize potential impacts on natural resources. Environmental considerations include periods when few sensitive species are present, avoidance of critical reproductive periods, and weather patterns that influence the trajectory of potential releases during operations.

4.2.2.30 Wastewater/Pollutant Discharge

Water quality essential to salmon and their habitat can be altered when pollutants are introduced through surface runoff, through direct discharges of pollutants into the water, when deposited pollutants are resuspended (e.g., dredging), and when flow is altered (e.g., nitrogen supersaturation at dams).

Atmospheric discharges of pollutants from power plants or industrial facilities can deposit metals, complex hydrocarbons, and synthetic chemicals into salmon EFH. These pollutants can be carried directly into salmon EFH or can settle on land and be carried into the water through rain run-off or snow-melt.

Similarly, wastewater or pollutants can be directly or indirectly discharged into ocean, estuarine, or fresh water environments. Examples of direct input of pollutants include the wastewater discharges of municipal sewage or stormwater treatment plants, power generating stations, industrial facilities (e.g., pulp mills, desalination plants, fish processing facilities), spills or seepage from oil and gas platforms, marine fueling facilities, hatcheries, boats (e.g., sewage, bilge water), the dumping of dredged materials or sewage sludge, or even from vessel maintenance, if it occurs over the water. These sources can result in the introduction of heavy metals, nutrients, hydrocarbons, synthetic compounds, organic materials, salt, warm water, disease organisms, or other pollutants into the environment.

Indirect sources of water pollution in salmon habitat results from run-off from streets, yards, construction sites, gravel or rock crushing operations, or agricultural and forestry lands. This run-off can carry oil and other hydrocarbons, lead and other heavy metals, pesticides, herbicides, sediment, nutrients, bacteria, and pathogens into salmon habitat. Water pollution can also result from the resuspension of buried contaminated sediments (e.g., from dredging operations). (See Sections 4.2.2.2 Agriculture; 4.2.2.7 Construction/Urbanization; 4.2.2.13 Dredging and Dredged Spoil Disposal; 4.2.2.15 Forestry; 4.2.2.16 Grazing; and 4.2.2.21 Mineral Mining).

The introduction of pollutants into EFH can create both lethal and sublethal habitat conditions to salmon and their prey. For example, fish kills may result from a pesticide run-off event, high water temperatures, or when algae blooms caused by excess nutrients deplete the water of oxygen.

Pollutant and water quality impacts to EFH can also have more chronic effects detrimental to fish survival. Contaminants can be assimilated into fish tissues by absorption across the gills or through bio-accumulation as a result of consuming contaminated prey. Pollutants either suspended in the water column (e.g., nitrogen, contaminants, fine sediments) or settled on the bottom (through food chain effects) can affect salmon. Many heavy metals and persistent organic compounds such as pesticides and polychlorinated biphenyls tend to adhere to solid particles. As the particles are deposited these compounds or their degradation products (which may be equally or more toxic than the parent compounds) can bioaccumulate in benthic organisms at much higher concentrations than in the surrounding waters (Oregon Territorial Sea Management Study 1987; Stein et al. 1995).

Potential conservation measures for wastewater/pollutant discharge

Numerous Federal and state programs have been established to improve and protect water quality. One of the most important programs relating to salmon EFH is the Clean Water Act's Section 319 program administered by the EPA. Under this section, states are required to submit to EPA for approval of an assessment of waters within the state that, without additional action to control nonpoint sources of pollution, cannot be expected to attain or maintain applicable water quality standards. In addition, states are to submit to EPA their management programs that identify measures to reduce pollutant loadings, including BMPs and monitoring programs. It is, therefore, critical that actions aimed at improving EFH water quality, especially in streams and rivers, are taken in concert with state agencies (e.g., Oregon Department of Environmental Quality, WDOE California Water Resources Control Board; Idaho Department of Health and Welfare) responsible for water quality management.

Some pollutant discharges are regulated through discharge permits which set effluent discharge limitations and/or specify operation procedures, performance standards, or BMPs. Additional effort to improve water quality is also being fostered by states under the guidance of the Coastal Zone Management Reauthorization Act. These efforts rely on the implementation of BMPs to control polluted run-off (EPA 1993). Although not yet a consistently applied mechanism to improve water quality, vegetated buffers along streams have been shown to be effective in providing such functions as sediment trapping, removal of nutrients and metals, moderation of water temperatures, increasing stream and channel stability and allowing recruitment of woody debris.

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by both point and nonpoint sources of pollution. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process, and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the protection and restoration of properly functioning salmon habitat. The following suggested measures are adapted from Gauvin (1997), Washington Fish and Wildlife Commission (WFWC) (1997), NMFS (1997b), The Resources Agency of California (RAC) (1997) and EPA (1993).

- Monitor water quality discharges following National Pollutant Discharge Elimination System requirements from all discharge points (including municipal stormwater systems, and desalinization plants). , and irrigation ditches).

- Apply the management measures developed for controlling pollution from run-off in coastal areas to all watersheds affecting salmon EFH.
- For those water bodies that are defined as water quality limited in salmon EFH (303(d) list), establish total maximum daily loads (TMDLs)and develop appropriate management plans to attain management goals.
- Allocate more resources to complete existing and future TMDLs established on waterbodies designated as water quality limited in salmon EFH habitat.
- Where in-stream flows are insufficient for water quality maintenance, establish conservation guidelines for water use permits, encourage the purchase or lease of water rights and the use of water to conserve or augment instream flows in accordance with state and Federal water law.
- Establish and update, as necessary, pollution prevention plans, spill control practices, and spill control equipment for the handling or transporting toxic substances in salmon EFH. Consider bonds or other damage compensation mechanisms to cover clean-up, restoration, and mitigation costs.
- Actively reduce the size of mixing zones that discharge to coastal areas and watersheds.
- Utilize biological effects thresholds, for example those recently established for dissolved copper, for transportation facilities that discharge to salmon EFH habitat.

4.2.2.31 Wetland and Floodplain Alteration

Potential adverse effects from wetland and floodplain alteration

Many river valleys in the west were once marshy and well vegetated, filled with mazes of floodplain sloughs, beaver ponds, and wetlands. Salmon evolved within these systems. Juvenile salmon, especially coho salmon, can spend large portions of their fresh water residence rearing and over-wintering in floodplain environments and riverine wetlands. Spring Chinook salmon also will spend up to a year rearing in freshwater and will rely on floodplains for refuge during flood conditions, and access to such floodplain refuge improves their overall growth and fitness (Sommer et al. 2001). Salmon survival and growth are often better in floodplain channels, oxbow lakes, and other river-adjacent waters than in mainstream systems (NRC 1996). Additionally floodplains and wetlands provide other ecosystem functions important to salmonids such as regulation of stream flow, stormwater storage and filtration, and often provide key habitat for beavers (that in turn may provide instream habitat benefits to coho salmon from their active and continual placement of wood in streams) (OCSRI 1997).

Floodplains, including side channels, and wetlands throughout the region have been converted through diking, draining, and filling to create agricultural fields, livestock pasture, areas for ports, cities, and industrial lands. Floodplains and wetlands have been further altered to improve navigation along rivers. These changes have transformed the complex river valley habitat, with many backwater areas, into a simplified drainage systems most of whose flow is confined to the mainstream (Sedell and Luchessa 1982). As a result of these alterations, these areas became less capable of absorbing flood waters and supporting salmon. Further habitat alteration often occurs as flood control projects are then undertaken. These projects include such things as water storage dams, dredging to increase channel capacity and flow conveyance, or the building of dikes and levees to prevent rivers from inundating adjacent lands.

The construction of dikes, levees, roads, and other structural development in the floodplain that confine the river have further effects on salmon habitat. These structures prevent the connections between the rivers and floodplain, and frequently prevent or reduce lateral channel movement. Historically, unconfined river reaches often provided the highest quality and most diverse freshwater and estuarine habitats available for salmonid use (see, e.g. Junk et al. 1989). Channels that are free to move across the floodplain also provide more aquatic habitat per linear river mile than confined river reaches. This natural geomorphic process of channel migration is particularly important in providing a dynamic mosaic of complex habitats. Lateral channel migration creates, modifies, and maintains a diverse assemblage of complex habitats and provides numerous beneficial functions crucial to successful salmon rearing, migration, and spawning. In part, these functions provide velocity reduction, off-channel areas, groundwater recharge, base flows, reduced summer water temperatures, floodplain access, sediment sorting and storage, large wood production and recruitment, and undercut banks.

A river confined by adjacent development and/or flood control and erosion control structures, can no longer move across the floodplain and support the natural processes that 1) maintain floodplain connectivity and fish access that provide velocity refugia for juvenile salmon during high flows; 2) reduce flow velocities that reduce streambed erosion, channel incision, and spawning redd scour; 3) create side channels and off-channel areas that shelter rearing juvenile salmon; 4) allow fine sediment deposition on the floodplain and sediment sorting in the channel that enhance the substrate suitability for spawning salmon; 5) maintain riparian vegetation patterns that provide shade, large wood, and prey items to the channel; 6) provide the recruitment of large wood and spawning gravels to the channel; 7) create conditions that support hyporheic flow pathways that provide thermal refugia during low water periods; and 8) contribute to the nutrient regime and food web that support rearing and migrating juvenile salmon in the associated mainstem river channels.

Structures that confine and deprive the river of a place to deposit sediment also transport more sediment downstream causing stream channel aggradation and estuary filling, which increases the need for future episodes of dredging. Dredging itself has a host of consequences to suitability of spawning and rearing habitat for salmonids. Additional indirect effects of development in floodplains adjacent to rivers and wetlands include the pollutant load from runoff and stormwater generated in an urbanizing environment, which discharges into these aquatic habitats.

Potential conservation measures for wetland and floodplain alteration

Following are the types of measures that can be undertaken by the action agency on a site-specific basis to conserve salmon EFH in areas that have the potential to be affected by wetland and floodplain alterations. Not all of these suggested measures are necessarily applicable to any one project or activity that may adversely affect salmon EFH. More specific or different measures based on the best and most current scientific information may be developed prior to, or during, the EFH consultation process, and communicated to the appropriate agency. The options represent a short menu of general types of conservation actions that can contribute to the protection and restoration of properly functioning salmon habitat. The following suggested measures are adapted from NMFS (1997b), Metro (1997) and Streif (1996).

In addition to applicable measures described in the estuarine alteration section, the following general measures may apply:

- Minimize alteration of floodplains and wetlands for nonwater-dependent uses in areas of salmon EFH.
- Minimize adverse effects on floodplains and wetlands from water-dependent uses.
- Wherever possible avoid floodplain development, and mitigate for unavoidable floodplain losses to existing floodplain functions and processes, including water quality, water storage capacity and lateral channel movement.
- Wherever possible complete compensation mitigation for unavoidable floodplain or wetland loss prior to conducting activities that may adversely affect floodplains or wetlands, and perform such mitigation only in areas that have been identified as having long term viability and functionality.
- Design floodplain and wetland mitigation to meet specific performance objectives for function and value, and monitor to assure achievement of these objectives. Use mitigation and enhancement ratios that are sufficient to attain a net gain in acreage as well as function and value.

- Determine cumulative effects of all past and current floodplain and wetland alterations before planning activities that further alter wetlands and floodplains.
- Promote awareness and use of the USDA's wetland and conservation reserve programs to conserve and restore wetland and floodplain habitat.
- Promote restoration of degraded floodplains and wetlands, including in part reconnecting rivers with their associated floodplains and wetlands and invasive species management.

5. ADDITIONAL INFORMATION AND RESEARCH NEEDS

The EFH regulatory guidance states that each FMP should contain recommendations for research efforts that the Councils and NMFS view as necessary to improve upon the description and identification of EFH, the identification of threats to EFH from fishing and other activities, and the development of conservation and enhancement measures for EFH. The lack of specific and comprehensive information on distribution prevented detailed delineation and fine-scale mappings of EFH in both freshwater and marine habitats. While far more research has been conducted on Pacific salmon life history and habitat requirements than most other marine fishes, significant research gaps still exist, particularly with regard to distribution and marine life history and habitat requirements. The following information and research needs were identified in Amendment 14 and/or during the 2011 EFH review process.

1. Improve fine scale mapping of salmon distribution to inform future reviews of EFH for Pacific Coast salmon and aid in a more precise and accurate designation of EFH. The lack of specific and comprehensive distribution data prevented detailed delineation and fine-scale mapping of EFH More refined EFH designations would facilitate the consultation process by clarifying which Federal actions warranted an EFH consultation and could lead to more effective Conservation Recommendations. It should be noted, however, that more detailed and precise freshwater distribution data will not eliminate the need for a watershed-based approach for recovery and protection of Pacific salmon EFH Potential approaches to address this information need include, but are not limited to:
   a. Develop freshwater distribution data at the 5^{th} or 6^{th} field HUs, across the geographic range of these species
   b. Develop habitat models that can be used to predict suitable habitat, both current and historical, across the geographic range of these species.
   c. Develop seasonal distribution data at a 1:24,000 or finer scale, particularly in freshwater.

2. Improve data on habitat conditions, including how they affect salmon survival, across the geographic range of Pacific Coast salmon to help refine EFH in future reviews and focus restoration efforts. A detailed analysis of salmon production and watershed condition throughout the Pacific Northwest is needed to determine the characteristics of productive watersheds and stream reaches for Pacific salmon. Incorporating physical variables, such as water quality, riparian vegetation, land-use, etc. into a watershed framework could help determine the potential productivity of a watershed and help to identify those in need of restoration. A better understanding of watershed productivity could inform future EFH reviews.

3. Improve data on marine distribution of Pacific Coast salmon, especially during early ocean residence, and develop models that incorporate oceanic conditions to predict marine distribution to inform revisions to EFH in future reviews. Fine scale seasonal information is needed to better understand the marine distribution of juvenile and adult Pacific salmon, which is thought to change depending upon ocean conditions. Early ocean residence is believed to be a critical period for salmon survival and better data on habitat utilization, feeding, and survival during this stage would allow a more precise description of marine EFH,

4. Improve data on the possibility of adverse effects of fishing gear on the EFH of Pacific Coast salmon. Impacts to salmon EFH from fishing gear can include removal of prey species, smothering or damage to benthic habitats utilized by salmon and their prey, removal of salmon carcasses that supply nutrients that enhance salmonid growth and survival, and derelict fishing gear effects. Although these potential effects have been identified, the extent to which they impact salmon EFH is poorly understood.

5. Advance the understanding of how a changing climate can affect Pacific Coast salmon EFH. Attempts to predict future climate conditions are based on mathematical models, and the results of these models vary substantially, making it difficult to determine what salmon habitat conditions will be like in the future. However, anticipated effects associated with climate change, including increased freshwater temperatures, changes in precipitation patterns and reduced snowpacks that can alter the seasonal hydrograph, and ocean acidification, have the potential for widespread impacts on Pacific salmon EFH. Therefore, as new information becomes available, it will be important to try to understand how climate change will affect salmon EFH, and what steps can be taken to minimize or mitigate these effects.

6. LITERATURE CITED

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

Abbott, R. and E. Bing-Sawyer. 2002. Assessment of pile driving impacts on the Sacramento blackfish (*Orthodon microlepidotus*). Draft report prepared for Caltrans District 4. San Francisco, CA: Caltrans.

Abbott, R., J. Reyff, J. and G. Marty. 2005. Final report: monitoring the effects of conventional pile driving on three species of fish. Richmond, CA: Manson Construction Company.

Able, K.W., J.P. Manderson, and A.L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: the effects of man-made structures in the lower Hudson River. Estuaries 21:731-744.

Ackerman, N.K. 2002. Effects of vessel wake stranding of juvenile salmonids in the lower Columbia River, 2002-a pilot study. S.P. Cramer & Associates, Inc., Portland, Oregon.

Adams, P. and J. Ringer. 1994. The effects of timber harvesting and forest roads on water quantity and quality in the Pacific Northwest: Summary and annotated bibliography. Oregon State University. Forest Engineering Department. Corvallis, Oregon.

Adams, S.R., T.M. Keevin, K.J. Killgore, and J.J. Hoover. 1999. Stranding potential of young fishes subjected to simulated vessel-induced drawdown. Transactions of the American Fisheries Society 128(6):1230-1234.

ADFG (Alaska Department of Fish and Game). 1983. Fish culture manual. Alaska Dept. Fish Game, Juneau.

ADFG. 1985. Genetic policy. Alaska Dept. Fish Game, Juneau.

ADFG. 1988. Regulation changes, policies and guidelines for Alaska fish and shellfish health and disease control. Alaska Dept. Fish Game, Juneau.

AFS (American Fisheries Society). 1980. Management and Protection of Western Riparian Stream Ecosystems; Position Paper. 24 p.

AHGP (Aquatic Habitat Guidelines Program). 2010. Protecting nearshore habitat and functions in Puget Sound. Prepared in association with EnviroVision and Herrera Environmental. June revision. 122p.

Allen, G.H. and W. Aron. 1958. Food of salmonid fishes of the western north Pacific Ocean. U.S. Fish Wild. Serv. Spec. Sci. Rep. Fish. 237:11.

Allen, M.A. and T.J. Hassler. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)--Chinook salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.49). U.S. Army Corps of Engineers, TR EL-82-4, 26 p.

Allen, M.J. and G.B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-66, 151 p.

Amaral M, Lee V, Rhodes J. 2005. Environmental guide for marinas: controlling nonpoint source and storm water pollution in Rhode Island: best management practices for marinas. University of Rhode Island, Rhode Island Sea Grant Publication #RIU-H-96-002, Narragansett, Rhode Island.

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

Argue, A.W. 1970. A study of factors affection exploitation of Pacific salmon in the Canadian gauntlet fishery of Juan de Fuca Strait. Fish. Serv. (Can.) Pac. Reg. Tech. Rep. 1970-11:259.

Arkoosh, M.R., E. Casillas, E. Clemons, A.N. Kagley, R. Olson, P. Reno, and J.E. Stein. 1998. Effect of pollution on fish diseases: Potential impacts on salmonid populations. Journal of Aquatic Animal Health 10:182-190.

Armour, C.L., D.A. Duff, and W. Elmore. 1994. The effects of livestock grazing on riparian and stream ecosystems, Fisheries. 16(1):7-11.

Armstrong, J.B., D.E. Schindler, K.L. Omori, C.P. Ruff, and T.P. Quinn. 2010. Thermal heterogeneity mediates the effects of pulsed subsidies across a landscape. Ecology 91(5):1445-1454.

Armstrong, J.L., J.L. Boldt, A.D. Cross, J.H. Moss, N.D. Davis, K.W. Myers, R.V. Walker, D.A Beauchamp, L.J. Haldorson. 2005. Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. Deep-sea Research II 52: 247-265.

Armstrong, J.L., K.W Myers, D.A. Beauchamp, D.D. Davis, R.V. Walker, J.L. Boldt, J.J. Piccolo, L.J. Haldorson, and J.H. Moss. 2008. Interannual and spatiqal feeding patterns of hatchery and wild juvenile pink salmon in the Gulf of Alaska in years of low and high survival. Transactions of the American Fisheries Society 137(5):1299-1316.

Aro, K.V. and M.P. Shepard. 1967. Salmon of the North Pacific Ocean--Part IV. Spawning populations of north Pacific salmon. 5. Pacific salmon in Canada. Int. North Pac. Fish. Comm. Bull. 23:225-327.

Asplund, T.R. 2000. The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Integrated Science Services. University of Wisconsin, PUBL-SS-948-00, Madison. 21 p.

Asplund, T.R. and C.M. Cook. 1997. Effects of motor boats on submerged aquatic macrophytes. Lake and Reservoir Management 13(1):1-12.

Atkinson, C.E., T.H. Rose, and T.O. Duncan. 1967. Salmon of the North Pacific Ocean. Part IV. Spawning populations of North Pacific salmon. 4. Pacific salmon in the United States. Int. North Pac. Fish. Comm. Bull. 23:43-223.

Ayers, R.J. 1955. Pink salmon caught in Necanicum River. Ore. Fish Comm. Res. Briefs 6(2):20.

Bailey, J.E., B.L. Wing, and C.R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon, *Oncorhynchus gorbuscha* and chum salmon, *Oncorhynchus keta*, in Traitors Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull. (U.S.) 73:846-861.

Baker, T.T., A.C. Wertheimer, R. Burkett, R.Dunlap, D.M. Eggers, E.L. Fritts, A.J. Gharrett, R.A. Holmes, and R.L. Wilmot. 1996. Status of Pacific salmon and steelhead escapements in Southeastern Alaska. Fisheries 21(10): 6-18.

Bakshtansky, E.L. 1980. The introduction of pink salmon into the Kola Peninsula, pp. 245-259. In: J. Thorpe, ed. Salmon ranching. Academic Press, New York, NY.

Baldwin, D.H., C.P. Tatara, N.L. Scholtz. 2011. Copper-induced olfactory toxicity in salmon and steelhead: Extrapolation across species and rearing environments. Aquatic Toxicology 101:295-297.

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

Baldwin, W.J. 1954. Underwater explosions not harmful to salmon. California Fish and Game, 40(1):77.

Bao, V.W.W., K.M.Y. Leung, G.C.S. Lui, and M.H.W. Lam. 2013. Acute and chronic toxicities of Irgarol alone and in combination with copper to the marine copepod *Tigriopus japonicus*. Chemosphere 90(3):1140-1148.

Barnard, R.J., J. Johnson, P. Brooks, K. M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P. D. Powers. 2013. Water crossings design guidelines, Washington Department of Fish and Wildlife, Olympia, Washington. Available at http://wdfw.wa.gov/hab/ahg/culverts.htm.

Barnes, D.K.A. 2005. Remote islands reveal rapid rise of southern hemisphere sea debris. The Scientific World Journal 5:915-921.

Barnes, D.K.A., F. Galani, R.C. Thompson, and M. Barlaz. 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society 364:1985-1998.

Barr, B.W. 1993. Environmental impacts of small boat navigation: vessel/sediment interactions and management implications. Pages 1756-1770 in O.T. Magoon, editor. Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management, July 19-23, American Shore and Beach Preservation Association, New Orleans, Louisiana.

Barraclough, W.E. and D.Robinson. 1972. The fertilization of Great Central Lake. III. Effect on juvenile sockeye salmon. Fish. Bull. (U.S.) 70:37-48.

Barrett, J.C., G.D. Grossman, and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distance of rainbow trout. Transactions of the American Fisheries Society 121:437-443.

Bash, J., C. Berman, and S. Bolton. 2001. Effects of turbidity and suspended solids on salmonids. Final Research Report, Research project T1803, Task 42, Seattle, Washington.

Bates, K., B. Barnard, B. Heiner, J.P. Klavas, and P.D. Powers. 2003. Design of road culverts for fish passage. Washington Department of Fish and Wildlife, Olympia, WA. 112pp.

Battin, J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences 104(16):6720-6725.

Bauersfeld, K. 1977. Effects of peaking (stranding) of Columbia River dams on juvenile anadromous fishes below The Dalles Dam, 1974 and 1975. Washington Department of Fisheries, Technical Report No. 31, Olympia, Washington.

Beacham, T.D. 1982. Fecundity of coho salmon (*Oncorhynchus kisutch*) and chum salmon (*O. keta*) in the northeast Pacific ocean. Can. J. Zool. 60:1463-1469.

Beacham, T.D. 1986. Type, quantity and size of food of Pacific salmon (*Oncorhynchus*) in the Strait of Juan de Fuca, British Columbia. Fish. Bull., U.S. 84: 77-89.

Beacham, T.D. and C.B. Murray. 1987. Adaptive variation in body size, age, morphology, egg size and developmental biology of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Sci. 44:244-261.

Beacham, T.D. and C.B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). J. Fish Biol. 42:485-508.

Beacham, T.D., R.E. Withler, C.B. Murray, and L.W. Barner. 1988. Variation in body size, morphology, egg size and biochemical genetics of pink salmon in British Columbia. Trans. Am. Fish. Soc. 117:109-126.

Beamer, E., B. Hayman, and S. Hinton. 2005. Linking watershed conditions to egg-to-fry survival of Skagit Chinook salmon, Appendix B. Skagit salmon recovery plan. Skagit River System Cooperative and Washington Dept. of Fish and Wildlife.

Beamer, E.M., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River chinook salmon: Linking estuary restoration to wild chinook salmon populations. Appendix D of Skagit Chinook Recovery. Report to Skagit River System Cooperative La Conner, WA.

Beamish, R.J., D.J. Noakes, G.A. McFarlane, W. Pinnix, R. Sweeting, and J. King. 2000. Trends in coho marine survival in relation to the regime concept. Fisheries Oceanography 9:114-119.

Beckman, B.R. and Larsen, D. A. 2005. Upstream migration of minijack (age-2) Chinook salmon in the Columbia River: Behavior, abundance, distribution, and origin. Transactions of the American Fisheries Society 134:1520-1541.

Beckman, B.R., W.T. Fairgrieve, K.A. Cooper, C.V. Mahnken, and R.J. Beamish. 2004. Evaluation of endocrine indices of growth in individual postsmolt coho salmon. Transactions of the American Fisheries Society, 133:1057-1067.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for restoration. N. Am. J. Fish. Manag. 14:797–811.

Beechie, T., E. Huhle, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. Hydrologic regime and the conservation of salmon life history diversity. Biological Conservation 130:560-572.

Beechie, T., Imaki, H., Greene., J,. Wade, A., Wu H., Pess, G., Rony, P., Kimbakk, J., Stanford, J. Kiffney, P. and N. Mantua. 2012. Restoring salmon habitat for a changing climate. River Research and Applications. (online at: http://onlinelibrary.wiley.com/doi/10.1002/rra.2590/abstract).

Beechie, T.J. and T.H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Trans. Amer. Fish. Soc. 126:217-229.

Beechie, T.J., B.D. Collins, and G.R. Pess. 2001. Holocene and recent geomorphic processes, land use and salmonid habitat in two north Puget Sound river basins. Pp. 37-54 in: J.B. Dorava, D.R. Montgomery, F. Fitzpatrick, and B. Palcsak, eds. Geomorphic processes and riverine habitat, Water Science and Application Volume 4, American Geophysical Union, Washington D.C.

Beechie, T.J., C.N. Veldhuisen, E.M. Beamer, D.E. Schuett-Hames, R.H. Conrad, and P. DeVries. 2005. Monitoring treatments to reduce sediment and hydrologic effects from roads. P. 35-66 in: P. Roni (ed.). Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, MD.

Beechie, T.J., D.A. Sear, J.D. Olden, G.R. Pess, J.M. Buffington, H. Moir, P. Roni and M.M. Pollock. 2010. Process-based principles for restoring river ecosystems. BioScience 60: 209-222.

Bellmore, J.R., C.V. Baxter, P.J. Connolly, and K. Martens. In press. The floodplain food web mosaic: a study of its importance to salmon and steelhead with implications for their recovery. Ecological applications.

Ben-David, M., T.A. Hanley, D.R. Klein, and D.M. Schell. 1997. Seasonal changes in diets of coastal and riverine mink: The role of spawning Pacific salmon. Can. J. Zool. 75:803-811.

Bennett, T.R., R.C. Wissmar, and P. Roni. 2011. Fall and spring emigration timing of juvenile coho salmon from East Twin River, Washington. Northwest Science 85(4):562-570/.

Berman, C.H. 1990. Effect of elevated holding temperatures on adult spring chinook salmon reproductive success. M.S. thesis. University of Washington, Seattle.

Berman, C.H. and T.P. Quinn. 1991. Behavioural thermoregulation and homing by spring Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. Journal of Fish Biology 39(3):301-312.

Berto, D., R.Boscolo Brusa, F. Cacciatore, S. Covellli, F. Rampozzo, O. Giovanardi, and M. Giani. 2012. Tin free antifouling paints as potential contamination source of metals in sediments and gastropods of the Southern Venice Lagoon. Continental Shelf Research 45(0):34-41.

Berwick, S. 1976. Range, forest, and wildlife ecology. The Gir Forest: An endangered ecosystem. American Society, 61 (1).

Berwick, S. 1978. Dry-gulched by policy, editorial, Op-Ed page of The New York Times, December 8.

Beschta, R L., J. Griffith, and T. Wesche. 1993. Field review of fish habitat improvement projects in central Idaho. BPA project No. 84-24; 83-359, Bonneville Power Administration, Div. of Fish and Wildlife, Portland.

Beschta, R.L. 1990. Effects of fire on water quantity and quality. Pp. 219-232 in: J.D. Walstad and S.R. Radosevich, eds. Natural and prescribed fire in Pacific Northwest forests. Oregon State University Press, Corvallis, OR.

Beschta, R.L., J.R. Boyle, C.C. Chambers, W.P. Gibson, S.V. Gregory, J. Grizzel, J.C Hagar, J.L. Li, W.C. McComb, M.L. Reiter, G.H. Taylor, and J.E. Warila. 1995. Cumulative effects of forest practices in Oregon. Oregon State University, Corvallis, Oregon. Prepared for Oregon Dept. of Forestry, Salem, OR.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Pp. 191-232 in: E.O. Salo and T.W. Cundy, eds. Streamside management: forestry and fishery interactions. University of Washington, Institute of Forest Resources, Seattle. Contribution 57.

Bhowmik, N.G. 1991. Commercial navigation in large rivers and the development of appropriate management alternatives. Hydrology for the Water Management of Large River Basins in Proceedings of the Vienna Symposium. Publication No. 201:93-102.

Bhowmik, N.G., A.C. Miller, and B.S. Payne. 1993. Techniques for studying the physical effects of commercial navigation traffic on aquatic habitats. U.S. Army Corps of Engineers Waterways Experiment Station, Technical Report EL-90-10, Vicksburg, Mississippi.

Bhowmik, N.G., M. Demissie, and C.Y. Guo. 1982. Waves generated by river traffic and wind on the Illinois and Mississippi rivers, Illinois State Water Survey, Water Resources Center Research Report No. 167, Urbana, Illinois.

Bhowmik, N.G., T.W. Soong, W.F. Reichelt, and N.M.L. Seddik. 1991. Waves generated by recreational traffic on the upper Mississippi River system. Illinois State Water Survey, Water Resources Center Research Report No. 117, Champaign, Illinois.

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. J. Forestry 82:609-613.

Bilby, R.E. and J.W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Trans. Am. Fish. 118:368-378.

Bilby, R.E. and P.A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Can. J. Fish. Aquat. Sci 49:540-551.

Bilby, R.E. and P.A. Bisson. 1998. Function and distribution of large woody debris. Pp. 324-346 in: R.J. Naiman and R.E. Bilby, eds. River ecology and management: lessons from the Pacific coastal ecoregion. Springer, New York.

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: Evidence from stable isotopes. Can. J. Fish. Aquat. Sci. 53:164-173.

Bilby, R.E., B.R. Franson, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Can. J. Fish. Aquat. Sci. 50:164-173.

Bilton, H. and W. Ricker. 1965. Supplementary checks on the scales of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*). J. Fish. Res. Board Can. 22:1477-1489.

Birtwell, I.K. 1978. Studies on the relationship between juvenile Chinook salmon and water quality in the industrialized estuary of the Somass River. Fish. Mar. Serv. (Can.) Tech. Rep. 759:58-78.

Bisson, P., G. Reeves, R. Bilby and R. Naiman. 1997. Watershed management and Pacific salmon: Desired future conditions. In: Stouder, D., P. Bission and R. Naiman, eds. Pacific Salmon and their ecosystems, status and future options. Chapman and Hall, New York.

Bisson, P.A., R.E. Bilby, M.D. Bryant, C.A. Dolloff, G.B. Grette, R.A. House, M.L. Murphy, K.V. Koski, and J.R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. Pp. 143-190 in: E.O. Salo and T.W. Cundy, eds. Streamside management: forestry and fishery interactions. University of Washington, Institute of Forest Resources, Seattle. Contribution 57.

Bisson, P.A., T.A. Quinn, G.H. Reeves, and S.V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. P. 189-232 in: R.J. Naiman, ed. Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York.

Bjorkstedt, E.P., B.C. Spence, J.C. Garza, D.G. Hankin, D. Fuller, W.E. Jones, J.J. Smith, R. Macedo. 2005. An analysis of historical population structure for evolutinarily significant units of Chinook salmon, coho salmon, and steelhead in the North-Central California Coast recovery domain. NOAA Technical Memorandum NMFS-SWFSC-382.

Bjornn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138. In: W. R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats, pp. 519-557. American Fisheries Society, Bethesda, Maryland. American Fisheries Society Special Publication 19.

Blackbourn, D. J. 1990. Comparison of size and environmental data with the marine survival rates of some wild and enhanced stocks of pink and chum salmon in British Columbia and Washington State. In: P. A. Knudsen, ed. Proceedings of the 14th northeast Pacific pink and chum salmon workshop, pp. 82-87. Wash. Dep. Fish., Olympia, Washington.

Blackmon, D., T. Wyllie-Echeverria, and D.J. Shafer. 2006. The role of seagrasses and kelps in marine fish support. Wetlands Regulatory Assistance Program ERDC TNWRAP-06-1. February 2006.

Blankenship, L. and R. Tivel. 1980. Puget Sound wild stock coho trapping and tagging, 1973-1979. Wash. Dep. Fish. Prog. Rep. 111, 62.

Blankenship, L., P. Hanratty, and R. Tivel. 1983. Puget Sound wild stock coho trapping and tagging, 1980-1982. Wash. Dep. Fish. Prog. Rep. 198, 34.

Blaxter, J.H.S. 1969. Development: Eggs and larvae. Pp. 177-252 in: W.S. Hoar, Randall, D.J., Conte, F.P., eds. Fish Physiology. New York, NY: Academic Press, Inc.

Bledsoe, L.J., D.A. Somerton, and C.M. Lynde. 1989. The Puget Sound runs of salmon: An examination of the changes in run size since 1896. Pp. 50-61 in: C.D. Levings, L.B. Holtby, and M.A. Henderson (eds.). Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks, May 6-8, 1987, Nanaimo, B.C. Can. Spec. Publ. Fish. Aquat. Sci. 105.

Boeger, W.A., M.R. Pie, A. Ostrensky, and M.F. Cardoso. 2006. The effect of exposure to seismic prospecting on coral reef fishes. Brazilian Journal of Oceanography 54, 235–239.

Boehlert, G.W. and A.B. Gill. 2010. Environmental and ecological effects of ocean renewable energy development: a current synthesis. Oceanography 23(2) 68-81.

Bollens, S.M., R.V. Hooff, M. Butler, J. R. Cordell, and B.W. Frost. 2010. Feeding ecology of juvenile Pacific salmon (*Oncorhynchus* spp.) in a northeast Pacific fjord: diet, availability of zooplankton, selectivity for prey, and potential competition for prey resources. Fishery Bulletin 108:393-407.

Bonin, H.L., R.P. Griffiths, and B.A. Caldwell. 2000. Nutrient and microbiological characteristics of fine benthos organic matter in mountain streams. J. N. Am. Benthol. Soc. 19:235-249.

Booman, C., H. Dalen, H. Heivestad, A. Levsen, T. van der Meeren, and K. Toklum, 1996. Effekter av luftkanonskyting pa egg, larver og ynell. Undersekelser ved Hauforskningstituttet ogtoclgisk Laboratorium, Universitet; Bergen. Fisken og Havet, 3.

Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55(1-4):3-23.

Botkin, D, K. Cummins, T. Dunne, H. Reiger, M. Sobel, L. Talbot, and L. Simpson. 1995. Status and future of salmon of western Oregon and northern California: Findings and options. Center for the Study of the Environment, Report 8, Santa Barbara, California.

Bottom, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal and Shelf Science 64: 79-93.

Bouwmeester, J., E.J. van de Kaa, H.A. Nuhoff, and R.G.J. van Orden. 1977. Various aspects of navigation in restricted waterways. Pages 139-158 in Proceedings of the 24th International Navigation Congress. Permanent International Association of Navigation Congresses, Section 1, Subject 3, Leningrad, Russia.

Boyd, Steve. 1994. Memo to Joe Miyamoto, East Bay Municipal District. Striped bass predation in the Woodbridge Dam afterbay. Oakland, California.

Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52:1327-1338.

Bradford, M.J., R.A. Myers, and J R. Irvine. 2000. Reference points for coho salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences 57: 677-686.

Brady, N.C., R.R. Weil. 1996. The nature and properties of soils. Upper Saddle River, NJ: Prentice Hall. xi, 740 p.

Brakensiek, K.E. and D.G. Hankin. 2007. Estimating overwinter survival of juvenile coho salmon in a northern California stream: accounting for effects of passive integrated transponder tagging mortality and size-dependent survival. Transactions of the American Fisheries Society 136:1423–1437.

Brazier, J.R. and G.W. Brown. 1973. Buffer strips for stream temperature control. Research Paper 15. Forest Research Laboratory, Oregon State University. 9 p.

Brennan, J.S., K.F. Higgins, J.R. Cordell, and V.A. Stamatiou. 2004. Juvenile salmon composition, timing, distribution, and diet in marine nearshore waters of Central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, WA. 164 pp.

Brett, J.R. 1952. Skeena River sockeye escapement and distribution. J. Fish. Res. Board Can. 8:453-468.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. Calif. Dep. Fish Game Fish. Bull. 94:62.

Brodeur, R.D. 1991. Ontogenic variations in the type and size of prey consumed by juvenile coho, *Oncorhynchus kisutch*, and Chinook, *O. tshawytscha*, salmon. Environmental Biology of Fishes 30:303-315.

Brodeur, R.D., E.A. Daly, R.A. Schabetsberger, and K.L. Mier. 2007. Interannual and interdecadal variability in juvenile coho salmon (*Oncorhynchus kisutch*) diets in relation to environmental change in the northern California current. Fisheries Oceanography 16: 395-408.

Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin. 1997. Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. Ecological Applications 7:1188-1200.

Brown, G.W. 1970. Predicting the effect of clearcutting on stream temperature. Journal of Soil and Water Conservation 25:11-13.

Brown, G.W. and J.T. Krygier. 1970. Effects of clearcutting on stream temperature. Water Resources Research 6:1133 1139.

Brown, L. R. and P. B. Moyle. 1991. Status of coho salmon in California. Report to the National Marine Fisheries Service, pp. 114.

Brown, L.R., P.B. Moyle, and R.M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. N. Am. J. Fish. Manage. 14:237-261.

Brown, R.A. and E.V. Theusen, 2011. Biodiversity of mobile benthic fauna in geoduck (*Panopea generosa*) aquaculture beds in southern Puget Sound, Washington. Journal of Shellfish Research, 30:771-776.

Brown, T.C. and D. Binkley. 1994. Effect of management on water quality in North American forests. General Technical Report RM-248. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 27 p.

Brown, T.G. and G.F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117: 546-551.

Bryant, G.J. 1994. Status review of coho salmon in Scott Creek and Waddell Creek, Santa Cruz County, California. Natl. Mar. Fish. Serv., SW Region, Protected Species Management Division, p.102. (Available from NFMS, Southwest Region, 501 Ocean Blvd., Suite 4200, Long Beach, California, 90802).

Bryant, L.D. 1985. Livestock management in the riparian ecosystem. Pp. 285-289 in: R. R. Johnson, C. D. Ziebell, and D.R. Patton eds. Riparian ecosystems and their management: reconciling conflicting uses. Proc. 1 No. Amer. Riparian Conf. Tucson, AZ. USDA Forest Service Rocky Mountain Forest and Range Expt. Sta. Gen. Tech. Rep. RM-120. Ft. Collins, Colorado.

Buck, E.H. 2010. Ballast water management to combat invasive species. Congressional Research Service Report for Congress, Paper 25.

Buckley, R.M. 1969. Analysis of the Puget Sound sport fishery for resident coho salmon, *Oncorhynchus kisutch*, (Walbaum). M.S. thesis. University of Washington, Seattle, WA. 73. p.

Buffington, J.M. and D.R. Montgomery. 1999. Effects of hydraulic roughness on surface texture of gravel-bed rivers. Water Resour. Res. 35:3507-3521.

Buhle, E.R., K.K. Holsman, M.D. Scheuerell, and A. Albaugh. 2009. Using an unplanned experiment to evaluate the effects of hatcheries and environmental variation on threatened populations of wild salmon. Biological Conservation 142:2449-2455.

Bullard, S.G, G. Lambert, M.R. Carman, J. Byrnes, R.B. Whitlatch, G. Ruiz, R.J. Miller, L. Harris, P.C. Valentine, J.S. Collie, J. Pederson, D.C. Mcnaught, A. Cohen, G. Asch, J. Dijkstra, and K. Heinonen. 2007. The colonial ascidian *Didemnum* sp A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. J Exp Mar Biol Ecol 342: 99-108.

Bulleri, F. and M.G. Chapman. 2010. The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology 47: 26-53.

Burchsted, D., M. Daniels, R. Thorson and J. Vokoun. 2010. The river discontinuum: Applying beaver modifications to baseline conditions for restoration of forested headwaters. BioScience 60: 908-.

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

Burger, C.V., R.L. Wilmot, and D.B. Wangaard. 1985. Comparison of spawning areas and times for two runs of Chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai River, Alaska. Can. J. Fish. Aquat. Sci. 42:693-700.

Burgner, R.L. 1980. Some features of ocean migration and timing of Pacific salmon. Pp. 153-164 in: W.J. McNeil and D.C. Himsworth (eds.). Salmonid ecosystems of the north Pacific. Oregon State University Press, Corvallis, Oregon.

Burke, B.J., W.T. Peterson, B.R. Beckman, C.A. Morgan, E.A. Daly, M. Litz. 2012. Multivariate Models of Adult Pacific Salmon Returns. PLoS ONE, 8(1):e54134. doi:10.1371/journal.pone.0054134.

Burke, J.L. 2004. Life histories of Columbia River juvenile Chinook salmon, 1914 to the present. M. S. thesis. Oregon State University, Corvallis.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. Fish. Bull., U.S. 52:95-110.

Burnett, K.M., G.H. Reeves, D.J. Miller, S. Clarke, K. Vance-Borland and K. Christiansen. 2007. Distribution of salmon habitat potential relative to landscape characteristics and implications for conservation. Ecological Applications 17: 66-80.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Bd. Can. 32:667-680.

Calfish (2012). Coho distribution. California Department of Fish and Game, June 2012. Calfish.org 2013 URL:<ftp://ftp.dfg.ca.gov/BDB/GIS/BIOS/Public_Datasets>

Caltrans (California Department of Transportation). 2001. Pile installation demonstration project, fisheries impact assessment. PIDP EA 012081. San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Caltrans Contract 04A0148 San Francisco, CA: Caltrans.

Caltrans. 2010a. Mad River bridges replacement project: Effects of pile driving sound on juvenile steelhead. March 24, 2010. Prepared by ICF Jones &Stokes, Seattle, WA.

Caltrans. 2010b. Necropsy and histopathology of steelhead trout exposed to steel pile driving at the Mad River bridges, U.S. Highway 101, July 2009. Prepared by G. D. Marty, DVM, Ph.D., Fish Pathology Services, Abbotsford, British Columbia, Canada.

Campell, P.M. and R.H. Devlin. 1997. Increased CYP1A1 ribosomal protein L5 gene expression: The response of juvenile Chinook salmon to coal dust exposure. Department of Fisheries and Oceans, Vancouver, Canada.

Carlton, J.T. 1999. Molluscan invasions in marine and estuarine communities. Malacologia 41: 439-454.

Carrasquero, J. 2001. Overwater structures: Freshwater issues. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation. Olympia, Washington.

Carter, L., D. Burnett, S. Drew, G. Marle, L. Hagadorn, D. Bartlett-McNeil, and N. Irvine. 2009. Submarine cables and the oceans-connecting the world. The United Nations Environment Programme World Conservation Monitoring Centre (UNEP_WCMC) Biodiversity Series No. 31. 64p.

Carter, M.M., D.E. Shoup, J.M. Dettmers, and D.H. Wahl. 2010. Effects of turbidity and cover on prey selectivity of adult smallmouth bass, Transactions of the American Fisheries Society 139(2):353-361.

Casper, B.M., A.N. Popper, F. Matthews, T.J. Carlson, and M.B. Halvorsen. 2012 Recovery of barotrauma injuries in Chinook salmon, *Oncorhynchus tshawytscha* from exposure to pile driving sound. PLoS ONE 7(6): e39593. doi:10.1371/journal.pone.0039593.

Castro, J. 2003. Geomorphologic impacts of culvert replacement and removal: avoiding channel incision. Portland, OR: U.S. Fish and Wildlife Service - Oregon Fish and Wildlife Office.

CEC (California Energy Commission). 2005. Issues and Environmental Impacts Associated with Once-Through Cooling at California's Coastal Power Plants. Staff Report in support of the 2005 Environmental Performance Report and 2005 Integrated Energy Policy Report.

Cederholm, C.J. and N.P. Peterson. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Can. J. Fish. Aquat. Sci. 42:1222-1225.

Cederholm, C.J. and W.J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pp. 98-110 in: E. L. Brannon and E. O. Salo, eds. Proceedings of the salmon and trout migratory behavior symposium. Univ. Wash. School Fish. Seattle, Washington.

Cederholm, C.J., D.B. Houston, D.L. Cole, and W.J. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Can. J. Fish. Aquat. Sci. 46:1347-1355.

Chamberlin, J.W., T.E. Essington, J.W. Ferfuson, and T.P. Quinn. 2013. The influence of hatchery rearing practices on salmon migratory behavior: Is the tendency of Chinook salmon to remain within Puget Sound affected by size and date of release? Transactions of the American Fisheries Society 140(5):1398-1408.

Chamberlin, T.W., R.D. Harr and F.H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. P. 181-205 in: W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publ. 19.

Chambers, P. A. 1987. Nearshore occurrence of submersed aquatic macrophytes in relation to wave action. Canadian Journal of Fisheries and Aquatic Sciences 44(9):1666-1669.

Chan, S.S., D. Larson, and P.D. Anderson. 2004. Microclimate patterns associated with density management and riparian buffers. An interim report on the riparian buffer component of the density management studies. USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR.

Chaney, E. and W. Elmore, and W. Platts. 1993. Livestock grazing on western riparian areas. Produced for the U.S. Environmental Protection Agency by the Northwest Resource Information Center, Eagle Idaho, 45.

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. J. Fish. Res. Board Can. 19:1047-1080.

Chapman, D.W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Am. Fish. Soc. 94(1):40-52.

Chapman, D.W. and E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. Transactions of the American Fisheries Society 109: 357-363.

Chapman, W.M. 1943. The spawning of Chinook salmon in the mainstem Columbia River. Copeia 1943:168-170.

Chestnut, T.J. 2002. A review of closed bottom stream crossing structures (culverts) in fish-bearing streams in the Kamloops Forest District, June 2001. Canadian Manuscript Report of Fisheries and Aquatic Science 2602.

Childs,A.B. 2003. CTUIR Grande Ronde subbasin restoration project annual report, 2002-2003. Confederated Tribes of the Umatilla Indian Reservation, Mission, Oregon. Report submitted to Bonneville Power Administration, Project No.199608300.

Clarke Murray, C., E.A. Pakhomov, and T.W. Therriault. 2011. Recreational boating: A large unregulated vector transporting marine invasive species. Diversity and Distributions 17(6):1161-1172.

Clarke Murray, C.L. 2012. The role of recreational boating in the introduction and spread of marine invasive species. Doctor of Philosophy Thesis, University of British Columbia, Vancouver, Canada.

Clary, W.P. and B.F. Webster. 1989. Managing grazing of riparian areas in the Intermountain Region. General Technical Report INT-263, U.S. Dept. of Agriculture, USFS, Intermountain Research Station, Ogden, Utah. 11p.

Cleaver, F.C. 1969. Effects of ocean fishing on the 1961-brood fall Chinook salmon from Columbia River hatcheries. Res. Rep. Fish. Comm. Ore., 1:76.

Cluer, B. and C. Thorne. 2013. A stream ecosystem model integrating habitat and ecosystem benefits. River Research and Applications Online.

COE (U.S. Army Corps of Engineers). 2012a. The U.S. waterway system transportation facts and information. Navigation and Civil Works Decision Support Center.

Coe, H.J., P.M. Kiffney, G.R. Pess, K.K. Kloehn, and M.L. McHenry. 2009. Periphyton and invertebrate response to wood placement in large pacific coastal rivers. River Research and Applications. DOI: 10.1002/rra.1201.

COE. 2012b. U.S. port and inland waterways modernization: Preparing for post-Panamax vessels. Institute for Water Resources.

Cohen, A. 1997. The invasion of the estuaries. In: Second international spartina conference proceedings 1997. Kim Patten, ed. Washington State University, Long Beach, Washington. Document available: http://www.willapabay.org/~coastal.

Cohen, A.N., D.R. Calder, J.T. Carlton, J.W. Chapman, L.H. Harris, T. Kitayama, C.C. Lambert, C. Piotrowski, M. Shouse, and L.A. Solorzano. 2005. Rapid assessment shore survey for exotic species in San Francisco Bay-May 2004. Final Report for the California State Coastal Conservancy, Association of Bay Area Governments/San Francisco Bay-Delta Science Consortium, National Geographic Society and Rose Foundation. San Francisco Estuary Institute, Oakland, CA.

Collen, P. and R.J. Gibson. 2000. The general ecology of beavers (Castor spp.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish - a review. Reviews in Fish Biology and Fisheries 10: 439-461.

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

Collins, B.D., D.R. Montgomery, A.J. Sheikh. 2003. Reconstructing the historic riverine landscape of the Puget Lowland. Pp. 79-128 in: S. Bolton, Montgomery, D.R., Booth, D., eds. Restoration of Puget Sound Rivers. Seattle, WA: University of Washington Press.

Collins, K.J., A.C. Jensen, A.P.M. Lockwood, S.J. Lockwood. 1994. Coastal structures, waste materials and fishery enhancement. Bulletin of Marine Science 55(2-3):1240-1250.

Compton, J.E., C.P. Andersen, D.L. Phillips, J.R. Brooks, M.G. Johnson, M.R. Church, W.E. Hogsett, M.A. Cairns, P.T. Rygiewicz, B.C. McComb, and C.D. Shaff. 2006. Ecological and water quality consequences of nutrient addition for salmon restoration in the Pacific Northwest. Front. Ecol. Environ. 4(1):18-26.

Congleton, J.L., S.K. Davis, and S.R. Foley. 1981. Distribution, abundance, and outmigration timing of chum and Chinook fry in the Skagit salt marsh. Pp. 153-163 in: E.L. Brannon and E.O. Salo, eds. Proceedings of the salmon and trout migratory behavior symposium. School of Fisheries, University of Washington, Seattle, Washington.

Cook, C. 1985. Tourist boats erode banks of the Gordon River. Australian Ranger Bulletin 3:26-27.

Cooper, A.C. 1977. Evaluation of the production of sockeye and pink salmon at spawning and incubation channels in the Fraser River system. Int. Pac. Salmon Fish. Comm. Prog. Rep. 36:80.

Cope, O.B. (ed.). 1979. Proceedings of the forum - grazing and riparian/stream ecosystems. Trout Unlimited. 94 p.

Coronado-Hernandez, M.C. 1995. Spatial and temporal factors affecting survival of hatchery-reared Chinook, coho, and steelhead in the Pacific Northwest. Ph. D. Dissertation, Univ. Washington, Seattle, 235.

Cover, M.R., C.L. May, W.E. Dietrich, and V.H. Resh. 2008. Quantitative linkages among sediment supply, streambed fine sediment, and benthic macroinvertebrates in northern California streams. J. N. Am. Benthol. Soc. 27:135-149.

Cowardin, L.M., V. Carter, F.C. Golet, E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm (Version 04DEC98).

Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. North American Journal of Fisheries Management 13: 96-102.

Croke, J.C. and P.B. Hairsine. 2006. Sediment delivery in managed forests: a review. Environ. Rev. 14:59-87.

Crone, R.A. and C.E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeastern Alaska. Fish. Bull., U.S., 74(4):897-923.

Cummins, K.W. and G.L. Sprengler. 1974. Stream ecosystems. Water Spectrum. 10:1-9.

Dahl, T.E. 2011. Status and trends of wetlands in the conterminous United States 2004 to 2009. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C.

Daly, E.A., R.D. Brodeur, and L.A. Weitkamp. 2009. Ontogenic shifts in diets of juvenile and subadult coho and Chinook salmon in coastal marine waters: Important for marine survival? Transaction of the American Fisheries Society 138: 1420-1438.

Danehy, R.J., S.S. Chan, G.T. Lester, R.B. Langshaw, and R.B. Turner. 2007. Periphyton and macroinvertebrate assemblage structure in headwaters bordered by mature, thinned, and clearcut Douglas-fir stands. For. Sci. 53:294-307.

Darby, S.E. and A. Simon, Eds. 1999. Incised River Channels, John Wiley and Sons. Chichester.

Dauble, D. 1994. Influence of water practices on fisheries resources in the Yakima River basin. Northwest Science 68:121. Conference information for the 67th annual meeting of the Northwest Scientific Association, Ellensburg, Washington.

Davidson, F.A. 1934. The homing instinct and age at maturity of pink salmon (*Oncorhynchus gorbuscha*). Bull. Bur. Fish. (U.S.) 48:27-29.

Davidson, I., G. Ashton, G. Ruiz, and C. Scianni. 2010. Biofouling as a vector of marine organisms on the US West Coast: A preliminary evaluation of barges and cruise ships. Final Report by the Aquatic Bioinvasion Research and Policy Institute to the California State Lands Commission.

Davis, J.W. 1982. Livestock vs. riparian habitat management - there are solutions. Pp. 175-184. In: Wildlife-livestock relationships symposium: Proc. 10 Univ. Of Idaho Forest, Wildlife, and Range Expt. Sta., Moscow.

Dawley, E.M., R.D. Ledgerwood, T.H. Blahm, C.W. Sims, J.T. Durkin, R.A. Kirn, A.E. Rankis, G.E. Monan, and F.J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. Final Rep. to Bonneville Power Admin., Contract DE-A179-84BP39652, 256.

Day, J.W, C.A.S. Hall, W. M. Kemp, and A. Yanez-Arancibia. 1989. Estuarine Ecology. John Wiley and Sons, New York, 558.

Dethier, M. N. 1990. A marine and estuarine habitat classification system for Washington State. Washington Natural Heritage Program, Department of Natural Resources, Olympia, Washington.

Dethier, M.N. 2006. Native shellfish in nearshore ecosystems of Washington State. Puget Sound Nearshore Partnership Report No. 2006-04, Seattle, Washington.

Dorava, J.M. 1999. Effectiveness of Streambank-Stabilization Techniques along the Kenai River, Alaska. USGS Water-Resources Investigations Report 99-4156. 27 p.

Doyle, R.D. 1999. Effects of waves on the early growth of *Vallisneria americana*. U.S. Army Corps of Engineers Waterways Experiment Station, ENV Report 12, Vicksburg, Mississippi.

Doyle, R.D. 2001. Effects of waves on the early growth of *Vallisneria americana*. Freshwater Biology 46:389-397.

Drucker, B. 1972. Some life history characteristics of coho salmon of Karluk River system, Kodiak Island, Alaska. Fish. Bull. (U.S.) 70:79-94.

Duff, D. 1983. Livestock grazing impacts on aquatic habitat in Big Creek, Utah, pp. 129-142 in Menke 1983. Proceedings, workshop on livestock and wildlife-fisheries relationships in the great basin. University of California. Ag. Sci. Spec. Publ, 3301, Berkley.

Duffy, E.J. and D.A. Beauchamp. 2008. Seasonal patterns of predation on juvenile Pacific salmon by anadromous cutthroat trout in Puget Sound. Transactions of the American Fisheries Society 137:165-181.

Duffy, E.J., D.A. Beauchamp, R.M. Sweeting, R.J. Beamish, and J.S. Brennan. 2010. Ontogenetic diet shifts of juvenile Chinook salmon in nearshore and offshore habitats of Puget Sound. Transactions of the American Fisheries Society 139:803-823.

Duffy-Anderson, J.T. and K.W. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a study across a pier edge. Marine Biology 133:409-418. (http://link.springer.de/link/service/journals/00227/index.htm)Glasby 1999a.

Dugan, J.E., D.M. Hubbard, D.L. Martin, J.M. Engle, D.M. Richards, G.E. Davis, K.D. Lafferty, R.F. Ambrose. 2000. Macrofauna communities of exposed sandy beaches on the Southern California mainland and Channel Islands. Pp. 339-346 in: D.R. Brown, Mitchell, K.L., Chang, H.W., eds. Proceedings of the Fifth California Islands Symposium. Minerals Management Service Publication #99-0038.

Duke (Duke Energy South Bay, LLC). 2004. Duke Energy South Bay Power Plant - SBPP cooling water system effects on San Diego Bay Volume I: Compliance with Section 316(a) of the Clean Water Act for the South Bay Power Plant. Duke Energy South Bay, LLC, Chula Vista.

Dumbauld, B.R., J.L. Ruesink, and S.S. Rumrill. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam culture in West Coast (USA) estuaries. Aquaculture 290:196-223.

Dunford, W.E. 1975. Space and food utilization by salmonids in marsh habitats of the Fraser River estuary. M. Sc. thesis, Univ. British Columbia, Vancouver, 81p.

Dunham, J., J. Lockwood, and C. Mebane. 2001. Salmonid distribution and temperature. Issue Paper 2. Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA 910 D 01 002. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. 22 p.

Dvinin, P.A. 1952. The salmon of south Sakhalin. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 37:69-108 (Transl. From Russian; Fish. Res. Board Can. Transl. Ser. 120).

Ebersole, J.L., M.E. Colvin, P.J. Wigington, S.G. Leibowitz, J.P. Baker, M.R. Church, J.A. Compton, B.A. Miller, M.A. Cairns, B. P. Hansen, and H.R. Lavigne. 2009. Modeling stream network-scale variation in coho salmon overwinter survival and smolt size. Transactions of the American Fisheries Society 138:564–580.

Ebersole, J.L., P.J. Wigington, J.P. Baker, M.A. Cairns, M.R. Church, B.P. Hansen, B.A. Miller, H.R. LaVigne, J.E. Compton, and S.G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transactions of the American Fisheries Society 135(6): 1681–1697.

Ehinger, W., T. Quinn, G. Volkhardt, M. McHenry, E. Beamer, P. Roni, C. Greene, and R. Bilby. 2007. Study plan for the intensively monitored watershed program: Skagit River estuary complex. Intensively Monitored Watersheds Scientific Oversight Committee.

Eisler, R. 1998. Copper hazards to fish, wildlife, and invertebrates: A synoptic review. U.S. Geological Survey, Biological Science Report USGS/BRD/BSR-1997-0002, Contaminant Hazard Reviews Report No. 33, Laurel, Maryland.

Ellis, C.H. and R.E. Noble. 1959. Even year-odd year pink salmon. Wash. Dep. Fish. Annu. Rep. 69, 1959, 36-29.

Ellis, R.J. 1969. Return and behavior of adults of the first filial generation of transplanted pink salmon and survival of their progeny, Sashin Creek, Baranof Island, Alaska. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 589:13.

Emmett, R.L., G.K. Kruzikowsky, and P. Bentley. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: relationship to oceanographic conditions, forage fish, and juvenile salmonids. Progress in Oceanography 68: 1-26.

Engås, A. and S. Løkkeborg. 2002. Effects of seismic shooting and vessel-generated noise on fish behaviour and catch rates. Bioacoustics 12:313–315.

Engås, A., S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Canadian Journal of Fisheries and Aquatic Science 53:2238–2249.

Enger, P.S., H.E. Karlsen, F.R. Knudsen, and O. Sand. 1997. Detection and reaction of fish to infrasound. ICES Marine Science Symposium 196:108-112.

EPA (Environmental Protection Agency). 1985. Coastal marinas assessment handbook. EPA 904/6-85-132, Atlanta, Georgia.

EPA (Environmental Protection Agency). 1996. Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES) for Section 402 modifications of Section 404 permits for Log Transfer Facilities which received a Section 404 permit prior to October 22, 1985. NPDES Permit Number AK-G70-1000. EPA Response to Comments from September 1996 Public Notice. (http://info.dec.state.ak.us/DECPermit/water31rtc.pdf).

EPA and MA (Maritime Administration). 2006. National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs. EPA842-B-06-002.

EPA. 1993. Guidance specifying management measures for sources of non-point pollution in coastal waters. Office of Water. Washington, D.C. 840-B-92-002.

EPA. 1996. Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES) for Section 402 modifications of Section 404 permits for log transfer facilities which received a Section 404 permit prior to October 22, 1985. NPDES Permit Number AK-G70-1000. EPA Region 10 Response to Comments from September 1996 Public Notice.

EPA. 2000. Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES) for Section 402 modifications of Section 404 permits for Log Transfer Facilities which received a Section 404 permit prior to October 22, 1985. NPDES Permit Number AK-G70-0000. (http://www.state.ak.us/dec/dawq/waterpermits/pdf/gpnew.pdf.

EPA. 2001. National management measures guidance to control nonpoint source pollution from marinas and recreational boating. EPA 841-B-01-005, Washington DC.

EPA. 2007. Aquatic life ambient freshwater quality criteria – copper. CAS Registry Number 7440-50-8, Washington, DC.

EPRI (Electric Power Research Institute). 2007. Assessment of cooling water intake structure impacts to California coastal fisheries. EPRI, Palo Alto, CA.

Eriksson, B.K., A. Sandström, M. Isæus, H. Schreiber, and P. Karås. 2004. Effects of boating activities on aquatic vegetation in the Stockholm Archipelago, Baltic Sea. Estuarine, Coastal and Shelf Science 61(2):339-349.

Ettlinger, E., M. Horwitz, B. Schleifer, and G.M. Andrew. 2012. Lagunita Creek salmon spawner survey report 2011-2012. Prepared for the Marin Municipal Water District. Corte Madera, CA. November 2012. 25 p.

Evans, A.F., N.J. Hostetter, D.D. Roby, K. Collis, D. E. Lyons, B.P. Sandford, R.D. Ledgerwood, and S. Sebring. 2012. System wide evaluation of avian predation on juvenile salmonids from the Columbia

River based on recoveries of passive integrated transponder tags. Transactions of the American Fisheries Society 141:975-989.

Everest, F.H. and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile Chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Can. 29:91-100.

Falco, J. 1992. Preserving coastal water quality. In: Stemming the tide of coastal fish habitat loss, proceedings of a symposium on conservation of coastal fish habitat, Baltimore, March 1991. National Coalition for Marine Conservation, Savannah, Georgia.

Faulkner, H., V. Edmonds-Brown, and A. Green. 2000. Problems of quality designation in diffusely populated urban streams- the case of Pymme's Brook, North London. Environmental Pollution 109: 91–107.

Federal Interagency Working Group. 2006. Sediment removal from active stream channels in Oregon: Considerations for Federal Agencies for the Evaluation of Sediment Removal Actions from Oregon Streams. USFWS. March 1, 2006.

Feist, B.E., J.J. Anderson, and R. Miyamoto. 1992. Potential impacts of pile driving on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon behavior and distribution. Fisheries Research Institute, School of Fisheries, University of Washington, Seattle, WA.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management; and ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team. U.S. Government Printing Office 1993-793-071. U.S. Government Printing Office for the U.S.D.A. Forest Service; U.S. Department of Interior, Fish and Wildlife Service, Bureau of Land Management, and National Park Service; U.S. Department of Commerce, National Oceanic and Atmospheric Administration and National Marine Fisheries Service; and the U.S. Environmental Protection Agency.

FERC. 2010. Biological assessment and essential fish habitat assessment for the Oregon LNG terminal and pipeline project. October, 2010. Office of Energy Projects, Washington, DC. Hightower et al. 2004.

Ferguson, J.A., J. Romer, J.C. Sifneos, L. Madsen, C.B. Schreck, M. Glynn, and M.C. Kent. 2012. Impacts of multispecies parasitism on juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon. Aquaculture 362-363: 184-192.

Fewtrell, J.L. and R.D. McCauley. 2011. Impact of air gun noise on the behaviour of marine fish and squid. Marine Pollution Bulletin 62:984-993.

FHWG (Fisheries Hydroacoustic Working Group). 2008. Agreement in principle for interim criteria for injury to fish from pile driving activities. Memorandum, June 12, 2008.

Fiscus, C.H. 1980. Marine mammal-salmonid interactions: A review. Pp. 121-132 in: W.J. McNeil and D.C. Himsworth eds. Salmonid ecosystems of the north Pacific. Oregon State University Press, Corvallis, Oregon.

Fisher, J.P. 2004. An overview of international initiatives, treaties, agreements and management actions addressing alien invasive species. In: M. Phillips, P. Bueno, J. Fisher and M. Reantaso (eds.), "Building capacity to combat impacts of aquatic invasive alien species and associated transboundary pathogens in ASEAN countries, July 12-16, Penang, Malaysia." Bangkok, Network of Aquaculture Centres of Asia.

Fisher, J.P. and W.G. Pearcy. 1995. Distribution, migration, and growth of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, off Oregon and Washington. Fish. Bull. 93: 274-289.

Fisher, J.P., W.C. Pearcy, and A.W. Chung. 1983. Studies of juvenile salmonids off the Oregon and Washington coast, 1982. Oregon State University, College of Oceanography. Cruise report 83-2:41.

Fisher, J.P., W.C. Pearcy, and A.W. Chung. 1984. Studies of juvenile salmonids off the Oregon and Washington coast, 1983. Oregon State University, College of Oceanography. Cruise report 83-2; Oregon State University, Sea grant Coll. Program ORESU-T-85-004:29.

Flagg, T.A., F.W. Waknitz, D.J. Maynard, G.B. Milner, and C.V. Mahnken. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. Am. Fish. Soc. Symp. 15:366-375.

Flagg, T.A., F.W. Waknitz, D.J. Maynard, G.B. Milner, and C.V. Mahnken. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. Am. Fish. Soc. Symp. 15:366-375.

Flanders, L.S. and J. Cariello. 2000. Tongass road condition survey report. Technical Report 00-7. Douglas, AK: Alaska Department of Fish and Game, Southeast Regional Office of the Habitat and Restoration Division.

Fleming, I.A. and M.R. Gross. 1990. Latitudinal clines: Trade-off between egg number and size in Pacific salmon. Ecology 71(1):1-11.

Fleuret, J.M. 2006. Examining effectiveness of Oregon's forest practice rules for maintaining warm-season maximum stream temperature patterns in the Oregon Coast Range. M.S. thesis. Oregon State University, Corvallis, OR.

Foerster, R.E. and W.E. Ricker. 1953. The coho salmon of Cultus Lake and Sweltzer Creek. J. Fish. Res. Board Can. 10(6):293-319.

Ford, J.K.B. and G.M. Ellis. 2006. Selective foraging by fish-eating killer whales (*Orcinus orca*) in British Columbia. Marine Ecology Progress Series 316: 185–199.

Foster, M. 2005. An assessment of the studies used to detect impacts to marine environments by California's coastal power plants using once-through cooling: A plant by plant review. Prepared for the California Energy Commission.

Foster, M.S. and D.R. Schiel. 1985. The ecology of giant kelp forests in California: A community profile, U. S. Fish Wildlife Service Biological Report 85(7.2).

Franco, J.; Schad, S.; Cady, W.C. 1994. California's experience with a voluntary approach to reducing nitrate contamination of groundwater: the Fertilizer Research and Education Program (FREP). Journal of Soil and Water Conservation. v. 49(2,suppl.) p. 76-81.

Fraser, F.J., E.A. Perry, and D.T. Lightly. 1983. Big Qualicum River salmon development project. Can. Tech. Rep. Fish. Aquat. Sci., 1189:198.

Frechette, D., A.K. Osterback, S.A. Hayes, M.H. Bond, J.W. Moore, S.A. Shaffer, and J.T. Harvey. 2012.

Assessing avian predation on juvenile salmonids using passive integrated transponder tag recoveries and mark-recapture methods. North American Journal of Fisheries Management 32: 1237-1250.

French, R.R., R.G. Bakkala, and D.F. Sutherland. 1975. Ocean distribution of stocks of Pacific salmon *Oncorhynchus* spp. and steelhead trout, *Salmo gairdnerii*, as shown by tagging experiments. U.S. Dep. Commer., NOAA Tech. Rep NMFS SSRF-689, 89.

Frenkel, R.E. and J.E. Morlan. 1991. Can we restore our salt marshes? Lessons from the Salmon River, Oregon. Northwest Environmental Journal. 7: 119-135.

Fresh K., M. Dethier, C. Simenstad, M. Logsdon, H. Shipman, C. Tanner, T. Leschine, T. Mumford, G. Gelfenbaum, R. Shuman, and J. Newton. 2011. Implications of observed anthropogenic changes to the nearshore ecosystems in Puget Sound. Prepared for the Puget Sound Nearshore Ecosystem Restoration Project. Technical Report 2011-03, Seattle, Washington.

Fresh, K. 1997. The role of competition and predation in the decline of Pacific salmon and steelhead. In: Stouder, D., P. Bisson, and R. Naiman eds. Pacific salmon and their ecosystems: Status and future options. Chapman and Hall. New York.

Fresh, K.L. 2006. Juvenile Pacific salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06, Seattle, Washington.

Fresh, K.L. 2006. Juvenile Pacific salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. 21 p.

Fresh, K.L., E. Casillas, L.L. Johnson, and D.L. Bottom. 2005. Role of the estuary in the recovery of Columbia River basin salmon and steelhead: an evaluation of the effects of selected factors on salmonid population viability. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-69, 105 p.

FRI (Fisheries Research Institute). 1981. Juvenile salmonid and baitfish distribution, abundance and prey resources in selected areas of Grays Harbor, Washington. Report Number FRI-UW-8116, University of Washington, Seattle, Washington 98195.

Fujiwara, M., M.S. Mohr, A. Greenberg, J.S. Foott, and J.L. Bartholomew. 2011. Effects of ceratomyxosis on population dynamics of Klamath fall-run Chinook salmon. Transactions of the American Fisheries Society 140: 1380-1391.

Fullerton, A.H., S. Lindley, G.R. Pess, B.E. Feist, E.A. Steel, and P. McElhany. 2011. Human influence on the spatial structure of threatened pacific salmon metapopulations. Conservation Biology 25(5):932-944.

Fulton, L. A. 1970. Spawning areas and abundance of steelhead trout and coho, sockeye and chum salmon in the Columbia River Basin - past and present. U.S. Dept. of Commerce, NOAA Spec. Sci. Rept. Fish. 618, 37.

Furniss, M.J., T.D. Roelofs, and C.S. Kee. 1991. Road construction and maintenance, p. 297-323. In: W.R. Meehan, ed. Influences of Forest and Rangeland management on Salmonid Fishes and Their Habitats. American Fisheries Society. Special Publication 19. Bethesda, Maryland, 751.

Furniss, M.J., T.D. Roelofs, and C.S. Yee. 1991. Road construction and maintenance. P. 297-323 in: W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publ. 19.

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

Gauvin, Charles. 1997. Water-management and water-quality decision making in the range of pacific salmon habitat. Pacific Salmon and their Ecosystems. Springer US. Pp. 389-409.

Gelfenbaum, G., T. Mumford, J. Brennan, H. Case, M. Dethier, K. Fresh, F. Goetz, M. van Heeswijk, T.M., Leschine, M. Logsdon, D. Myers, J. Newton, H. Shipman, C.A. Simenstad, C. Tanner, and D. Woodson, 2006. Coastal Habitats in Puget Sound: A research plan in support of the Puget Sound Nearshore Partnership. Puget Sound Nearshore Partnership Report No. 2006-1, Seattle, Washington.

Gerke, R.J. and V.W. Kaczynski. 1972. Food of juvenile pink and chum salmon in Puget Sound, Washington. Wash. Dep. Fish. Tech. Rep.10:27.

Gerstein, J.M. and R.R. Harris. 2005. Protocol for Monitoring the Effectiveness of Bank Stabilization Restoration. University of California, Center for Forestry, Berkeley, CA. 24 pp.

Gharrett, A.J., C. Smoot, and A.J. McGregor. 1988. Genetic relationships of even-year northwestern Alaskan pink salmon. Trans. Am. Fish. Soc. 117:536-545.

Gilbert, C.H. 1912. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus*. Fish Bull., U.S. 32:3-22.

Gill, A.B. 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology 42: 605-615.

Gillilan, D.M. and T.C. Brown. 1997. Instream flow protection -- seeking a balance in western water use, Island Press Washington, DC, 417.

Glasby, T.M. 1999a. Differences between subtidal epibiota on pier pilings and rocky reefs at marinas in Sydney, Australia. Estuarine, Coastal, and Shelf Science. 48: 281-290.

Glasby, T.M. 1999b. Effects of shading on subtidal epibiotic assemblages. Journal of Exp. Mar. Biol. and Ecol. 234:275-290.Glasby, T.M., S.D. Connell, M.G. Holloway, and C.L. Hewitt. 2007. Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? Marine Biology 151: 887-895.

Godfrey, H. 1965.; Salmon of the North Pacific Ocean-Part IX. Coho, chinook and masu salmon in offshore waters. 1. Coho salmon in offshore waters. International North Pacific Fisheries Commission, Bulletin 16:1-39.

Godfrey, H. 1968. Ages and physical characteristics of maturing Chinook salmon on the Nass, Skeena, and Fraser Rivers in 1964, 1965, and 1966. Fish. Res. Board Can. Manuscript report 967.

Godfrey, H., K. A. Henry, and S. Machidori. 1975. Distribution and abundance of coho salmon in offshore waters of the north Pacific Ocean. Int. North Pac. Fish. Comm. Bull. 31, 80.

Godin, J.G.J. 1981. Daily patterns of feeding behavior, daily rations, and diets of juvenile pink salmon (*Oncorhynchus gorbuscha*) in two marine bays of British Columbia. Can. J. Fish. Aquat. Sci. 38: 10-15.

Goloranov, I.S. 1982. Natural reproduction of pink salmon, *Oncorhynchus gorbuscha* (Salmonidae) on the northern shore of the Okhotsk Sea. J. Ichthyol. 22:32-39.

Gomi, T., R.D. Moore, and A.S. Dhakal. 2005. Headwater stream temperature response to clear-cut harvesting with different riparian treatments, coastal British Columbia, Canada. Water Resour. Res. 42:W08437, doi:10.1029/2005WR004162.

Goniea, T.M., Keefer, M.L., Bjornn, T.C., Peery, C.A., Bennett, D.H., Stuehrenberg, and L.C. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia river water temperatures. Transactions of the American Fisheries Society, 135(2): 408-419.

Gonzales, E.J. 2006. Diet and prey consumption of juvenile coho salmon (*Oncorhynchus kisutch*) in three northern California streams. M. S. thesis, Humboldt State University.

Good, J.W. 2000. Summary and current status of Oregon's estuarine ecosystems. Section 3.3, Estuarine Ecosystems. Oregon Progress Board, Salem. Available at: http://egov.oregon.gov/DAS/OPB/docs/SOER2000/Ch3_3a.pdf

Gordon, D.K. and C.D. Levings. 1984. Seasonal changes of inshore fish populations on Sturgeon and Roberts Bank, Fraser River estuary, British Columbia. Can. Tech. Rep. Fih. Aquat. Sci. 1240:81.

Gordon, D.K. and C.D. Levings. 1984. Seasonal changes of inshore fish populations on Sturgeon and Roberts Bank, Fraser River estuary, British Columbia. Can. Tech. Rep. Fih. Aquat. Sci. 1240:81.

Govoni, J.J, L.R Settle, and M.A. West. 2003. Trauma to juvenile pinfish and spot inflicted by submarine detonations. Journal of Aquatic Animal Health 15:111–19.

Govoni, J.J., M.A. West, L.R. Settle, R.T. Lynch, and M.D. Greene. 2008. Effects of underwater explosions on larval fish: implications for a coastal engineering project. Journal of Coastal Research 24:228-233.

Grant, G.E., S.L. Lewis, F.J. Swanson, J.H. Cissel, J.J. McDonnell. 2008. Effects of forest practices on peak flows and consequent channel response: a state-of-science report for western Oregon and Washington. Gen. Tech. Rep. PNW-GTR-760. U.S. Dept. of Ag., Forest Service, Pacific Northwest Research Station, Portland, OR. 76 p.

Gravelle J.A., G. Ice, T.E. Link, and D. Cook. 2009. Nutrient concentration dynamics in an inland Pacific Northwest watershed before and after timber harvest. Forest Ecology and Management 257:1663-1675.

Graybill, J.P. 1979. Role of depth and velocity for nest site selection by Skagit River pink and chum salmon, p. 391-392. In: J.C Mason, ed. Proceedings of the 1978 northeast Pacific pink and chum salmon workshop. Pacific Biological Station, Nanaimo, B.C.

Gregory, J.S. and B.L. Gamett. 2009. Cattle trampling of simulated bull trout redds. North American Journal of Fisheries Management 29:361–366.

Gregory, M.R. 2009. Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions: Biological Sciences 364(1526):2013-2025.

Gregory, R.S. and C.D. Levings. 1998. Turbidity reduces predation on migrating juvenile pacific salmon. Trans. Am. Fish. Soc. 127:275-285.

Gregory, R.S. and T.G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. Can. J. Fish. Aquat. Sci. 50:233-240.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8):540-551.

Gresswell, R.E., B.A. Barton, and J.L. Kershner (eds.). 1989. Practical approaches to riparian resource management: an educational workshop. May 8 -11, 1989, Billings, Montana. USDI Bureau of Land Management: BLM-MT-PT-89-001-4351. 193 p.

Gribanov, V.I. 1948. The coho salmon (*Oncorhynchus kisutch* Walb.)-a biological sketch. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 28:43-101. (Trans. from Russian; Fish. Res. Bd. Can. Transl. Ser. 370.).

Grimes, C.B. 1975. Entrapment of fishes on intake water screens at a steam electric generating station. Chesapeake Science 16: 172-177.

Groom J.D., L. Dent L., L.J. Madsen and J. Fleuret. 2011. Response of western Oregon (USA) stream temperatures to contemporary forest management. Forest Ecology and Management 262:1618–1629.

Groot, C. and L. Margolis (eds). 1991. Pacific salmon life histories. UBC press, 1991.

Gucinski, H., M.J. Furniss, R.R. Ziemer, and M.H. Brookes. 2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNW-GTR-509. U.S. Dept. of Ag., Forest Service, Pacific Northwest Research Station, Portland, OR. 104 p.

Guenther, P.M. And W.A. Hubert 1993. Method for determining minimum pool requirements to maintain and enhance salmonid fisheries in small Wyoming reservoirs. Environmental Management. 17:645-653.

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity. Progress in Physical Geography 22: 167-189.

Haas, M.A., C.A. Simenstad, Jr., J.R. Cordell, D.A. Beauchamp, and B.S. Miller. 2002. Effects of large overwater structures on epibenthic juvenile salmon prey assemblages in Puget Sound, Washington. Prepared for the Washington State Transportation Commission, Washington State Department of Transportation, the U.S. Department of Transportation, and Federal Highway Administration. Final research report No. WA-RS 550.1. 114 p. Available: http://depts.washington.edu/trac/bulkdisk/pdf/550.1.pdf. (January 2010).

Haertel, L. and C. Osterberg. 1967. Ecology of zooplankton, benthos and fishers in the Columbia River Estuary. Ecology 48(3):459-472.

Hakala, J.B., R.K. Seemel, R. Richey, and J.E. Keurtz. 1971. Fire effects and rehabilitation methods – Swanson-Russian River fires. Pp. 87-99 in: C.W. Slaughter, R.J. Barry, and G.M. Hanson, eds. Fire in the northern environment – a symposium. U.S. department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Hall, C., R. Howarth, B. Moore, and C. Vorosmarty. 1978. Environmental impacts of industrial energy systems in the coastal zone. Ann. Rev. Energy. 3:395-475.

Hall, J.D. and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. P. 355-375 in: T. G. Northcote, ed. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver, Canada.

Hallock, R.J. and D.H. Fry, Jr. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game 53:5-22.

Halvorsen, M.B. 2012. Personal communication with Craig Johnson and John Stadler, National Marine Fisheries Service.

Halvorsen, M.B., B.M. Casper, C.M. Woodley, T.J. Carlson, and A.N. Popper. 2011. Predicting and mitigating hydroacoustic impacts on fish from pile installations. NCHRP Research Results Digest 363, Project 25-28, National Cooperative Highway Research Program, Transportation Research Board, National Academy of Sciences, Washington, D.C.

Halvorsen, M.B., B.M. Casper, C.M. Woodley, T.J. Carlson, and A.N. Popper. 2012. Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. PLoS ONE 7(6): e38968. doi:10.1371/journal.pone.0038968.

Hammack, E.A., D.S. Smith, and R.L. Stockstill. 2008. Modeling vessel-generated currents and bed shear stresses. U.S. Army Corps of Engineers Research and Development Center, ERDC/CHL TR-08-7, Vicksburg, Mississippi.

Hanavan, M.G. and B.E. Skud. 1954. Intertidal spawning of pink salmon. Fish. Bull. Fish Wild. Serv. 56:167-185.

Hanson M.B., R.W. Baird, J.K.B. Ford, J. Hempelmann-Halos, D.M. Van Doornik, J.R. Candy, C.K. Emmons, G.S. Schorr, B. Gisborne, K.L. Ayres, S.K. Wasser, K.C. Balcomb, K. Balcom-Bartok, J.G. Sneva, and M.J. Ford. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endangered Species Research 11: 69–82.

Hanson, C.H., J.R. White, and H.W. Li. 1977. Entrapment and impingement of fishes by power plant cooling water intakes: an overview. Marine Fisheries Review 39:7-17.

Hard, J.J., R.G. Kope, W.S. Grant, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1996. Status review of pink salmon from Washington, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-25, 131.

Harden Jones, F.R. 1968. Fish migration. St. Martin's Press, New York, 325 p.

Harmon, M.H., J.F. Franklin, F.J. Swanson, et al., 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15, 133–302.

Harr, R.D., W.C. Harper, J.T. Krygier, and F.S Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in Oregon Coast Range. Water Resour. Res. 11(3):436-444.

Harrison, C.S. 1984. Terns Family Laridae Pages 146-160 in D. Haley, D. editor. Seabirds of eastern North Pacific and Arctic waters. Pacific Search Press. Seattle. 214 p.

Harrison, P. 1983. Seabirds: an Identification Guide. Houghton Mifflin Company. Boston. 448 p.

Hart, J.L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Bd. Can. 180:740.

Hart, S.K. 2006. Riparian litter inputs for streams in the central Oregon Coast Range. M.S. thesis. Oregon State University, Dept. of Forest Science, Corvallis, OR.

Hartman, G.F. and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223. Department of Fisheries and Oceans, Ottawa, Ontario, Canada.

Hartt, A.C. 1980. Juvenile salmonids in the oceanic ecosystem-the critical first summer. Pp. 25-57 in: W.J. McNeil and D.C. Himsworth, eds. Salmonid ecosystems of the North Pacific. Oreg. State Univ. Press and Oreg. State Univ. Sea Grant College Prog., Corvallis.

Hartt, A.C. and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Int. North Pac. Fish. Comm. Bull. 46, 105.

Harvey, BC. and J. L. White. 2008. Use of benthic prey by salmonids under turbid conditions in a laboratory stream. Transactions of the American Fisheries Society 137:1756-1763.

Hassan, M.A., D.L. Hogan, S.A. Bird, C L. May, T. Gomi, and D. Campbell. 2005. Spatial and temporal dynamics of wood in headwater streams of the Pacific Northwest. J. Am. Water Resour. As. 41:899-919.

Hastings, K.P. Hesp, and G. Kendrick. 1995. Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. Ocean and Coastal Management 26:225-246.

Hastings, M. 2007. Calculation of SEL for Govoni et al (2003, 2007) and Popper et al. (2007) studies: Report for amendment to Project 15218, J&S working group. December 14, 2007. 7p.

Hastings, M.C. and A.N. Popper. 2005. Effects of Sound on Fish. California Department of Transportation Con-tract 43A0139, Task Order 1.

Hastings, M.C., C.A. Reid, C.C. Grebe, R.L. Hearn, and J.G. Colman. 2008. The effects of seismic airgun noise on the hearing sensitivity of tropical reef fishes at Scott Reef, Western Australia. Underwater Noise Measurement, Impact and Mitigation, Proceedings of the Institute of Acoustics 30 (5).

Hayes, F.A. 1978. Streambank and meadow condition in relation to livestock grazing in mountain meadows of central Idaho. M.S. Thesis, University of Idaho.

Heady, H.F. and R. D. Child. 1994. Rangeland ecology and management. Westview Press, Boulder, 519.

Healey, M.C. 1967. Orientation of pink salmon (*Oncorhynchus gorbuscha*) during early marine migration from Bella Coola River system. J. Fish. Res. Board Can. 24:2321-2338.

Healey, M.C. 1978. The distribution, abundance and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Fish. Mar. Serv. (Can.) Tech. Rep. 788:49.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. Pp. 203-229 in: W. J. McNeil and D. C. Hinsworth eds., Salmonid ecosystems of the North Pacific,. Oregon State University Press, Corvallis, Oregon.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. Pp. 203-229 in: W. J. McNeil and D. C. Hinsworth eds., Salmonid ecosystems of the North Pacific,. Oregon State University Press, Corvallis, Oregon.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: The life support system. In: V. S. Kennedy, ed., Estuarine comparisons, pp. 315-341. Academic Press, New York.

Healey, M.C. 1983. Coastwide distribution and ocean migration patterns of stream-type and ocean-type Chinook salmon. Canadian Field-Naturalist 97:427-433.

Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. In: D. J. Meerburg, ed., Salmonid age at maturity, pp. 39-52. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Healey, M.C. 1991. The life history of Chinook salmon (*Oncorhynchus tshawytscha*). Pp. 311-393 in: C. Groot and L. Margolis eds., Life history of Pacific salmon. Univ. BC Press, Vancouver, British Columbia, Canada.

Healey, M.C. and C. Groot. 1987. Marine migration and orientation of ocean-type Chinook and sockeye salmon. Pp. 298-312 in: M. J. Dadswell, R. J. Klanda, C. M. Moffitt, R. L. Saunders, R. A. Rulifson, and J. E. Cooper, eds. Common strategies of anadromous and catadromous fishes. Am. Fish. Soc. Symp. 1.

Healey, M.C. and W.R. Heard. 1984. Inter- and intra-population variation in the fecundity of Chinook salmon (*Oncorhynchus tshawytscha*) and its relevance to life history theory. Can. J. Fish. Aquat. Sci. 41:476-483.

Heard, W.R. 1991. Life history of pink salmon, *Oncorhynchus gorbuscha*. Pp. 119-230 in: Groot. C. and L. Margolis, eds., Pacific salmon life histories. UBC Press, Vancouver.

Hecht, S.A, D.H. Baldwin., C.A. Mebane, T. Hawkes, S.J, Gross, N.L. Scholtz. 2007. An overview of sensory effects on juvenile salmonids exposure to dissolved copper: Applying a benchmark concentration approach to evaluate sublethal neurobehavioral toxicology. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-83, 39 p.

Heintz, R.A., S.D. Rice, A.C. Wertheimer, R.F. Bradshaw, F.P. Thrower, J.E. Joyce, and J.W. Short. 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208:205-216.

Helfield, J. M. and R. J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. Ecology 82: 2403-2409.

Helfman, G.S. 1981. The advantage to fish of hovering in shade. Copeia(2):392-400.Hilton and Phillips 1982.

Helle, J.H. 1970. Biological characteristics of intertidal and fresh-water spawning pink salmon at Olsen Creek, Prince William Sound, Alaska, 1962- 63. U.S. Fish Wild. Serv. Spec. Sci. Rep. Fish. 602:19.

Helton, D. 2003. Wreck removal: A Federal perspective. In Proceedings of the Abandoned Vessel Program -National Maritime Salvage Conference, September 9-11, Crystal City, Virginia.

Helvey, M. 1985. Behavioral factors influencing fish entrapment at offshore cooling-water intake structures in southern California. Marine Fisheries Review 47:18-26.

Helvey, M. and P.B. Dorn. 1987. Selective removal of reef fish associated with an offshore cooling-water intake structure. Journal of Applied ecology 24:1-12.

Herbert, D.W.M, and J.M. Richards. 1963. The growth and survival of fish in some suspensions of industrial origin. International Journal of Air and Water Pollution 7:297-302.

Herke, W.H. and B.D. Rogers. 1993. Maintenance of the estuarine environment. Pp. 263-286 in: C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Herrmann, R. B. 1959. Occurrence of juvenile pink salmon in a coastal stream south of the Columbia River. Res. Briefs Fish Comm. Oreg. 7(1):81.

Hetrick, N.J., M.A. Brusven, W.R. Meehan, and T.C. Bjornn. 1998. Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska. Trans. Am. Fish. Soc. 127:859-875.

Hicks, B.J., J.D. Hall, P.A. Bisson and J.R. Sedell. 1991a. Responses of salmonids to habitat changes. P. 483-518 in: W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publ. 19.

Hicks, B.J., R.L. Bestcha, and R.D. Harr. 1991b. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resour. Bull. 27.

Higgins, S.N. and M.J. Vander Zanden. 2010. What a difference a species makes: a meta-analysis of dreissenid mussel impacts on freshwater ecosystems. Ecol Monogr 80: 179-196.

Higgs, D.A., J.S. Macdonald, C.D. Levings, and B.S. Dosanjh. 1995. Nutrition and Feeding Habits in Relation to Life History Stage. In: Physiological Ecology of Pacific Salmon, 161-315, edited by C. Groot, L. Margolis, and W. C. Clarke. Vancouver, BC: University of British Columbia Press.

Hilton, J. and G.L. Phillips. 1982. The effect of boat activity on turbidity in a shallow broadland river. Journal of Applied Ecology 19(1):143-150.

Hiss, J.M. 1995. Environmental factors influencing spawning escapement of Dungeness River pink salmon (*Oncorhynchus gorbuscha*) 1959-1993. Unpubl. Manuscr. 33. (Available from U.S.Fish and Wildlife Service, Western Washington Fishery Resource Office, 2625 Parkmont Lane SW, Bldg. A, Olympia, Washington 98502.) .

Hoar, W. S. 1958. The evolution of migratory behaviour among juvenile salmon of the genus *Oncorhynchus*. J. Fish. Res. Board Can. 15:391-428.

Hoar, W.S. 1956. The behaviour of migrating pink and chum salmon fry. J. Fish. Res. Board Can. 13:309-325.

Hoekstra, J.M., K.K. Bartz, M.H. Ruckelshaus, J.M. Moslemi, and T.K. Harms. 2007. Quantitative threat analysis for management of an imperiled species: Chinook salmon (*Oncorhynchus tshawytscha).* Ecological Applications 17:2061–2073.

Hofer, T. 1998. Part II: Environmental and health effects resulting from marine bulk liquid transport. Environmental Science and Pollution Research 5(4):231-7.

Holland, L.E. 1987. Effect of brief navigation-related dewaterings on fish eggs and larvae. North American Journal of Fisheries Management 7(1):145-147.

Holsman, K.K., M.D. Scheuerell, E. Buhle, and R. Emmett. 2012. Interacting effects of translocation, artificial propagation, and environmental conditions on the marine survival of Chinook salmon from the Columbia River, Washington, USA. Conservation Biology 26:912-922.

Holtby, L.B. and M.C. Healey. 1986. Selection for adult size in female coho salmon (*Oncorhynchus* kisutch). Can. J. Fish. Aquat. Sci. 43:1946-1959.

Hoss, D.E. and G.W. Thayer. 1993. The importance of habitat to the early life history of estuarine dependent fishes. American Fisheries Society Symposium 14:147-158.

Hourston, W.R. and D. MacKinnon. 1956. Use of an artificial spawning channel by salmon. Trans. Am. Fish. Soc. 86:220-230.

Houston, D.B. 1983. Anadromous fish in Olympic National Park: A status report. Natl. Park Serv. Pacific Northwest Region, 72. (Available from Olympic National Park, 600 East Park Avenue, Port Angeles, Washington, 98362.) .

Hubbs, C.L. 1946. Wandering of pink salmon and other salmonid fishes into southern California. Calif. Fish Game 81-86.

Hubbs, C.L. and A.B. Rechnitzer. 1952. Report on experiments designed to determine effects of underwater explosions on fish life. California Fish and Game 38:333-365.

Huenemann, T.W., E.D. Dibble, and J.P. Fleming. 2012. Influence of turbidity on the foraging of largemouth bass, Transactions of the American Fisheries Society, 141(1):107-111.

Hunter Community Environment Centre. 2013. Protecting Communities for Coal Dust: A guide to international best practice techniques to minimise and control dust from coal mining and export activities from pit to port. New South Wales, Australia

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16:835-886.

Hynes, H.B.N. 1960. The biology of polluted waters. Liverpool University Press, Liverpool, UK.

Independent Scientific Group. 2000. Return to the River 2000: restoration of salmonid fishes in the Columbia River Ecosystem. NPPC 2000-12, Northwest Power Planning Council, Portland, Oregon.

Irvine, J.R. and B.R. Ward. 1989. Patterns of timing and size of wild coho salmon (*Oncorhynchus* kisutch) smolts migrating from the Keogh River Watershed on northern Vancouver Island. Can. J. Fish. Aquat. Sci. 46:1086-1094.

Isaak, D.J., R.F. Thurow, B.E. Rieman, and J.B. Dunham. 2007. Chinook salmon use of spawning patches: relative roles of habitat quality, size, and connectivity. Ecological Applications. 17:352-364.

ISAB (Independent Scientific Advisory Board). 2007. Climate change impacts on Columbia River basin fish and wildlife. ISAB, Report 2007-2, Portland, Oregon. Available online at: http://www.nwcouncil.org/library/isab/ISAB%202007-2%20Climate%20Change.pdf.

Ito, J. 1964. Food and feeding habits of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Res. Lab. 29:85-97. (Transl. from Japanese; Fish. Res. Board Can. Transl. Ser. 1309.).

Jackson, R.G. 1986. Effects of bark accumulation on benthic infauna at a log transfer facility in Southeast Alaska. Marine Pollution Bulletin 17(6):258-262.

Jacobson, K. and 16 others. 2012. Marine ecology of juvenile Columbia River basin salmonids: A synthesis of research, 1998-2011. Report to Northwest Power and Conservation Council.

Jakob, M. 2000. The impacts of logging on landslide activity at Clayoquot Sound, British Columbia. Catena 38:279-300.

Janisch, J.E., S.M. Wondzell, and W.J. Ehinger. 2012. Headwater stream temperature: interpreting response after logging, with and without riparian buffers, Washington, USA. Forest Ecology and Management 270:302-313.

Jaworski, N. 1981. Sources of nutrients and the scale of eutrophication problems in estuaries. Pp. 83-110 in: B. Neilson and L. Cronin, eds., Estuaries and Nutrients. Humana, Clifton, New Jersey.

Jeffres, C.A., J.J Opperman, P.B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83: 449–458.

Jensen, D.W., E.A. Steel, E.A. Fullerton and G. Pess. 2009. Impact of fine sediment on egg-to-fry survival of Pacific salmon: a meta-analysis of published studies. Reviews in Fisheries Science 17:348–359.

Jensen, H.M. 1956. Migratory habits of pink salmon found in the Tacoma Narrows area of Puget Sound. Wash. Dep. Fish. Fish. Res. Pap. 1:21-24.

JNCC (Joint Nature Conservation Committee). 2010. JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. August 2010. 16 p.

Johnson, C.L., P. Roni, and G.R. Pess. 2012. Parental effect as a primary factor limiting egg-to-fry survival of spring Chinook salmon in the Upper Yakima River basin. Transactions of the American Fisheries Society 141: 1295-1309.

Johnson, J. 1998. Oregon Department of Fish and Wildlife. Personal communication. Newport, Oregon.

Johnson, L. 2000. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. White paper from National Marine Fisheries

Service, Northwest Fisheries Science Center, Seattle, WA. Johnson et al. 1999.

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

Johnson, R. and R.M. Bustin. 2006. Coal dust dispersal around a marine coal terminal (1977-1999), British Columbia: The fate of coal dust in the marine environment. International Journal of Coal Geology 68 (2006) 57-69.

Johnson, R.R., C.D. Ziebell, D.R. Patton, P.F. Folliet, and R.H. Hamre (Tech. Coordinators). 1985. Riparian ecosystem and their management: reconciling conflicting uses; first North America riparian conference; April 16-18. Tucson, Arizona. USDA Forest Service Gen. Tech. Rpt. Rm-120. 523 p.

Johnson, S. 1994. Recreational boating impact investigations - Upper Mississippi River System, Pool 4, Red Wing, Minnesota. Report by the Minnesota Department of Natural Resources, Lake City, Minnesota, for the National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, February 1994. EMTC 94-S004. 48 p. + appendixes (2 p.).

Johnson, S.L. 2004. Factors influencing stream temperatures in small streams: substrate and a shading experiment. Can. J. Fish. Aquat. Sci. 61:93-923.

Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. Can. J. Fish. Aquat. Sci. 57(Suppl. 2):30B39.

Johnson, S.P. and D.E. Schindler. 2009. Trophic ecology of Pacific salmon (*Oncorhynchus*) in the ocean: a synthesis of stable isotope research. Ecological Research 24: 855-863.

Johnston, C.A. 1994. Cumulative impacts to wetlands. Wetlands 14(1):49-55.

Jones, J.A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. Water Resour. Res. 36(9):2621-2642.

Jordan, T.E., D.E. Weller. 1996. Human contributions to terrestrial nitrogen flux: Assessing the sources and fates of anthropogenic fixed nitrogen. BioScience 46:655.

Junk, W.J., P.B. Bayley and R.E. Sparks. 1989. The Flood Pulse Concept in River Floodplain Systems. Can Spec Publ. Fish Aquatic Sci 106. pp 110- 127. Proceedings of the International Large River Symposium.

Kaczynski, V.W., R.J. Feller, and J. Clayton. 1973. Trophic analysis of juvenile pink and chum salmon (*Oncorhynchus gorbuscha* and *Oncorhynchus keta*) in Puget Sound. J. Fish. Res. Board Can. 30:1003-1008.

Kaeriyama, M., M. Nakamura, R. Edpalina, J. R. Bower, H. Yamaguchi, R.V. Walker and K.W. Myers. 2004. Change in feeding ecology and trophic dynamics of Pacific salmon (*Oncorhynchus* spp.) in the central Gulf of Alaska in relation to climate events. Fisheries Oceanography 13: 197-207.

Kahler, T., M. Grassley, and D. Beauchamp. 2000. A summary of the effects of bulkheads, piers and other artificial structures and shorezone development on ESA-listed salmonids in lakes. Final Report to the City of Bellevue. The Watershed Company, Kirkland, Washington. 74 p.

Karpenko, V.I. 1982. Biological peculiarities of juvenile coho, sockeye, and Chinook salmon in coastal waters of east Kamchatka. Sov. J. mar. Viol. 8:317-324.

Karpenko, V.I. 1987. Growth variation of juvenile pink salmon, *Oncorhynchus gorbuscha* and chum salmon *Oncorhynchus keta*, during the coastal period of life. J. Ichthyol. 27:117-125.

Kauffman, J. B. 1982. Synecological effects of cattle grazing riparian ecosystems. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Kauffman, J. B. and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications - a review. Journal of Range Management 37(5):430-438.

Keevin, T.M. and G.L. Hempen. 1997. The environmental effects of underwater explosions, with method to mitigate impacts. A manual published by the US Army Corps of Engineers, St Louis District, St. Louis, Missouri.

Keevin. T.M. 1998. A review of natural resource agency recommendations for mitigating the impacts of underwater blasting. Reviews in Fisheries Science 6(4):281-313.

Kelpšaite, L., K.E. Parnell, and T. Soomere. 2009. Energy pollution: The relative influence of wind-wave and vessel-wake energy in Tallinn Bay, the Baltic Sea. Journal of Coastal Research (Special Issue 56):812-816.

Kennish, M. 1997. Practical handbook of estuarine and marine pollution. CRC Press, Boca Raton, Florida.

Keppler, E.T. and R.R. Ziemer. 1990. Logging effects of streamflow: water yield and summer low flows at Caspar Creek in Northwestern California. Water Resour. Res. 26(7):1669-1679.

Kiffney, P.M, G.R. Pess, J.H. Anderson, P. Faulds , K. Burton , and S.C. Riley. 2009. Changes in fish communities following recolonization of the Cedar River, WA, USA by Pacific salmon after 103 years of local extirpation. River Research and Applications 25(4):438-452.

Kiffney, P.M. 2008. Response of lotic producer and consumer trophic levels in headwater streams of southwestern British Columbia in response to gradients of resource supply and predation pressure. Oikos 114:1428-1440.

Kiffney, P.M. and J.S. Richardson. 2010. Organic matter inputs into headwater streams of southwestern British Columbia as a function of riparian reserves and time since harvesting. Forest Ecology and Management 260:1931-1942.

Kiffney, P.M., J.S. Richardson, and J.P. Bull. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. J. Appl. Ecol. 40:1060-1076.

Kiffney, P.M., J.S. Richardson, and J.P. Bull. 2004. Establishing light as a causal mechanism structuring stream communities in response to experimental manipulation of riparian buffer width. J. N. Am. Benthol. Soc. 23:542-555.

Kiffney, P.M., R.E. Bilby, and B.L. Sanderson. 2005. Monitoring the effects of nutrient enrichment on freshwater ecosystems. P. 237-266 in: P. Roni, ed. Monitoring stream and watershed restoration. American Fisheries Society, Bethesda, Maryland.

Kinch, G. 1989. Riparian area management: grazing management in riparian areas. U.S. Bureau of Land

Management, Denver, Colorado. Tech. Ref. 737-4. 44 p.

King, J. and L. Tennyson. 1984. Alteration of stream flow characteristics following road construction in north central Idaho. Water Resources Research 20:1159-1163.

King, J. R. and R. J. Beamish. 2000. Diet comparisons indicate a competitive interaction between ocean age-0 chum and coho salmon. North Pacific Anadromous Fisheries Commission Bulletin 2: 65-74.

King, J.G. 1979. Streamflow responses to road building and harvesting: A comparison with the equivalent clearcut procedure. Research Paper INT-401. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Moscow, Idaho.

Kirk, J.O. 1985. Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. Hydrobiologia 125(1):195-208.

Kirkpatrick, B., T.C. Shirley, C.E. O'Clair. 1998. Deep-water bark accumulation and benthos richness at log transfer and storage facilities. Alaska Fishery Research Bulletin 5(2):103-115.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher. 1982. Life history or fall-run juvenile Chinook salmon, *Oncorhynchus tshawytscha*. In: the Sacramento-San Joaquin estuary, California. In: V. S. Kennedy ed., Estuarine Comparisons, pp. 393-411. Academic Press, New York, New York.

Klein, R. 1997. The effects of marinas and boating activity upon tidal waterways, Owings Mills, Maryland.

Knudsen, F.R., C.B. Schreck, S.M. Knapp, P.S. Enger, and O. Sand. 1997. Infrasound produces flight and avoidance responses in Pacific juvenile salmonids. Journal of Fish Biology 51:824-829.

Knudsen, F.R., P.S. Enger, and O. Sand, O. 1992. Awareness reactions and avoidance responses to sound in juvenile Atlantic salmon, *Salmo salar* L. Journal of Fish Biology 40:523-534.

Konecki, J.T., C.A. Woody, and T.P. Quinn. 1995. Critical thermal maxima of coho salmon (*Oncorhynchus kisutch*) fry under field and laboratory acclimation regimes. Can. J. Zool. 73:993-996.

Koski, K. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14:4. Available: http://www.ecologyandsociety.org/vol14/iss1/art4/. .

Kramer, S., M. Previsic, P. Nelson, and S. Woo. 2010. Re Vision DE-003: Deployment effects of marine renewable energy technologies-framework for identifying key environmental concerns in marine renewable energy projects. U.S. Department of Energy, Advanced Waterpower Program. 93p.Langford, T.E., N.J.

Labelle, M. 1992. Straying patterns of coho salmon (*Oncorhynchus kisutch*) stocks from southeast Vancouver Island, British Columbia. Can. J. Fish. Aquat. Sci. 49:1843-1855.

Landingham, J.H. 1982. Feeding ecology of pink and chum salmon fry in the nearshore habitat of Auke Bay, Alaska. M.Sc. thesis. University of Alaska, Juneau, Alaska. 132.

Latterman, S. and T. Hoepner. 2008. Environmental impact and impact assessment of seawater desalination. Desalination 220:1-15.

Lawson, P. 1997. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries: 22(5).

Lebow, S.T., P. Cooper, P.K. Lebow. 2004. Variability in evaluating environmental impacts of treated wood. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Research Paper FPL-RP-620, Madison, Wisconsin.

LeBrasseur, R.J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23:85-100.

LeBrasseur, R.J. and R.R. Parker. 1964. Growth rate of central British Columbia pink salmon (*Oncorhynchus gorbuscha*). J. Fish. Res. Board Can. 21:1101-1128.

Lee, D.C., J.R. Sedell, B.E. Reiman, R.F. Thurow, J.E. Williams. 1997. Broadscale assessment of aquatic species and habitats. Pp. 1058-1496 in: T.M. Quigley and S.J. Arbelbide, eds. An Assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins. U.S. Forest Service General Technical Report PNW-GTR-405. Portland, OR.

Leidy, R.A. 2005. Historical status of coho salmon in streams of the urbanized San Francisco Estuary, California. U.S. Environmental Protection Agency. San Francisco, California, 91405.

Leidy, R.A. 2007. Ecology, assemblage structure, distribution, and status of fishes in the streams tributary to the San Francisco Estuary, California. U.S. Environmental Protection Agency. Contribution No. 530. April 2007.

Leidy, R.A., G. Becker, and B.N. Harvey. 2005. Historical status of coho salmon in streams of the urbanized San Francisco estuary, California. California Fish and Game 91(4):219-254.

Leitritz, E. and R. C. Lewis. 1980. Trout and salmon culture (hatchery methods). Publ. No. 4100, Div. Agri. Sci., U. of Cal., Berkeley. 197 p.

Lenzi, J. 1983. Coho smolt enumeration on several small Puget Sound streams, 1978-1981. Wash. Dep. Fish. Prog. Rep. 199, 91.

Lenzi, J. 1985. Coho smolt enumeration on several small Puget Sound streams, 1982-1984. Wash. Dep. Fish. Prog. Rep. 232, 61.

Lenzi, J. 1987. Coho smolt enumeration on several small Puget Sound streams, 1985-1987. Wash. Dep. Fish. Prog. Rep. 262, 59.

Lestelle, L.C. and C. Weller. 1994. Summary report: Hoko and Skokomish River coho salmon indicator stock studies 1986-1989. Point No Point Treaty Council Tech. Rep. TR 94-1, 13 plus appendices. (Available from Point No Point Treaty Council, 7999 NE Salish Lane, Kingston, Washington, 98346).

Levings, C D. 1982. Short term use of a low tide refuge in a sandflat by juvenile Chinook, *Oncorhnychus tshawytscha*, in the Fraser River estuary. Can. Tech. Rep. Fish. Aquat. Sci. 1111:33.

Levings, C.D., C.D. McAllister, and B.D. Chang. 1986. Differential use of the Campbell River estuary, British Columbia by wild and hatchery-reared juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 43: 1386-1397.

Levings, C.D., D.E. Boyle, and T.R. Whitehouse. 1995. Distribution and feeding of juvenile Pacific salmon in freshwater tidal creeks of the lower Fraser River, British Columbia. Fish. Manage. Ecol. 2:299-308.

Levy, D.A. and T.G. Northcote. 1981. The distribution and abundance of juvenile salmon in marsh habitats of the Fraser River estuary. Westwater Res. Cent. Univ. Br. Col. Tech. Rep. 25:117.

Levy, D.A. and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Levy, D.A., T.G. Northcote, and G.J Birch. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Westwater Res. Cent. Univ. Br. Col. Tech. Rep. 23:70.

LGL and MAI. 2011. Environmental Assessment of Marine Vibroseis. LGL Rep. TA4604-1; JIP contract 22 07-12. Rep. from LGL Ltd., Environmental Research Associates, King City, Ont., Canada, and Marine Acoustics Inc., Arlington, VA, U.S.A., for Joint Industry Programme, E&P Sound and Marine Life, Intern. Assoc. of Oil & Gas Producers, London, U.K. 207p.

Li, H. 1994. Cumulative effects of riparian disturbances along high desert trout streams of the John Day Basin, Oregon. Transaction of the American Fisheries Society. 123:627-640.

Lister, D., D. Hickey and I. Wallace. 1981. Review of the effects of enhancement strategies on the homing, straying, and survival of Pacific salmonids. Prepared for Dep. Fish. Oceans, Salmonid Enhancement Prog. by Lister and Assoc., W. Vancouver, British Columbia, Canada., 51.

Lister, D.B. and H.S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of Chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Board Can. 27:1215-1224.

Lloyd, D.S., J.P. Koenings, J.D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.

Lockwood, Jeffrey. 1990. Seagrass as a consideration in the site selection and construction of marinas. In: Environmental management for marinas conference, September 5-7, 1990, Washington, D.C. Technical Reprint Series, International Marina Institute, Wickford, Rhode Island.

Loeffel, R.E. and W.O. Forster. 1970. Determination of movement and identity of stocks of coho salmon in the ocean using the radionuclide Zinc-65. Res. Rep. Fish Comm. Oregon, 2(1):1-13.

Loftus, W.F. and H.L. Lenon. 1977. Food habits of salmon smolts, (*Oncorhnychus tshawytscha* and *Oncorhnychus keta*), from the Salcha River, Alaska. Trans. Am. Fish. Soc. 106:235-240.

Longmuir, C. and T. Lively. 2001. Bubble curtain systems for use during marine pile driving. Report by Fraser River Pile & Dredge Ltd., New Westminster, British Columbia.

Luiting, V., J. Cordell, A. Olson, and C. Simenstad. 1997. Does exotic *Spartina alterniflora* change benthic invertebrate assemblages? In Second International Spartina Conference Proceedings. 1997. Kim Patten, ed. Washington State University, Long Beach, Washington. Document available: http://www.willapabay.org/~coastal.

Lu*keta*, A., M.M. Hightower, and S. Attaway. 2008. Breach and safety analysis of spills over waters from large liquefied natural gas carriers. SAND2008-3153. Sandia National Laboratory, Albuquerque, NM. May 2008.NMFS 2008.

MacDonald, A. and K. Ritland. 1989. Sediment Dynamics in type 4 and 5 waters: A review and synthesis. TFW-102-89-002. Prepared for the TFW/SMER Sediment, Hydrology, and Mass Wasting Steering Committee and Washington Department of Natural Resources, Forest Regulation and Assistance, Olympia, Washington.

Macdonald, J.S., C.D. Levings, C.D. McAllister, U.H.M. Fagerlund, and J.R. McBride. 1988. A field experiment to test the importance of estuaries for Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 45: 1366-1377.

MacKinnon, D. 1963. Salmon spawning channels in Canada, pp. 108-110. In: R.S. Croer, ed. Report of Second Governor's Conference on Pacific Salmon. State Printing Plant, Olympia, Washington.

Magnusson, A. and R. Hilborn. 2003. Estuarine influence on survival rates of coho (*Oncorhynchus kisutch*) and Chinook salmon (*Oncorhynchus tshawytscha*) released from hatcheries on the U.S. Pacific coast. Estuaries 26(4B): 1094-1103.

Mains, E.M. and J.M. Smith. 1964. The distribution, size, time, and current preferences of seaward migrant Chinook salmon in the Columbia and Snake Rivers. Wash. Dep. Fish., Fish. Res. Pap. 2(3):5-43.

Major, R.L., J. Ito, S. Ito and H. Godfrey. 1978. Distribution, and origin of Chinook salmon in offshore waters of the north Pacific Ocean. Int. North Pac. Fish. Comm. Bull. 38:54.

Major, W.W. III, J.M. Grassley, K.E. Ryding, C.E. Grue, T.N. Pearsons, D.A. Tipton, and A.E. Stephenson. 2005. Abundance and consumption of fish by California gulls and ring-billed gulls at water and fish management structures within the Yakima River, Washington. Waterbirds 28:366–377.

Mallory, M.A. and J.S. Richardson. 2005. Complex interactions of light, nutrients and consumer density in a stream periphyton-grazer (tailed frog tadpoles) system. J. Anim. Ecol. 74:1020-1028.

Manzer, J. I. 1968. Food of Pacific salmon and steelhead trout in the northeast Pacific Ocean. J. Fish. Res. Board Can. 25:1085-1089.

Manzer, J.I. 1964. Preliminary observations on the vertical distribution of Pacific salmon (genus *Oncorhynchus*) in the Gulf of Alaska. J. Fish. Res. Board Can. 21:891-903.

Manzer, J.I. and M.P. Shepard. 1962. Marine survival, distribution, and migration of pink salmon (*Oncorhynchus gorbuscha*) off the British Columbia coast. In: N. J. Wilimovsky, ed., Symposium on pink salmon, pp. 113-122. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver.

Manzer, J.I. and R.J. LeBrasseur. 1959. Further observations on the vertical distribution of salmon in the northeast Pacific. Fish. Res. Board Can. MS Rep. Ser. 689:9.

Manzer, J.I., T. Ishida, A.E. Peterson, and M.G. Hanavan. 1965. Salmon of the north Pacific Ocean. Part V: Offshore distribution of salmon. Int. North Pac. Fish. Comm. Bull. 15:452.

Marcus, M., M. Young, L. Noel, and B. Mullan. 1990. Salmonid-habitat relationships in the western united states. General tech report RM-GTR-188. U.S. Dept. of Ag. Forest Service. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Marine, K.R. 1992. A background investigation and review of the effects of elevated water temperature on reproductive performance of adult chinook salmon. Department of Wildlife and Fisheries Biology, University of California, Davis.

Marine, K.R. and J.J. Cech, Jr. 2004. Effects of High water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River chinook salmon. N. Amer. J. Fish. Mgt. 24:198-210.

Marshall, P., C. Christie, K. Dobbs, A. Green, D. Haynes, J. Brodie, K. Michalek-Wagner, A. Smith, J. Storrie, and E. Turak. 2002. Grounded ship leaves TBT-based antifoulant on the great barrier reef: An overview of the environmental response. Spill Science & Technology Bulletin 7(5–6):215-221.

Martin, J.W. 1966. Early sea life of pink salmon, pp. 111-125. In: W.L. Sheridan, ed. Proceedings of the 1966 northeast pacific pink salmon workshop. Alaska Dept. Fish Game Inf. Leafl. 87.

Maser, C. and J.R. Sedell. 1994. (From the forest to the sea: The ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press. FL. 200.

Mastran, T.A., A.M. Dietrich, D.L. Gallagher, and T.J. Grizzard. 1994. Distribution of polyaromatic hydrocarbons in the water column and sediments of a drinking water reservoir with respect to boating activity. Water Research 28(11):2353-2366.

Materna, E. 2001. Temperature interaction. Issue paper 4. Prepared as part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-004. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. 33 p.

Mathisen, O.A. 1994. Spawning characteristics of the pink salmon (*Oncorhynchus gorbuscha*) in the eastern north Pacific Ocean. Aquacult. Fish. Manage. 25 (Suppl. 2):147-156.

May, C., E. Welch, R. Horner, J. Karr, and B. Mar. 1997. Quality indices for urbanization effects in Puget Sound lowland streams. Department of Ecology, Olympia, Washington. Publication number 98-04.

May, C.L. and R.E. Gresswell. 2003. Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, U.S.A. Can. J. For. Res. 33:1352-1362.

Maynord, S. 1990. Velocities induced by commercial navigation. U.S. Army Corps of Engineers Waterways Experiment Station, Technical Report HL-90-15, Vicksburg, Mississippi.

Maynord, S. 1996. Return velocity and drawdown in navigable waterways. U.S. Army Corps of Engineers Waterways Experiment Station, Technical Report HL-96-7, Vicksburg, Mississippi.

Maynord, S. 2005. Wave height from planing and semi-planing small boats. River Research and Applications 21(1):1-17.

Maynord, S.T., D.S. Biedenharn, C.J. Fischenich, and J.E. Zufelt. 2008. Boat-wave-induced bank erosion on the Kenai River, Alaska. U.S. Army Engineer Research and Development Center, ERDC TR-08-5, Vicksburg, Mississippi.

Mazumder, B., N. Bhowmik, and T. Soong. 1993. Turbulence in rivers due to navigation traffic. Journal of Hydraulic Engineering 119(5):581-597.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustic Society of America 113:638–642.

McClain, M.E., R.E. Bilby, F.J. Triska. 1998. Nutrient cycles and responses to disturbance. Pp. 347-372 in: R.J. Naiman and R.E. Bilby, eds. River ecology and management: lessons from the pacific coastal region Springer-Verlag, New York.

McClelland, D.E., R.B. Foltz, W.D. Wilson, T.W. Cundy, R. Heinemann, J.A. Saurbier, and R.L. Schuster. 1997. Assessment of the 1995 and 1996 floods and landslides on the Clearwater National Forest, part I: landslide assessment. A report to the Regional Forester, Northern Region, U.S. Forest Service. 52 p. December.

McConchie, J.A. and I.E.J. Toleman. 2003. Boat wakes as a cause of riverbank erosion: a case study from the Waikato River, New Zealand. Journal of Hydrology (NZ) 42(2):163-179.

McCullough, D. and A. Espinosa Jr. 1996. Columbia River Inter-Tribal Fish Commission. A monitoring strategy for application to salmon watersheds. Portland, Oregon.

McCullough, D.A. J.M. Bartholow, H.I. Jager, R.L. Beschta, E.F. Cheslak, M.L. Deas, J.L. Ebersole, J.S. Foott, S.L. Johnson, K.R. Marine, M.G. Mesa, J.H. Souchon, Y., K.F. Tiffan, and W.A. Wurtsbaugh. 2009. Research in thermal biology: burning questions for coldwater stream fishes. Reviews in Fisheries Science 17(1):90-115.

McCullough, D.A., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Summary of technical literature examining the physiological effects of temperature on salmonids. Issue paper 5. Prepared as part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-005. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. 114 p.

McDade, M.H., F.J. Swanson, W.A. McKee [and others]. 1990. Source distances for coarse woody debris entering small stream in western Oregon and Washington. Can. J. For. Res. 20:326-330.

McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Board Can. 17:655-676.

McDonald, J.S., I.K. Birtwell, and G.M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44:1233-1246.

McGarry, E.V. 1994. A quantitative analysis and description of the delivery and distribution of large woody debris in Cummins Creek, Oregon. M.S. thesis, Oregon State University, Corvallis, OR.

McIntyre, J.K; D.H. Baldwin, D.A. Beauchamp, N.L. Scholz. 2012. Ecological Applications 22:5: 1460-1471.

McMahon, T.E. 1983. Habitat suitability index models: coho salmon. U.S. Dept. Of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.49, 29.

McMahon, T.E. and L.B. Holtby. 1992. Behavior, habitat use and movements of coho salmon (*Oncorhynchus kisutch*) smolts during seaward migration. Can. J. Fish. Aquat. Sci. 49:1478-1485.

McNeil, W.J. 1962. Mortality of pink and chum salmon eggs and larvae in southeast Alaska streams. Ph.D. thesis. University of Washington, Seattle, Washington, 270.

McNeil, W.J. 1980. Vulnerability of pink salmon populations to natural and fishing mortality. Pp. 147-151 in: W.J. McNeil and D.C. Himsworth, eds. Salmonid ecosystems of the north Pacific. Oregon State University Press, Corvallis, Oregon.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Bull. Fish. Res. Board Can. 173:38.

Meador, J.P., J.E. Stein, W.L. Reichert, and u. Varanasi. 1995. Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. Reviews of Environmental Contamination and Toxicology 143:79-165.

Meager, J.J., P. Domenici, A. Shingles, and A.C. Utne-Palm. 2006. Escape responses in juvenile Atlantic cod *Gadus morhua* L.: The effects of turbidity and predator speed. The Journal of Experimental Biology 209:4174-4184.

Meehan, W.R. and D.B. Siniff. 1962. A study of the downstream migrations of anadromous fishes in the Taku River, Alaska. Trans. Am. Fish. Soc. 91:399-407.

Meehan, W.R. and W.S. Platts. 1978. Livestock grazing and the aquatic environment. Journal of Soil and Water Conservation November - December 1978:274-278.

Megahan, W.F. 1972. Subsurface flow interception by a logging road in mountains of central Idaho. Pp. 350-356 in: National symposium on watersheds in transition. AWRA Proceedings No. 14, Middleburg, VA.

Megahan, W.F. 1980. Nonpoint source pollution from forestry activities in the western United States: results of recent research and research needs. P. 92-151 in: Proceedings of the Water Pollution Control Federation Seminar, Richmond, VA.

Megahan, W.F. and G.L. Ketcheson. 1996. Predicting downslope travel of granitic sediments from forest roads in Idaho. Water Resources Bulletin 32(2):371-382.

Meleason, M.A., S.V. Gregory, and J.P. Bolte. 2003. Implications of riparian management strategies on wood in streams of the Pacific Northwest. Ecological Applications 13(5):1212-1221.

Menke, J. (ed.). 1977. Proceedings of the Workshop on Livestock and Wildlife-Fisheries Relationships in the Great Basin. Sparks, Nevada. Agricultural Sciences Publications Division of Agricultural Sciences, University of California, Berkeley CA. 170 p.

Merkel, T.J. 1957. Food habits of the king salmon, *Oncorhnychus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. Calif. Fish Game 43:249-270.

Merz, J.E. 2001. Diet of juvenile fall-run Chinook salmon in the Lower Mokelumne River, California. California Fish and Game 87: 102-114.

Metro. 1997. Policy analysis and scientific literature review for Title 3 of the urban growth management functional plan: Water quality and floodplain management conservation. Metro. Growth Management Services Department. Portland, Oregon.

Meyer, B. 1998. NMFS, personal communication Portland, Oregon.

Michael, J.H., Jr. 1995. Enhancement effects of spawning pink salmon on stream rearing juvenile coho salmon: managing one resource to benefit another. Northwest Science 69: 228–233.

Miles, E.L., A.K. Snover, A.F. Hamlet, B. Callahan, and D. Fluharty. 2000. Pacific northwest regional assessment: the impacts of climate variability and climate change on the water resources of the Columbia River Basin. Journal of the American Water Resources Association 36:399-420.

Miller, B.A. and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132:546–559.

Miller, D.R., J.G. Williams, and C.W. Sims. 1983. Distribution, abundance, and growth of juvenile salmonids off the coast of Oregon and Washington, summer 1980. Fish. Res., 2:1-17.

Milliken, A.S. and V. Lee. 1990. Pollution impacts from recreational boating: A bibliography and summary review. University of Rhode Island, Rhode Island Sea Grant Publication #RIU-G-90-002, Narragansett, Rhode Island.

Mills, K.E. and M.S. Fonseca. 2003. Mortality and productivity of eelgrass *Zostera marina* under conditions of experimental burial with two sediment types. Marine Ecology Progress Series 255:127-134.

Mirata, A. 1998. Personal Communication. Oregon Department of Fish and Wildlife, Portland, Oregon.

Moazzam, M. and S.H.N. Rizvi. 1980. Fish entrapment in the seawater intake of a power plant at Karachi coast. Environmental Biology of Fish 5:49-57.

Montgomery, D. R., G. Pess, E. M. Beamer, and T. P. Quinn. 1999. Channel type and salmonid distributions and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56: 377-387.

Montgomery, D.R., and J.M. Buffington. 1998. Channel processes, classification, and response. Pages 13-42 *in* B.E. Bilby and R.J. Naiman, editors. River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York.

Montgomery, D.R., J.M. Buffington, R.D. Smith, K.M. Schmidt, and G. Pess. 1995. Pool spacing in forest channels. Water Resour. Res. 31:1097-1105.

Montgomery, D.R., R.D. Smith, K.M. Schmidt, G.R. Pess. 1995. Pool spacing in forest channels. Water Resources Research 31:1097-1105.

Moore R.D., D.L. Spittlehouse, and A. Story. 2005a. Riparian microclimate and stream temperature response to forest harvesting: a review. Journal of the American Water Resources Association 41:13-834.

Moore, R.D., P. Sutherland, T. Gomi, and A. Dhakal. 2005b. Thermal regime of a headwater stream within a clear-cut, coastal British Columbia, Canada. Hydrol. Process. 19:2591-2608.

Morgan, J.D. and C.D. Levings. 1989. Effects of suspended sediment on eggs and larvae of lingcod (*Ophiodon elongatus*), pacific herring (*Clupea harengus pallasi*), and surf smelt (*Hypomesus pretiosus*). Department of Fisheries and Oceans, No. 1729, West Vancouver, British Columbia, Canada.

Mosely, J., P.S. Cok, A.J. Griffiths, and J. O'Laughlin. 1997. Guidelines for managing cattle grazing in riparian areas to protect water quality; Review of research and best management practices policy.

Report No. 15, Idaho Forest, Wildlife Range Policy Analysis Group.

Mosisch, T.D. and A.H. Arthington. 1998. The impacts of power boating and water skiing on lakes and reservoirs. Lakes & Reservoirs: Research and Management 3:1-17.

Moss. J.H., D.A. Beauchamp, A.D. Cross, K.W. Myers, E.V. Farley Jr., J.M. Murphy and J.H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society 134: 1313-1322.

Mote, P.W. and E.P. Salathé. 2009. Future climate in the Pacific Northwest. In: Washington Climate Change Impacts Assessment: Evaluating Washington's future in a changing climate. Climate Impacts Group, University of Washington, Seattle, Washington. http://www.cses.washington.edu/db/pdf/wacciach1scenarios642.pdf.

Mote, P.W., E.A. Parson, A.F. Hamlet, W.S. Keeton, D. Letternmaier, N. Mantua, E.L. Miles, D.W. Peterson, D.L. Peterson, R. Slaughter, and A.K. Snover. 2003. Preparing for climate change: the water, salmon, and forests of the Pacific Northwest. Climate Change 61:45-88.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams and E.D. Wikramanayake. 1995. Fish species of special concern in California, 2nd ed. Calif. Dep. Fish Game, Sacramento California, 272.

Mueller-Blenkle, C., P.K. McGregor, A.B. Gill, M.H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D.T. Wood, and F. Thomsen. 2010. Effects of pile-driving noise on the behaviour of marine fish. COWRIE Ref: Fish 06-08, Technical Report 31st March 2010.

Mull, K.E. 2005. Selection of spawning sites by coho salmon (*Oncorhynchus kisutch*) in Freshwater Creek, California. M. S. Thesis, Humboldt State University.

Mumford, T.F. 2007. Kelp and eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 007-05, Seattle, Washington.

Mundy, P.R. 1997. The role of harvest management in the future of Pacific salmon populations: Shaping human behavior to enable the persistence of salmon. Pp. 315-329 in: Stouder, D.A., P.A. Bisson, and R.J. Naiman (eds.), Pacific Salmon and Their Ecosystems: Status and Future Options. Chapman & Hall, New York, NY.

Murphy, K.J. and J.W. Eaton. 1983. Effects of pleasure-boat traffic on macrophyte growth in canals. Journal of Applied Ecology 20(3):713-729.

Murphy, M. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska -- Requirements for protection and restoration, NOAA Coastal Ocean Program, Decision Analysis Series No. 7, Washington, D.C.

Murphy, M.L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska: Requirements for protection and restoration. NOAA Coastal Ocean Program Decision Analysis Series No. 7. NOAA Coastal Ocean Office, Silver Spring, MD. 156 p.

Murphy, M.L. and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38:137-145.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski, and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Aquat. Sci. 43:1521-1533.

Murray, C.B., T.D. Beacham, and J.D. McPhail. 1990. Influence of parental stock and incubation on the early development of coho salmon (*Oncorhynchus* kisutch) in British Columbia. Can. J. Zool. 68:347-358.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grant, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of Chinook salmon from Washington, Oregon, Idaho, and California. NOAA Tech. Memo NMFS-NWFSC 35, 443.

Myers, K. W. and H. F. Horton. 1982. Temporal use of an Oregon estuary by hatchery and wild juvenile salmon. In: V. S. Kennedy, ed., Estuarine comparisons, pp. 377-392. Academic Press, New York.

Myers, K.W. 1980. An investigation of the utilization of four study areas in Yaquina Bay, Oregon, by hatchery and wild juvenile salmonids. M. Sc. Thesis, Oregon State Univ., Corvallis, 233.

Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956-1995. NPAFC Doc. 192 (FRI-UW-961), 4 plus figures and appendices. (Available from Univ. Wash., Fisheries Research Institute, Box 357980, Seattle, Washington, 98195-7980).

Myers, L. and B. Whited. 2010. Bacteria contamination of surface waters due to livestock grazing in the Stanislaus National Forest, California. Central Sierra Environmental Resource Center.

Nagrodski, A., G.D. Raby, C.T. Hasler, M.K. Taylor, and S.J. Cooke. 2012. Fish stranding in freshwater systems: Sources, consequences, and mitigation. Journal of Environmental Management 103:133-41.

Naiman, R.J. 1988. Alteration of North American streams by beaver. BioScience, 38(11):753-762.

Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olson and A.E. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In: R. J. Naiman, ed., Watershed Management, pp. 127-188. Springer-Verlag, New York.

Neave, F. 1948. Fecundity and mortality in Pacific salmon. Proc. Trans. R. Soc. Can. Ser. 3 42(5):97-105.

Neave, F. 1952. 'Even-year' and 'odd-year' pink salmon populations. Proc. Trans. R. Soc. Can. Ser. 3 46(5):55-70.

Neave, F. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. J. Fish. Res. Board Can. 9:450-491.

Neave, F. 1962. The observed fluctuations of pink salmon in British Columbia. Pp. 3-14. In: N. J. Wilimovsky, ed. Symposium on pink salmon. H. R. MacMillan lectures in fisheries. Institute of Fisheries, University of British Columbia, Vancouver, British Columbia, Canada.

Neave, F. 1966. Pink salmon in British Columbia, pp. 71-79. In: Salmon of the north Pacific Ocean. Part III. A review of the life history of north Pacific salmon. Int. North Pac. Fish. Comm. Bull. 18.

Neave, F. and W.P. Wickett. 1953. Factors affecting the freshwater development of Pacific salmon in British Columbia. Proc. 7th Pac. Sci. Congr. 1949(4):548-556.

Neave, F., T. Ishida, and S. Murai. 1967. Salmon of the north Pacific Ocean. Part VI. Pink salmon in offshore waters. Int. North Pac. Fish. Comm. Bull. 22:33.

Neff, J.M. 1985. Polycyclic aromatic hydrocarbons. P. 416-454 in: G.M. Rand and S.R. Petrocelli, eds. Fundamentals of aquatic toxicology. Hemisphere Publishing, Washington, D.C.

Negri, A.P., L.D. Smith, N.S. Webster, and A.J. Heyward. 2002. Understanding ship-grounding impacts on a coral reef: Potential effects of anti-foulant paint contamination on coral recruitment. Marine Pollution Bulletin 44(2):111-117.

Nehlsen, W., J. Williams, and J. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Neilson, J.D. and C.E. Banford. 1983. Chinook salmon (*Oncorhynchus tshawytscha*) spawner characteristics in relation to redd physical features. Can. J. Zool. 61:1524-1531.

Neilson, J.D. and G.H. Geen. 1981. Enumeration of spawning salmon from spawner residence time and aerial counts. Trans. Am. Fish. Soc. 110:554-556.

Nelson, J. 1993. South central coastal stream coho salmon and steelhead trout population inventory and habitat assessment. Calif. Dep. Fish Game, Annual Performance Rep. F-51-R-5. 52 p. (Available from California Department of Fish and Game, 1416 Ninth, Sacramento, California, 95814).

Nelson, J. 1994. Coho salmon and steelhead habitat and population surveys of Scott Creek, Santa Cruz, California, 1993. Calif. Dep. Fish Game, Annual Report, 52. (Available from California Department of Fish and Game, 1416 Ninth, Sacramento, California, 95814).

Nelson, P.A., D. Behrens, J. Castle, G. Crawford, R.N. Gaddam, S.C. Hackett, J. Largier, D.P. Lohse, K.L. Mills, P.T. Raimondi, M. Robart, W.J. Sydeman, S.A. Thompson, and S. Woo. 2008. Developing wave energy in Coastal California: potential socio-economic and environmental effects. California Energy Commission, PIER Energy-Related Environmental Research Program & California Ocean Protection Council CEC-500-2008-083. 165 p.

Nelson, R. L., M. McHenry, and W. S. Platts. 1991. Mining. Influences of forest and rangeland management on salmonid fishes and their habitats. Pp. 425-457 In: W. Meehan, ed. Influences of forest and range management on salmonid fishes and their habitats. AFS Special Publication 19. Bethesda, Maryland.

Netboy, A. 1958. Salmon of the Pacific Northwest. Fish vs. Dams. Binfords & Mort, Portland, Oregon, 119.

Newcombe, C.P. and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: A synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16(4):693-727.

Nicholas, J.W. and D.G. Hankin. 1988. Chinook salmon populations in Oregon coastal river basins. Oregon Dept. Fish Wildl. Fish. Div. Info. Report 88-1. 359.

Nickleson, T.E., J.D. Rodgers, S.L. Johnson and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49:783-789.

Nielsen, L.A., R.J. Sheehan, and D.J. Orth. 1986. Impacts of navigation on riverine fish production in the United States. Polish Archives of Hydrobiology 33(3/4):277-294.

Nightingale, B. and C.A. Simenstad, Jr. 2001. Overwater structures: Marine issues. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation. Nordstrom 1989.

NISC (National Invasive Species Council). 2008. 2008-2012 National invasive species management plan. U.S. Department of the Interior, Washington, DC. 35 p.

Nislow, K.H. and W.H. Lowe. 2006. Influences of logging history and riparian forest characteristics on macroinvertebrates and brook trout (*Salvelinus fontinalis*) in headwater streams (New Hampshire, USA). Freshw. Biol. 51(2):388-397.

NMFS (National Marine Fisheries Service). 1996a. Factors for decline: A supplement to the notice of determination for West Coast steelhead under the Endangered Species Act. (Available from Environmental Technical Services Division, NMFS 525 NE Oregon St., Suite 500, Portland, Oregon, 97232).

NMFS. 1996b. National gravel extraction policy. Santa Rosa, California. (http://swr.ucsd.edu/hcd/gravelsw.htm).

NMFS. 1997a. Endangered and threatened species; threatened status for southern Oregon/northern California coast evolutionarily significant unit (ESU) of coho salmon. Federal Register 62(87):24588-24609.

NMFS. 1997b. Designated critical habitat; central California coast and southern Oregon/northern California coast coho salmon. Federal Register [Docket No. 971029257-7257-01 I.D. No. 101097A] 62(227):627641-62751.

NMFS. 1997c. Investigation of scientific information on impacts of California sea lions and Pacific harbor seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. U.S. Dep. Commerce., NOAA Tech. Memo. NMFS-NWFSC-28. (Available from NMFS Northwest Fisheries Science Center, 2725 Montlake Blvd., Seattle, Washington, 98112).

NMFS. 1997d. Coastal coho habitat factors for decline and protective efforts in Oregon. Habitat Conservation Program, Portland, Oregon. April 24, 1997.

NMFS. 1998. Endangered and threatened species: Proposed endangered status for two Chinook salmon ESUs and proposed threatened status for five Chinook salmon ESUs; proposed redefinition, threatened status and revision of critical habitat for one Chinook salmon ESU, proposed designation of Chinook salmon critical habitat in California, Oregon, Washington, and Idaho. Federal Registar [Docket No. 980225050-8050-01 I.D. 022398C] 63(45):11481-11520.

NMFS. 2001. Guidelines for salmonid passage at stream crossings. National Marine Fisheries Southwest Region. 14 p. Available at www.habitat.noaa.gov/pdf/salmon_passage_facility_design.pdf.

NMFS. 2005a. California Coastal Chinook distribution. National Marine Fisheries Service, August 2005. URL: http://swr.nmfs.noaa.gov/salmon/layers/finalgis.htm

NMFS. 2005b. Central Valley spring-run Chinook distribution. National Marine Fisheries Service, August 2005. URL: http://swr.nmfs.noaa.gov/salmon/layers/finalgis.htm

NMFS. 2008. Impacts to marine fisheries habitat from nonfishing activities in the northeastern United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Regional Office, NOAA Technical Memorandum NMFS-NE-209, Gloucester, Massachusetts.

NMFS. 2008a. Anadromous salmonid passage facility design. NMFS, Northwest Region, Portland, Oregon. NMFS. 2008a.

NMFS. 2008b. Endangered Species Act section 7 consultation biological opinion on Environmental Protection Agency registration of pesticides containing chlorpyrifos, diazinon, and malathion. November 18, 2008. Silver Spring, Maryland. U.S. Department of Commerce. NMFS.

NMFS. 2008c. Endangered Species Act section 7 consultation: biological opinion on the Federal Columbia River power system biological opinion. Portland, Oregon. U.S. Department of Commerce. Available: http://www.nwr.noaa.gov/Salmon-Hydropower/Columbia-Snake-Basin/final-BOs.cfm. NMFS. 2008b.

NMFS. 2008d. Species of concern fact sheet: Coho salmon, *Oncorhynchus kisutch*, Puget Sound/Strait of Georgia. NOAA National Marine Fisheries Service. Available at: http://www.nmfs.noaa.gov/pr/pdfs/species/cohosalmon_highlights.pdf.

NMFS. 2009a. Endangered Species Act section 7 consultation: biological opinion and conference opinion on the long-term operations of the Central Valley Project and State Water Project. Sacramento, California. U.S. Department of Commerce.

NMFS. 2009b. Endangered Species Act section 7 consultation biological opinion on Environmental Protection Agency registration of pesticides containing carbaryl, carbofuran, and methomyl. April 20, 2009. Silver Spring, Maryland. U.S. Department of Commerce.

NMFS. 2010. Endangered Species Act section 7 consultation biological opinion on Environmental Protection Agency registration of pesticides containing azinphos methyl, bensulide, dimethoate, disulfoton, ethoprop, fenamiphos, naled, methamidophos, methidathion, methyl parathion, phorate and phosmet. August 31, 2010. Silver Spring, Maryland. U.S. Department of Commerce.

NMFS. 2011a. Anadromous salmonid passage facility design. Northwest Region, Seattle, Washington.

NMFS. 2011b. Endangered Species Act section 7 consultation biological opinion on Environmental Protection Agency registration of pesticides 2,4-D, triclopyr BEE, diuron, linuron, captan, and chlorothalonil. June 30, 2011. Silver Spring, Maryland. U.S. Department of Commerce.

NMFS. 2011c. Impacts to essential fisheries habitat from nonfishing activities in Alaska. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Regional Office.

NMFS. 2012a. National Marine Fisheries Service Endangered Species Act section 7 consultation final biological opinion on Environmental Protection Agency registration of pesticides oryzalin, pendimethalin, trifluralin. May 31, 2012. Silver Spring, Maryland. U.S. Department of Commerce.

NMFS. 2012b. Biological opinion National Marine Fisheries Service Endangered Species Act section 7 consultation on Environmental Protection Agency's registration of thiobencarb. Silver Spring, Maryland. U.S. Department of Commerce.

NMFS. 2013. Endangered Species Act section 7 consultation. Draft conference and biological opinion on Environmental Protection Agency's resistration of pesticides containing diflubenzuron, fenbutatin oxide, and propargite. May 1, 2013. Silver Spring, Maryland. U.S. Department of Commerce.

NOAA (National Oceanic and Atmospheric Administration). 1996. Guidance documents for natural resource damage assessment under the oil pollution act of 1990. NOAA Damage Assessment and Restoration Program, Silver Spring, Maryland.

NOAA. 2010. Guidelines for desalination plants in the Monterey Bay National Marine Sanctuary. Prepared by NOAA's Monterey Bay National Marine Sanctuary and National Marine Fisheries Service. May 2010. Monterey, CA. 20 p.

Nordstrom, K.F. 1989. Erosion control strategies for bay and estuarine beaches. Coastal Management 17:25-35.

Norris, L.A. and W.L. Webb. 1989. The effects of fire retardant on water quality. P. 79-86 in: N.H. Berg, ed. Proceedings of the symposium on fire and watershed management. General Technical Report PSW-109. U.S. Department of Agriculture, Forest Service. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

Norris, L.A., H.W. Lorz, and S.V. Gregory. 1991. Forest chemicals. P. 207 296 in: W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publ. 19.

Northcote, T.C. and D.Y. Atagi. 1997. Pacific salmon abundance trends in the Fraser River watershed compared with other British Columbia systems. In: D. J. Stouder, P. A. Bisson, and R. J. Naiman, eds., Pacific salmon and their ecosystems, status, and future options. Chapman and Hall, Inc., New York.

Northcote, T.G., N.T. Hohnston, and K. Tsumara. 1979. Feeding relationships and food web structure of lower Fraser River fishes. Westwater Res. Cent. Univ. Br. Col. Tech. Rep. 16:73.

Nowacek, D.P., K. Bröker, G. Donovan, G. Gailey, R. Racca, R.R. Reeves, A.I. Vedenev, D.W. Weller, and B.L. Southall. 2013. Responsible practices for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. Aquatic Mammals 39(4):356-377.

NPFMC (North Pacific Fisheries Management Council). 1999. Environmental assessment for Amendment 55 to the Fishery Management Plan for the Groundfish Fishery of the Bering Sea and Aleutian Islands Area; Amendment 55 to the Fishery Management Plan for Groundfish of the Gulf of Alaska; Amendment 8 to the Fishery Management Plan for the King and Tanner Crab Fisheries in the Bering Sea/Aleutian Islands; Amendment 5 to the Fishery Management Plan for Scallop Fisheries off Alaska; Amendment 5 to the Fishery Management Plan for the Salmon Fisheries in the EEZ off the Coast of Alaska, Essential Fish Habitat. 605 West 4th Ave, Suite 306, Anchorage, AK 99501-2252.

NPPC (Northwest Power Planning Council). 1986. Compilation of Information on salmon and steelhead losses in the Columbia River Basin. Columbia River Basin Fish and Wildlife Program. Portland, Oregon.

NRC (National Research Council). 1989. Irrigation-induced water quality problems: what can be learned from the San Joaquin Valley experience. National Academy Press, Washington, D.C.

NRC. 1996. Upstream: salmon and society in the Pacific Northwest. Report of the committee on protection and management of Pacific northwest anadromous salmonids, Board on Environmental Studies and Toxicology, and Commission on Life Sciences. National Academy Press. Washington, D.C.

NWIFC (Northwest Indian Fisheries Commission) and WDFW. (Washington Department of Fish and Wildlife). 1998. Salmonid disease control policy of the fisheries co-managers of Washington State. NWIFC/WDFW, Olympia, Washington, 22.

O'Neal, J.O., J. Hawkins, and A. Shelly. 2010. Oregon Watershed Enhancement Board and Washington Salmon Recovery Funding Board Coordinated Monitoring Program for Livestock Exclusion Projects. 2009 Annual Progress Report. February 2010.

ODFW (Oregon Department of Fish and Wildlife). 1989. Waterway habitat alteration policies. Review. Draft prepared by B. Forsberg, A. Smith, C. Kunkel, G. Anderson, J. Muck.

ODFW. 1989. Waterway habitat alteration policies. Review. Draft prepared by B. Forsberg, A. Smith, C. Kunkel, G. Anderson, J. Muck.

ODFW. 1995. Comprehensive plan for production and management of Oregon's anadromous salmon and trout. Part III: Steelhead. Ore. Dept. Fish Wild., Portland, Oregon, 58.

Odum, W.E. 1971. Fundamentals in Ecology. W. B. Saunders. Philadelphia, Pennsylvania.

OGP (International Association of Oil and Gas Producers) and IAGC (International Association of Geophysical Contractors). 2011. An overview of marine seismic operations. Report No. 448. April 2011. 50p.

Ogura, M. 1994. Migratory behavior of Pacific salmon (*Oncorhynchus* spp.) in the open sea. Bull. Nat. Res. Inst. Far Seas Fish. 31:1-139.

Ohmart, R.D. and B.W. Anderson. 1982. North American desert riparian ecosystems. p. 433-466. In: G. L. Bender, ed., Reference Handbook on the Deserts of North America. Greenwood Press, Westport, Connecticut.

Olegario, A.O. 2006. Over-wintering diet, growth, and prey availability to juvenile coho salmon (*Oncorhynchus kisutch*) in the West Fork Smith River, Oregon. M. S. Thesis, Oregon State University.

Olson, A.M., S.V. Visconty, B.W. Witherspoon (II), K. Sweeny, R.M. Thom, D.K. Shreffler. 1997. Light environment and eelgrass shading around three WSDOT ferry terminals. Pp.52-74 in Simenstad, C.A.

Omernik, J.M. 1977. Nonpoint source-stream nutrient level relationships: A nationwide study. EPA-600/3/77-105. US Environmental Protection Agency. Corvallis, Oregon.

Ometo, J.P.; L.A. Martinelli, M.V. Ballester, A. Gessner, and A. Krusche. 2000. Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba River Basin, southeast Brazil. Freshwater Biology 44: 327–37.

O'Neill, S.M. and J.E. West. 2009. Marine distribution, life history traits, and the accumulation of polychlorinated biphenyls in Chinook salmon from Puget Sound, Washington. Transactions of the American Fisheries Society 138: 616-632.

Oregon Territorial Sea Management Study. 1987. Oregon Department of Land Conservation and Development, Salem, Oregon.

Orr, R. and J.P. Fisher. 2009. Trinational risk assessment guidelines for aquatic alien invasive species. Pp. 9-15 in: Trinational Risk Assessment Guidelines for Aquatic Alien Invasive Species: Test Cases for the Snakeheads (Channidae) and Armored Catfishes (Loricariidae) in North American Inland Waters (Fisher, J.P., R. Orr., P. Koleff and B. Cudmore [eds.]). Commission for Environmental Cooperation, Montreal, Canada.

OWRRI (Oregon Water Resources Research Institute). 1995. Gravel Disturbance Impacts on Salmon Habitat and Stream Health, Volume 1. Summary report. Oregon State University, Corvallis, Oregon.

Packer, D.B., K. Griffin, and K.E. McGlynn. 2005. National Marine Fisheries Service, National Gravel Extraction Guidance. A review of the effects of in- and near-stream gravel extraction on anadromous fishes and their habitats, with recommendations for avoidance, minimization, and mitigation. Silver Spring, Maryland.

Palmer, M.A. 2005. Standards for ecological successful river restoration. Journal of Applied Ecology 42: 208-217.

Parker, R.R. 1965. Estimation of sea mortality rates for the 1961 brood-year pink salmon of the Bella Coola area, British Columbia. J. Fish. Res. Board Can. 22:1523-1554.

Parker, R.R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. J. Fish. Res. Board Can. 25:757-794.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Parker, R.R. and R.J. LeBrasseur. 1974. Ecology of early sea life, pink and chum juveniles, p. 161-171. In: D. R. Harding, ed. Proceedings of the 1974 northeast Pacific pink and chum salmon workshop. Department of the Environment, Fisheries, Vancouver, British Columbia, Canada.

Paul, M.J., Meyer, J.L. 2001. Streams in the urban landscape. Annual Review of Ecological Systems 32: 333-365.

Pearce, T.A., J.H. Meyer, and R.S. Boomer. 1982. Distribution and food habits of juvenile salmon in the Nisqually Estuary, Washington, 1979-1980. U.S. Fish Wildl. Serv., Fish. Assist. Off., Olympia, Washington, 77. (Available from U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, 2625 Parkmount Lane, Bldg. A, Olympia, Washington, 98502).

Pearcy, W.G. 1992. Ocean ecology of north Pacific salmonids. Univ. Washington Press, Seattle, 179.

Pearcy, W.G. and J.P. Fisher. 1988. Migrations of coho salmon, *Oncorhynchus kisutch*, during their first summer in the ocean. Fish. Bull., U.S. 86(2):173-186.

Pearcy, W.G. and J.P. Fisher. 1990. Distribution and abundance of juvenile salmonids off Oregon and Washington, 1981-1985. NOAA Tech. Rep. 87. 83p.

Pearson, W.H. and J.R. Skalski. 2011. Factors affecting stranding of juvenile salmonids by wakes from ship passage in the lower Columbia River. River Research and Applications 27(7):926-936.

Pearson, W.H., J. R. Skalski, K. L. Sobocinski, M. C. Miller, G. E. Johnson, G. D. Williams, J. A. Southard, and R. A. Buchanan. 2006. A study of stranding of juvenile salmon by ship wakes along the Lower Columbia River using a Before-and-After Design: Before-phase results. Battelle Marine Sciences Laboratory, PNNL-15400, Sequim, Washington.

Pearson, W.H., W.C. Fleece, K. Gabel, S. Jenniges, and J.R. Skalski. 2008. Spatial analysis of beach susceptibility for stranding of juvenile salmonids by ship wakes, Final Report prepared for the Port of Vancouver by ENTRIX, Inc., Project No. 4154501, Olympia, Washington.

Peek, J.M. and P.D. Dalke. 1982. Wildlife – livestock relationships symposium; Proceedings 10. (ed). April 20-22, 1982, Coeur d'Alene, Idaho. Univ. of Idaho Forest, Wildlife, and Range Experiment Station. Moscow, Idaho.

Penttila, D. 2007. Marine forage fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-2003, Seattle, Washington.

Pess, G.R., R. and H.M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 59:613-623.

Pess, G.R., R. Hilborn, K. Kloehn, and T.P. Quinn. 2012. The influence of population dynamics and environmental conditions on pink salmon recolonization after barrier removal. Canadian Journal of Fisheries and Aquatic Sciences 69:970-982.

Pess, G.R., T.J. Beechie, J.E. Williams, D.R. Whitall, J.I. Lange, and J.R. Klochak. 2003. Watershed assessment techniques and the success of aquatic restoration activities. Pp. 185–201 in: R.C. Wissmar and P.A. Bisson, eds. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. Fisheries Society, Bethesda, MD.

Peterson, N. P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39:1308-1310

PFMC (Pacific Fishery Management Council). 1988. Eighth amendment to the fishery management plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, California commencing in 1978. Portland, Oregon.

PFMC. 1998. Preseason report I: Stock abundance analysis for 1998 ocean salmon fisheries. PFMC, 2130 SW Fifth Ave, Suite 224, Portland, Oregon, 97201.

PFMC. 1999. Identification and description of essential fish habitat, adverse impacts, and recommended conservation measures for salmon. Appendix A to Amendment 14, Pacific Coast salmon fishery management plan.

PFMC. 2012. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California as Revised through Amendment 17. PFMC, Portland, OR. 90 p.

Phillips, A.C. and W.E. Barraclough. 1978. Early marine growth of juvenile Pacific salmon in the Strait of Georgia and Saanich Inlet, British Columbia. Can. Fish. Mar. Serv. Tech. Rep. 830, 19.

Phillips, R. 1984. The ecology of eelgrass meadows in the Pacific Northwest: A community profile. U.S. Fish and Wildlife Service. FWS/OBS-84/24.

Piccolo, J.J. and M.S. Wipfli. 2002. Does red alder (*Alnus rubra*) in upland riparian forests elevate macroinvertebrate and detritus export from headwater streams to downstream habitats in southeastern Alaska? Canadian Journal of Fisheries and Aquatic Sciences 59:203-513.

Pilati, D.A. 1976. Cold shock: biological implications and a method for approximating transient environmental temperatures in the near-field region of a thermal discharge. Science of the Total Environment 6(3):227-37.

Pimentel, D. (ed.). 2002. Biological invasions: economic and environmental costs of alien plant, animal and microbe species. Boca Raton/London/New York/Washington DC; CRC Press, 369 pp.

Pimentel, D., L. Lach, R. Zuniga and D. Morrison. 2000. Environmental and economic costs of non-indigenous species in the Unites States. Bioscience, 50:53-65.

Pimentel, D., R. Zumniga and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological economics 52:273-288.

Platts, W.S. 1981. Influence of forest and rangeland management on anadromous fish habitat in western North America -effects of livestock grazing. USDA Forest Service Gen. Tech. Report PNW-124. 25 p.

Platts, W.S. 1991. Livestock grazing. Pp. 389-423. In: W. R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society. Special Publication 19. Bethesda, Maryland, 751.

Platts, W.S., R.J. Torquemada, M.L. McHenry, and C.K. Graham. 1989. Changes in salmon spawning and rearing habitat from increased delivery of fine sediment to the south fork Salmon River, Idaho. Trans. Am. Fish. Soc. 118:274-283.

Ploskey, G.R. 1983. Review of the effects of water-level changes on reservoir fisheries and recommendations for improved management. Technical report VESW/TR/E-83-3. U.S. Army, Engineering and Waterways Experiments Station. Vicksburg, Mississippi.

PNPCC (Pacific Northwest Pollution Control Council). 1971. Log storage and rafting in public waters. Task force report.

Pollock, M.M., Beechie, T.J., M. Liermann, and R E. Bigley. 2009. Stream temperature relationships to forest harvest in the Olympic Peninsula, Washington. Journal of the American Water Resources Association 45:141-156.

Pollock, M.M., G.R. Pess, T.J. Beechie and D.R. Montgomery. 2004. The importance of beaver dams to coho production in the Stillaguamish River basin, Washington, USA. North American Journal of Fisheries Management 24: 749-760.

Pollock, M.M., G.R. Pess, T.J. Beechie, and D.R. Montgomery. 2004. The importance of beaver ponds to

Pollock, M.M., J. Wheaton, C. Jordan and N. Bouwes. 2012. Working with Beaver to Restore Salmon Habitat In the Bridge Creek Intensively Monitored Watershed—Design Rationale and Hypotheses. NOAA Technical Memorandum NMFS-NWFSC-120. 34 pp + appendices.

Pollock, M.M., M. Heim, and D. Werner. 2003. Hydrologic and geomorphic effects of beaver dams and their influence on fishes. Am. Fish. Soc. Special Symposium 37:213-233.

Pollock, M.M., R.J. Naiman and T.A. Hanley. 1998. Predicting plant species richness in forested and emergent wetlands - A test of biodiversity theory. Ecology 79: 94-105.

Pollock, M.M., T.J. Beechie and C.E. Jordan. 2007. Geomorphic changes upstream of beaver dams in Bridge Creek, an incised stream in the interior Columbia River basin. Earth Surface Processes and Landforms 32: 1174-1185.

Pond, F.W. 1961. Effect of the intensity of clipping on the density and production of meadow vegetation. J. Range Manage. 14:34-38.

Poole, G.C. and C.H. Berman. 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management 27(6):787-802.

Poole, G.C., J. Dunham, M. Hicks, D. Keenan, J. Lockwood, E. Materna, D. McCullough, C. Mebane, J. Risley, and S. Sauter. 2001b. Technical synthesis: scientific issues relating to temperature criteria for salmon, trout, and char native to the Pacific Northwest. Prepared as part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA 910-R-01-007. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. 21 p.

Poole, G.C., J. Risley, and M. Hicks. 2001a. Spatial and temporal patterns of stream temperature (revised). Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-01-003. U.S. Environmental Protection Agency, Region 10, Seattle, Washington. 33 p.

Popper, A.N. and M.C. Hastings. 2009a. The effects of anthropogenic sources of sound on fishes. Journal of Fish Biology 75:455-489.

Popper, A.N. and M.C. Hastings. 2009b. The effects of human-generated sound on fish. Integrative Zoology 4:43-52.

Popper, A.N. and R.R. Fay. 2010. Rethinking sound detection by fishes. Hearing Research 237:25-36.

Popper, A.N., M.D. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann, D. A. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. Journal of the Acoustical Society of America 117:3958–3971.

Poston, T. 2001. Treated wood issues associated with overwater structures in marine and freshwater environments. White paper submitted to Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation by Batelle. Available at http://www.wa.gov/wdfw/hab/ahg/finaltw.pdf.Sargent et al. 1995.

Powers, S.P., M.A. Bishop, and G.H. Reeves. 2006. Estuaries as essential fish habitat for salmonids: Assessing residence time and habitat use of coho and sockeye salmon in Alaska estuaries. North

Pacific Research Board Project Final Report 310. 65pp.

Pozarycki, S., L. Weber, and H. Lee, II. 1997. The effects on English sole on carbaryl application on oyster beds. Poster presentation, Oregon State University, Hatfield Marine Science Center and EPA Coastal Ecology Branch, Newport, Oregon.

Prakash, A. 1962. Seasonal changes in feeding of coho and Chinook (spring) salmon in southern British Columbia waters. J. Fish. Res. Bd. Can. 19:851-866.

Precht, W.F., R.B. Aronson, and D.W. Swanson. 2001. Improving scientific decision-making in the restoration of ship-grounding sites on coral reefs. Bulletin of Marine Science 69(2):1001-1012.

Pressey, R.T. 1953. The sport fishery for salmon on Puget Sound. Washington Department of Fisheries, Fisheries Research Papers 1:33-48.

Previsic, M. 2010. RE Vision DE-001: Deployment effects of marine renewable energy technologies. Wave energy scenarios. U.S. Department of Energy, Advanced Waterpower Program. 106p.

Pritchard, A.L. 1934. Do caddis fly larvae kill fish? Can. Field-Nat. 48:39 p.

Pritchard, A.L. 1937. Variation in the time of run, sex proportions, size, and egg content of adult pink salmon (*Oncorhynchus gorbuscha*) at McClinton Creek, Masset Inlet, British Columbia, Canada J. Bill. Board Can. 3(5):403-416.

Pritchard, A.L. 1939. Homing tendency and age at maturity of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. J. Fish. Res. Board Can. 4:233-251.

Pritchard, A.L. 1940. Studies on the age of the coho salmon (*Oncorhynchus kisutch*) and the spring salmon (*Oncorhynchus tshawytscha*) in British Columbia. Trans. R. Soc. Can., Serv. 3, 34(V):99-120.

Pritchard, A.L. 1948. A discussion of the mortality in pink salmon (*Oncorhynchus gorbuscha*) during their period of marine life. Proc. Trans. R. Soc. Can. Ser. 3 42(5):125-133.

Pritchard, A.L. and A.C. DeLacy. 1944. Migration of pink salmon (*Oncorhynchus gorbuscha*) in southern British Columbia and Washington in 1943. Fish. Res. Board Can., Bull. 66, 23.

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

Quinn, T.P., J. Chamberlin, and E.L. Brannon. 2011. Experimental evidence of population-specific spatial distributions of Chinook salmon, *Oncorhynchus tshawytscha*. Environmental Biology of Fishes 92:313-322.

RAC (Resource Agency of California). 1997. California's ocean resources: An agenda for the future. Habitats and living resources. Sacramento, California.

Ralph, S., G. Poole, L.Conquest, and R. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins in western Washington. Canadian Journal of Fisheries and Aquatic Sciences. 51:37-51.

Ralph, S.C., G.C. Poole, L.L. Conquest, R.J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Can. J. Fish. Aquat. Sci. 51:37-51.

Rashin, E.B., C.J. Clishe, A.T. Loch, and J.M. Bell. 2006. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. Journal of the American Water Resources Association 42(5):1307-1327.

Rauzi, F. and C. L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Management. 26:126-129.

Raymond, H. 1979. Effects of dams and impoundment on migrations of juvenile Chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Amer. Fish. Soc. 108 (6):505-529.

Readman, J. W., L. L. W. Kwong, D. Grondin, J. Bartocci, J. Villeneuve, and L. D. Mee. 1993. Coastal water contamination from a triazine herbicide used in antifouling paints. Environmental Science and Technology 27:1940-1942.

Redding, J.M., C.B. Schreck, and F.H. Everest. 1987. Physiological effects on coho salmon and steelhead of exposure to suspended soils. Trans. Am. Fish. Soc. 116:737-744.

Reeves, G. H., F. H. Everest, and T. E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. U.S. Forest Service Gen. Tech. Rep. PNW-GTR-245, 18.

Reeves, G. H., L. E. Benda, K. M. Burnett, P. A. Bisson, and J. R. Sedell. 1995. A disturbance-based approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium 17:334-349.

Reeves, G.H., F.H. Everest, and J.D. Hall. 1987. Interaction between the redside shiner (Richardsonius balteatus) and the steelhead trout (Salmo gairdneri) in western Oregon: the influence of water temperature. Can. J. Fish. Aquat. Sci. 44:1603-1613.

Reeves, G.H., K.M. Burnett, and E.V. McGarry. 2003. Sources of large wood in the main stem of a fourth-order watershed in coastal Oregon. Can. J. For. Res. 33:1363-1370.

Reid, L.M. 1993. Research and cumulative watershed effects. General Technical Report PSW-GTR-141. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Reid, L.M. and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20:1753-1761.

Reimers, P. E. 1973. The length of residence of juvenile fall Chinook salmon in the Sixes River, Oregon. Oreg. Fish Comm. 4, 2-43.

Reisenbichler, R.R. 1997. Genetic factors contributing to declines of anadromous salmonids in the Pacific Northwest. Pp. 223-244 in D J. Stouder, P. A. Bisson, and R. J. Naiman, eds. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Rice, C.A., C.M. Greene, P. Moran, D.J. Teel, D.R. Kuligowski, R.R. Reisenbichler, E.M. Beamer, J.R. Karr, and K.L. Fresh. 2011. Abundance, stock origin, and length of marked and unmarked juvenile Chinook salmon in the surface waters of Greater Puget Sound. Transactions of the American Fisheries Society 140:170-189.

Rich, W.H. 1920. Early history and seaward migration of Chinook salmon in the Columbia and Sacramento Rivers. U.S. Bur. Fish., Bull. 37:74.

Richardson, J.S. 2008. Aquatic arthropods and forestry: effects of large-scale land use on aquatic systems in Nearctic temperate regions. Can. Entomol. 140:495-509.

Richardson, J.S. and R.J. Danehy. 2007. A synthesis of the ecology of headwater streams and their riparian zones in temperate forests. For. Sci. 53:131-147.

Ricker, W.E. 1962. Regulation of the abundance of pink salmon populations, pp. 155-206. In: N. J. Wilimovsky, ed. Symposium on pink salmon. H. R. MacMillan lectures in fisheries. Institute of Fisheries, University of British Columbia, Vancouver, British Columbia, Canada.

Ricker, W.E. 1964. Ocean growth and mortality of pink and chum salmon. J. Fish. Res. Board Can. 21:905-931.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. In: R. C. Simon and P. A. Larkin, eds., The stock concept in Pacific salmon, pp. 19-160. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver.

Ricker, W.E. 1980. Causes of decrease in size and age of Chinook salmon (*Oncorhynchus tshawytscha*). Can. Tech. Rep. Fish. Aquat. Sci. 944:2.

Ricker, W.E. and J.I. Manzer. 1974. Recent information on salmon stocks in British Columbia. Int. North Pac. Fish. Comm. Bull. 29:1-24.

Riley, W.D., D.L. Maxwell, M.G. Pawson, and M.J. Ives. 2009. The effects of low summer flow on wild salmon (*Salmo salar*), trout (*Salmo trutta*) and grayling (*Thymallus thymallus*) in a small stream. Freshwater Biology 54(12): 2581-2599.

Roberts, D.A., E.L. Johnston, and N.A. Knott. 2010. Impacts of desalination plant discharges on the marine environment: A critical review of published studies. Water Resources 44:5117-5128.

Robins, J.R., C.A. Abrey, T.P. Quinn, and D.E. Rogers. 2005. Lacustrine growth of juvenile pink salmon and a comparison with sympatric sockeye salmon. Journal of Fish Biology 66: 1671-1680.

Robison, E.G., K.A. Mills, J. Paul, L. Dent, A. Skaugset. 1999. Storm impacts and landslides of 1996: final report. Forest Practices Technical Report #4. Oregon Dept. of Forestry, Salem, OR.

Rogers, CA. 1976. Effects of temperature and salinity on the survival of winter flounder embryos. Fisheries Bulletin 74(1):52-8.

Rogers, P.H. and M. Cox. 1988. Underwater sound as a biological stimulus. Pp. 131–149 in: Sensory Biology of Aquatic Animals. Atema, J., R.R. Fay, A.N. Popper, and W.N. Tavolga, eds., New York, NY: Springer-Verlag.

Rohde, J., K.L. Fresh, A.N. Kagley, F.A. Goetz, and T.P. Quinn. In review. Partial migration and diel movement patterns in Puget Sound coho (*Oncorhynchus kisutch*). Transactions of the American Fisheries Society.

Roni, P. 1992. Life history and spawning habitat of four stocks of large-bodied Chinook salmon (*Oncorhynchus tshawytscha*). Master's thesis. University of Washington, Seattle: 96.

Roni, P. and T. Beechie, Eds. 2013. Stream and Watershed Restoration, Wiley-Blackwell. Oxford, UK.

Roni, P., T. Bennett, G. Pess, K. Hanson, R. Moses, M. McHenry, W Ehinger, and J. Walter. 2012. Factors affecting migration timing, growth, and survival of juvenile coho in two coastal Washington watersheds. Transactions of American Fisheries Society 141: 890-906.

Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. N. Am. J. Fish. Manag. 22:1-20.

Rosell, F., O. Bozser, P. Collen and H. Parker. 2005. Ecological Impact of beavers Castor Fibre and Castor canadensis and their ability to modify ecosystems. Mammalian Reviews 35: 248-276.

Rosenfeld, J. S., T. Leiter, G. Lindner, and L. Rotham. 2005. Food abundance and fish density alters habitat selection, growth, and habitat suitability curves for juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 62: 1691-1701.

Rounsefell, G. A. 1957. Fecundity in North American salmnonidae. U.S. Fish Wildl. Serv. Fish Bull. 57:451-468.

Ruggerone, G.T. and F.A. Goetz, F.A. 2004. Survival of Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) in response to climate-induced competition with pink salmon (*Oncorhynchus gorbuscha*). Canadian Journal of Fisheries and Aquatic Sciences 61: 1756-1770.

Ruggerone, G.T., S.E. Goodman, and R. Miner. 2008. Behavioral Response and Survival of Juvenile Coho Salmon to Pile Driving Sounds. Natural Resources Consultants, Inc., Seattle, Washington.

Ruiz, G.M., P.W. Fofonoff, J.T. Carlton, M.J. Wonham, and A.H. Hines. 2000. Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases. Annual Review of Ecology and Systematics 31:481-531.

Safavi, H.R. 1996. Quality control of urban runoff and sound management. Hydrobiologia., 320(1-3):131-141.

Saha, M.K. and S.K. Konar. 1986. Chronic effects of crude petroleum on aquatic ecosysytem. Environmental Ecology 4:506-510.

Salminen, E.M. and R.L. Beschta. 1991. Phosphorus and forest streams: the effects of environmental conditions and management activities. Dept. of Forest Engineering, Oregon State University, Corvallis, OR.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pp.231-310 in: Groot. C. and L. Margolis, eds., Pacific salmon life histories. UBC Press, Vancouver.

Sand, O., P.S. Enger, H.E. Karlsen, and F.R. Knudsen. 2001. Detection of infrasound in fish and behavioral responses to intense infrasound in juvenile salmonids and European silver eels: a minireview. American Fisheries Society Symposium 26:183-193.

Sandahl, J.F., D.H. Baldwin, J.J. Jenkins, N.L. Scholz. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. Environmental Science & Technology. 41(8):2998-3004.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). In: C. Groot and L. Margolis (editors), Pacific salmon life histories, p. 396-445. Univ. British Columbia Press, Vancouver.

Sanderson, B., K. Macneale, A. Goodwin and H. Coe. In preparation. Diets reveal minimal competition for prey among non-native brook trout and native salmonids in multiple Idaho streams.

Sanderson, B.L., K. A. Barnas, and A. M. Rub. 2009. Nonindigenous species of the Pacific Northwest: an overlooked risk to endangered salmon. Bioscience 59: 245-256.

Santulli, A., A. Modica, E. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. D'Amelio. 1999. Biochemical responses of European sea bass (Dicentrarchus labrax L.) to the stress induced by off shore experimental seismic prospecting. Marine Pollution Bulletin 38(12):1105-1114.

Sasaki, S. 1966. Distribution and food habits of king salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout (*Salmo gairdnerii*) in the Sacramento-San Joaquin delta. Calif. Dep. Fish Game Bull. 136:108-114.

Satterwaithe, T. 1998. Personal communication. Oregon Department of Fish and Wildlife, Gold Beach, Oregon.

Sauter, S.T., J. McMillan, and J. Dunham. 2001. Salmonid behavior and water temperature. Issue paper 1. Prepared as part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project. EPA-910-D-001. U.S. Environmental Protection Agency, Region 10, Seattle, Washington 36 p.

Schabetsberger, R., Morgan, C.A., Brodeur, R.D., Potts, C.L., Peterson, W.T. and Emmett, R.L. (2003) Prey selectivity and diel feeding chronology of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Columbia River plume. Fisheries Oceanography 12: 523–540.

Schaffelke, B. and C.L. Hewitt. 2007. Impacts of introduced seaweeds. Bot Mar 50: 397-417.

Schiel, D.R., J.R. Steinbeck, and M.S. Foster. 2004. Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. Ecology 85:1833-1839.

Schindler, D.E., M.D. Scheuerell, J.W. Moore, S.M., Gende, T.B. Francis, and W.J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. Frontiers in Ecology and the Environment 1:31-37.

Schullery, P. 1989. The fires and fire policy. Bioscience 39:686-694.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Bd. Can. 966p.

Scrivener, J.C. and B.C. Andersen. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 41:1097-1105.

SCS Enginners. 1989. Hazardous waste minimization audit study of marine yards for maintenance and repair. Prepared for California Department of Health Services, Alternative Technology and Policy Development Section. Sacramento, California.

Seals, J. and R. French. 2012. Supplemental Annual Report of the Mid-Columbia Fish District. 2011. Oregon Department of Fish and Wildlife. The Dalles, OR.

Sedell, J., G. Reeves, and P. Bisson. 1997. Habitat policy for salmon in the Pacific Northwest, In: Pacific salmon and their ecosystems: Status and future options, D. Stouder, P. Bisson, and R. Naiman, ed. Chapman and Hall, New York.

Seiler, D. 1989. Differential survival of Grays Harbor basin anadromous salmonids: Water quality implications. Can. Spec. Publ. Fish. Aquat. Sci. 105:123-135.

Seiler, D., S. Neuhauser, and M. Ackley. 1981. Upstream/downstream salmonid trapping project, 1977-1980. Wash. Dep. Fish. Prog. Rep. 144, 197.

Semko, R.S. 1954. The stocks of west Kamchatka salmon and their commercial utilization. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 41:3-109. (Transl. from Russian; Fish. Res. Board Can. Transl. Ser. 288).

Servizi, J.A. and D.W. Martens. 1991. Effect of temperature, season, and fish size on acute lethality of suspended sediments to coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 48:493-497.

Seton, E.T. 1929. Lives of game animals. Doubleday, Doran and Co., Inc. Garden City, New York, USA.

Shafer, D.J. 2002. Recommendations to minimize potential impacts to seagrasses from single-family residential dock structures in the Pacific Northwest. U.S. Army Corps of Engineers Research and Development Center, Vicksburg, Mississippi. 28 p.

Shaffer, G.P. 1984. The effect of sedimentation on the primary production of benthic microflora. Estuaries 7(4B):497-500.

Shaklee, J.B., D.C. Klaybor, S. Young, and B.A. White. 1991. Genetic stock structure of odd-year pink salmon, *Oncorhynchus gorbuscha* (Walbaum), from Washington and British Columbia and potential mixed-stock fisheries applications. J. Fish Bill. 39 (Suppl. A):21-34.

Shaklee, J.B., J. Ames, and D. Hendrick. 1995. Genetic diversity units and major ancestral lineages for pink salmon in Washington. In C. Busack and J.B. Shaklee, eds., Genetic diversity units and major ancestral lineages of salmonid fishes in Washington. Wash. Dep. Fish Wildl. Tech. Rep. RAD95-02, pp. B1-B37. (Available from Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington, 98501).

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California and recommendations regarding their management. Calif. Dep. Fish Game, Fish Bull. 98, 375.

Shaw, E.A. and J.S. Richardson. 2001. Direct and indirect effects of sediment pulse duration on stream invertebrate assemblages and rainbow trout (*Oncorhynchus mykiss*) growth and survival. Can. J. Fish. Aquat. Sci 58:2213-2221.

Sherwood, C., D. Jay, B. Harvey, P. Hamilton, and C. Simenstad. 1990. Historical changes in the Columbia River estuary. Progress in Oceanography, 25:299-352.

Shipman, H. 2009. Shoreline erosion on Puget Sound: Implications for the construction and potential impacts of erosion control structures. Presentation made at Puget Sound Shorelines and the Impacts of Armoring Workshop, May 12-14 2009. Abstract only. http://wa.water.usgs.gov/SAW/abstracts.html#shipman

Short, F.T., E.W. Koch, J.C. Creed, K.M. Magalhaes, E. Fernandez, and J.L. Gaeckle. 2006. SeagrassNet monitoring across the Americas: case studies of seagrass decline. Marine Ecology 27: 277-289.

Shreffler, D.K. and W.M. Gardiner. 1999. Preliminary findings of diving and lights surveys. In Simenstad, C.A., R.M. Thom, and A.M. Olson (eds.). 1997. Mitigation between regional transportation needs and preservation of eelgrass beds. Research report, vol. 1. Washington State Transportation Commission/USDOT. 103 pp.

Shrimpton, J.M., J.D. Zydlewski, and J.W. Heath. 2007. Effect of daily oscillation in temperature and increased suspended sediment on growth and smolting in juvenile Chinook salmon, *Oncorhynchus tshawytscha*. Aquaculture 273:269-276.

Shultz, R. and E. Dibble 2012. Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. Hydrobiologia 684:1-14.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: An unappreciated function. In: V. S. Kennedy, ed., Estuarine comparisons, pp. 343-364. Academic Press, New York.

Simenstad, C. and K. Fresh. 1995. Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: Scales of disturbance. Estuaries, 18:43-70.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (Sebastes spp.). Canadian Journal of Fisheries and Aquatic Sciences 49:1357–1365.

Skeesick, D.G. 1970. The fall immigration of juvenile coho salmon into a small tributary. Fish Comm. Oregon Res. Rep. 2(1):1-6.

Skiles, T.D., R.M. Yoshiyama, and P. Moyle. 2013. Pink salmon (*Oncorhynchus gorbuscha*) in the Salinas River, California: new record and historical perspective. California Fish and Game 99(1):55-59.

Slaney, T.L., K.D. Hyatt, T.G. Northcote, and R.J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21(10): 20-35.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research 67:143–150.

Smirnov, A.I. 1975. The biology, reproduction, and development of the Pacific salmon. Izdatel'stvo Moskovskogo Universiteta, Moscow, USSR. (Transl. from Russian; Fish. Res. Board Can. Transl. Ser. 2861).

Sommer, T.R., M.L. Nogriba, W.C. Harrell, W. Batham, W. J. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence for enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. Journal of the Acoustical Society of America 124:1360–1366.

Soria, M., P. Fréon, and F. Gerlotto. 1996. Analysis of vessel influence on spatial behaviour of fish schools using a multi-beam sonar and consequences for biomass estimates by echo-sounder. ICES Journal of Marine Science: Journal du Conseil 53(2):453-458.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R. Novitzki. 1996. An ecosystem approach to salmonid conservation. Prepared by Management Technology for the National Marine Fisheries Service. TR-4501-96-6057. 356p.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An ecosystem approach to salmonid conservation. Prepared by Management Technology for the National Marine Fisheries Service. TR-4501-96-6057. 356p. (Available from the NMFS Habitat Branch, Portland, Oregon).

Spence, B.C., S.L. Harris, W.E. Jones, M.N. Goslin, A. Agrawal, and E. Mora. 2005. Historical occurrence of coho salmon in streams of the Central California Coast coho salmon evolutionarily significant unit. NOAA Technical Memorandum NMFS-SWFSC-383.

Spence, B.C., W.G. Duffy, J.C. Garza, B.C. Harvey, S.M. Sogard, L.A. Weitkamp, T.H. Williams, and D.A. Boughton. 2011. Historical occurrence of coho salmon (*Oncorhynchus* kisutch) in streams of the Santa Cruz Mountain region of California: Response to an Endangered Species Act petition to delist coho slamnon south of San Francisco Bay. NOAA Technical Memorandum NMFS-SWFSC-472.

SRSRB (Snake River Salmon Recovery Board). 2006. Snake River salmon recovery plan for Southeast Washington. Available at: http://www.snakeriverboard.org/resources/library.htm.

Stadler, J., K. Griffin, E. Chavez, B. Spence, P. Roni, C. Gavette, B. Seekins, and A. Obaza. 2011. Pacific Coast Salmon 5-Year Review of Essential Fish Habitat. Final Report to the Pacific Fishery Management Council. 2011.

Stadler, J.H. 2002. Observations of fish kill at Winslow Ferry Terminal, Bainbridge Island, WA. October 7, 2002.

Stammerjohn, S., E. Smith, W.R. Boynton, and W.M. Kemp. 1991. Potential impacts from marinas and boats in Baltimore Harbor. Chesapeake Research Consortium, Inc., CRC Publication Number 139, Solomons, Maryland.

Stansell, R.J., K.M. Gibbons, and W.T. Nagy. 2010. Evaluation of pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2008-2010. U. S. Army Corp of Engineers Report.

Stednick, J.D. 1996. Monitoring the effects of timber harvest on annual water yield. J. Hydrology 176:79-95.

Stehr, C.M., D.W. Brown, T. Hom, B.F. Anulacion, W.L. Reichert, T.K. Collier. 2000. Exposure of juvenile chinook and chum salmon to chemical contaminants in the Hylebos Waterway of Commencement Bay, Tacoma, Washington. Journal of Aquatic Ecosystem Stress and Recovery 7:215-227.

Stein, J., T. Hom, T. Collier, D. Brown, and U. Varanasi. 1995. Contaminant exposure and biochemical effects in outmigrant juvenile Chinook salmon from urban and nonurban estuaries of Puget Sound, Washington. Environmental Toxicology and Chemistry, 14:1019-1029.

Steinblums, I. 1977. Streamside buffer strips: survival, effectiveness, and design. M.S. thesis. Oregon State

University, Corvallis, OR. 181 p.

Steinblums, I., H.A. Froehlich, and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. J. Forestry 82(1):49-52.

Stephenson, A.E., D.E. Fast, and Yakama Nation Fisheries. 2005. Monitoring and evaluation of avian predation on juvenile salmonids on the Yakima River, Washington, Annual Report 2004. Yakima Klickitat Fisheries Project. Yakama Nation Fisheries. Prepared for US Department of Energy, Bonneville Power Administration, Environment, Fish and Wildlife. Portland, OR.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2004. Changes in snowmelt runoff timing in western North America under a ‘business as usual' climate change scenario. Climatic Change 62:217-232.

Stewart, R.M., D.G. McFarland, D.L. Ward, S.K. Martin, and J.W. Barko. 1997. Flume study investigation of the direct impacts of navigation-generated waves on submersed aquatic macrophytes in the upper Mississippi River. U.S. Army Corps of Engineers Waterways Experiment Station, ENV Report 1, Vicksburg, Mississippi.

Stober, Q.J., M.R. Criben, R.V. Walker, A.L. Setter, I. Nelson, J.C. Gislason, R.W. Tyler, and E.O. Salo. 1979. Columbia River irrigation withdrawal environmental review: Columbia River fishery study. Final report, Contract Number DACW5779-C-0090, Corps, FRI-UW-7919, University of Washington, 244.

Story, A., R.D. Moore, and J.S. Macdonald. 2003. Stream temperatures in two shaded reaches below cutblocks and logging roads: downstream cooling linked to subsurface hydrology. Can. J. For. Res. 33:1383-1396.

Stotz, T. and J. Colby. 2001. January 2001 dive report for Mukilteo wingwall replacement project. Washington State Ferries Memorandum. 5 pp. + appendices.

Stratus Consulting Inc. 2006. Creosote-treated wood in aquatic environments: Technical review and use recommendations.

StreamNet GIS Data (2012d). Metadata for StreamNet generalized fish distribution, pink salmon spatial data set. Portland (OR). Streamnet, January 2012. [May 6, 2013]. URL:http://www.streamnet.org/gisdata/map_data_biological/FishDist_MSHv3_January2012/FishD_PinkSalmon_January2012.xml

StreamNet. (2012a). Metadata for StreamNet generalized fish distribution, fall Chinook spatial data set. Portland (OR): Streamnet, January 2012. [May 6, 2013]. URL:http://www.streamnet.org/gisdata/map_data_biological/FishDist_MSHv3_January2012/FishD_ChinookFall_January2012.xml

StreamNet. (2012b). Metadata for StreamNet generalized fish distribution, spring Chinook spatial data set. Portland (OR): Streamnet, January 2012. [May 6, 2013]. URL:http://www.streamnet.org/gisdata/map_data_biological/FishDist_MSHv3_January2012/FishD_ChinookSpring_January2012.xml

StreamNet. (2012c). Metadata for StreamNet generalized fish distribution, coho salmon spatial data set. Portland (OR): Streamnet, January 2012. [May 6, 2013]. URL:http://www.streamnet.org/gisdata/map_data_biological/FishDist_MSHv3_January2012/FishD_CohoSalmon_January2012.xml

Streif, 1996. Guidelines for environmentally friendly EWP projects, Natural Resources Conservation Service, U.S. Department of Agriculture, Salem, Oregon.

Strickland, R. and D. Chasan. 1993. The oil industry and its impacts. Washington State Sea Grant Program. University of Washington, Seattle, Washington.

Sullivan, K., T.E. Lisle, C.A. Dolloff, G.E. Grant, and L.M. Reid. 1987. Stream channels: the link between forests and fishes. Pp. 191-232 in: E.O. Salo and T.W. Cundy, eds. Streamside management: forestry and fishery interactions. Contribution 57, University of Washington, Institute of Forest Resources. Seattle, WA.

Sumner, F.H. 1953. Migrations of salmonids in Sand Creek, Oregon. Trans. Am. Fish. Soc. 82:139-149.

Suttle, K.B., M.E. Power, J.M. Levine, and N. McNeely. 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecol. Appl. 14:969-974.

Sutton, R., M. 2007. Klamath River thermal refugia study, 2006. U.S. Bureau of Reclamation Technical Memorandum 86-68290-01-07.

Svedrup, A., E. Kjellsby, P.G. Kruger, R. Fløysand, F.R. Knüdsen, P.S. Enger, G. Serck-Hanssen, and K.B. Helle. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. Journal of Fish Biology 45:973-995.

Swales, S. and C.D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:232-242.

Swales, S., F. Caron, J. R. Irvine, and C. D. Levings. 1988. Overwintering habitats of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Keogh River system, British Columbia. Can. J. Zool. 66:254-261.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64:1506-1514.

Swanson, F.J. and C.T. Dyrness. 1975. Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3:393-396.

Swanston, D.N. 1991. Natural processes. P. 139-179 in: W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Pub. 19. Bethesda, MD.

Swanston, D.N. and F.J. Swanson. 1976. Timber harvesting, mass erosion, and steepland forest geomorphology in the Pacific Northwest. P. 199-221 in: D.R. Coates, ed. Geomorphology and engineering. Dowden, Hutchinson, and Ross. Stroudsburg, PA.

Sweeting, R., R.J. Beamish, and C.A. Cooper. 2007. Comparison of juvenile salmon diets in the Strait of Georgia and Puget Sound 1997–2006. Proceedings of the 2007 Georgia Basin Puget Sound research conference. Puget Sound Action Team, Olympia, Washington.

Sylte, T.E. 2002. Providing for stream function and aquatic organism passage: An interdisciplinary design.

Stream Notes: January 2002. Stream Systems Technology Center, Rocky Mountain Research Station, Fort Collins, CO.

Tabor, R.A., K.L. Fresh, R.M. Piaskowski, H.A. Gearns, and D.B. Hayes. 2011. Habitat use by juvenile Chinook salmon in the nearshore areas of Lake Washington: Effects of depth, lakeshore development, substrate, and vegetation. North American Journal of Fisheries Management 31(4):700-713.

Takagi, K., K.V. Aro, A.C. Hartt, and M.B. Dell. 1981. Distribution and origin of pink salmon (*Oncorhynchus gorbuscha*) in offshore waters of the north Pacific Ocean. Int. North Pac. Fish. Comm. Bull. 40:195.

Taylor, E.B. 1990a. Environmental correlates of life-history variation in juvenile Chinook salmon, *Oncorhynchus tshawytscha*. (Walbaum). J. Fish Biol. 37:1-17.

Taylor, E.B. 1990b. Phenotypic correlates of life-history variation in juvenile Chinook salmon *Oncorhynchus tshawytscha*. J. Anim. Ecol. 59:455-468.

Taylor, F.H. 1969. The British Columbia offshore herring survey, 1968-1969. Fish. Res. Brd. Can. Tech. Rep. 140:54.

Taylor, S.G. 1980. Marine survival of pink salmon fry from early and late spawners. Trans. Am. Fish. Soc. 109:79-82.

Taylor, S.G. 1983. Vital statistics on juvenile and adult pink and chum salmon at Auke Creek, northern southeastern Alaska. Auke Bay Lab., U.S. Natl. Mar. Fish. Serv. MS Rep.-File MR-F 152:35.

Teleki, G.C. and A.J. Chamberlain. 1978. Acute effects of underwater construction blasting on fishes in Long Point Bay, Lake Erie. Journal of the Fisheries Research Board of Canada 35:1191–1198.

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

Thomas, D.W. 1983. Changes in the Columbia River estuary habitat types over the past century. Astoria: Columbia River Estuary Data Development Program.

Thompson, D.M. 2002. Long-term effect of instream habitat-improvement structures on channel morphology along the Blackledge and Salmon Rivers, Connecticut, USA. Environmental Management 29(1): 250-265.

Thorsteinson, F.V. 1962. Herring predation on pink salmon fry in a southeastern Alaska estuary. Trans. Am. Fish. Soc. 91:321-323.

Tierney, K.B., D.H. Baldwin, T.J. Hara, P.S. Ross, N. L. Scholz, and C. J. Kennedy. 2010. Olfactory toxicity in fishes. Aquatic Toxicology 96:2-26.

Tilton, F.A., S.C. Tilton, T.K. Bammler, R.P. Beyer, P. L. Stapleton, N.L. Scholz, E.P. Gallagher. 2011. Transcriptional impact of organophosphate and metal mixtures on olfaction: Copper dominates the chlorpyrifos-induced response in adult zebrafish. Aquatic Toxicology 102:205-215.

Torgersen, C.E., D.M. Price, H.W. Li, and B.A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. Ecological Applications 9: 301-319.

Travnichek, V.H., A.V. Zale, and W.L. Fisher. 1993. Entrainment of ichthyoplankton by a warmwater hydroelectric facility. Transactions of the American Fisheries Society 122(5):709-716.

Tschaplinski, P.J. 1982. Aspects of the population biology of estuary-reared and stream-reared juvenile coho salmon in Carnation Creek: A summary of current research. In: G. Hartman ed., Proceedings of the Carnation Creek workshop, a 10 year review, pp. 289-305. Dep. Fish. Oceans, Pacific Biol. Sta., Nanaimo, British Columbia, Canada.

Turner, A. 2010. Marine pollution from antifouling paint particles. Marine Pollution Bulletin 60(2):159-171.

Turner, A., H. Pollock, and M.T. Brown. 2009. Accumulation of Cu and Zn from antifouling paint particles by the marine macroalga, *Ulva lactuca*. Environmental Pollution 157:2314-2319.

Turner, C.E. and H.T. Bilton. 1968. Another pink salmon (*Oncorhynchus gorbuscha*) in its third year. J. Fish. Res. Board Can. 25:1993-1996.

Tyrell, M.C. and J.E. Byers. 2007. Do artificial substrates favor nonindigenous fouling species over native species? Journal of Experimental Marine Biology and Ecology 342: 54-60.

Tytler, P., J.E. Thorpe, and W.M. Shearer. 1978. Ultrasonic tracking of the movements of Atlantic salmon smolts (*Salmo salar* L.) in the estuaries of two Scottish river. J. Fish. Biol. 12:575-586.

Uhrin, A.V. and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass *Thalassia testudinum*. Marine Ecology Progress Series 250:61-70.

UNEP (United Nations Environment Programme). 2004. An ocean blueprint for the 21st Century, Final Report. U.S. Commission on Ocean Policy, Washington, DC.

UNEP. 2005. Marine litter: An analytical overview. Nairobi, Kenya.

USDOE (U.S. Department of Energy). 2009. Report to Congress on the potential environmental effects of marine and hydrokinetic energy technologies. Prepared in response to the Energy Independence and Security Act of 2007, section 633(B). December, 2009. 143 p.

USEPA (U.S. Environmental Protection Agency). 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. 840-B-92-002. EPA, Office of Water, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 1984. Fish health protection policy. USFWS, Washington, D.C.

USFWS. 2000. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. U.S. Fish and Wildlife Service, Sacramento, CA. Prepared for the US Army Corps of Engineers, Sacramento District.

Valentine, K.A. 1970. Influence of grazing intensity on improvement of deteriorated black grama range. Bulletin 553, Agricultural Experiment Station, New Mexico State University.

Vallion, A.C., A.C. Wertheimer, W.R. Heard, and R.M. Martin. 1981. Summary of data and research pertaining to the pink salmon population at Little Port Walter, Alaska, 1964-80. NWAFC Processed Rep. 81-10:102 p.

van den Berghe, E.P. and M.R. Gross. 1989. Natural selection resulting from female breeding competition in a Pacific salmon (coho: *Oncorhynchus kisutch*). Evolution 43(1):125-140.

van Katwijk, M.M., G.H.W. Schmitz, A.P. Gasseling, and P.H. van Avesaanth. 1999. Effects of salinity and nutrient load and their interaction on Zostera marina. Marine Ecology Progress Series 190: 155.

Vaughan, D.M. 2002. Potential impact of road-stream crossings (culverts) on the upstream passage of aquatic macroinvertebrates. U.S. Forest Service Report, U.S. Forest Service, Portland, Oregon.

Vermaat, J.E. and R.J. De Bruyne. 1993. Factors limiting the distribution of submerged waterplants in the lowland river Vecht (the Netherlands). Freshwater Biology 30(1):147-157.

Vernon, E.H. 1962. Pink salmon populations of the Fraser River system. In: N. J. Wilimovsky ed., Symposium on pink salmon, pp. 121-230. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver.

Vernon, E.H. 1966. Enumeration of migrant pink salmon fry in the Fraser River estuary. Int. Pac.Salmon Fish. Comm. Bull. 19, 83.

Volk, C.J., P.M. Kiffney, and R.L. Edmonds. 2003. Role of riparian red alder (Alnus rubra) in the nutrient dynamics of coastal streams of the Olympic Peninsula, Washington, USA. P. 213-228 in: John Stockner, ed. Nutrients in salmonid ecosystems: sustaining production and biodiversity. Am. Fish. Soc. Symp. 34. Bethesda, MD. .

Vronskiy, B.B. 1972. Reproductive biology of the Kamchatka River Chinook salmon (*Oncorhynchus tshawytscha* (Walbaum)). J. Ichthyol. 12:259-273.

Wahle, R.J. and R.R. Vreeland. 1977. Bioeconomic contribution of Columbia River hatchery fall Chinook salmon, 1961 through 1964 broods, to the Pacific salmon fisheries. Fish. Bull. 76(1):179-208.

Wahle, R.J., E. Chaney, and R.E. Pearson. 1981. Areal distribution of marked Columbia River basin spring Chinook salmon recovered in fisheries and at parent hatcheries. Mar. Fish. Rev. 43(12):1-9.

Waldichuk, M. 1993. Fish habitat and the impact of human activity with particular reference to Pacific salmon. Pp. 295-337 in: L.S. parsons and W.H. Lear, eds. Perspectives on Canadian marine fisheries management. Canadian Bulletin of Fisheries and Aquatic Sciences 226.

Walker, D., R. Lukatelich, G. Bastyan, and A.J. McComb. 1989. The effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany 36:69-77.

Walter, R.C. and D.J. Merritts. 2008. Natural streams and the legacy of water-powered mills. Science 319: 299-304.

Waples, R.S., D.J. Teel, J.M. Myers and A.R. Marshall. 2010. Life-history divergence in Chinook salmon: Historic contingency and parallel evolution. Evolution 58: 386-403.

Ward, D.L., A.A. Nigro, R.A. Farr, and C.J. Knutsen. 1994. Influence of Waterway Development on

Migrational Characteristics of Juvenile Salmonids in the Lower Willamette River, Oregon. North American Journal of Fisheries Management 14:362-371.

Ward, J.M. and A. Ricciardi. 2010. Community-level effects of co-occurring native and exotic ecosystem engineers. Freshwater Biol 55: 1803-1817.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research 21:1005–1027.

Warrington, P.D. 1999b. Impacts of outboard motors on the aquatic environment. http://www.nalms.org/bclss/impactsoutboard.htm.

Wasson, K., K. Fenn, and J.S. Pearse. 2005. Habitat differences in marine invasions of central California. Biological Invasions 7: 935-948.

Waters, T. 1995. Sediment in streams: Sources, biological effects, and control. American Fisheries Society Monograph 7. Bethesda, Maryland.

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

WDF (Washington Department of Fisheries). 1991. Revised stock transfer guidelines. Wash. Dept. Fish., Olympia, Washington, 10.

WDF and WDOE (Washington Department of Ecology). 1992. Supplemental environmental impact statement. Use of carbaryl to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor. Wash. Dept. Fish., Wash. Dept. Ecol., Olympia, Washington. 147.

WDFW (Washington Department of Fish and Wildlife). 1997. Final environmental impact statement for the Wild Salmonid Policy. Olympia, Washington.

WDFW. 1998. Gold and fish. Rules and regulations for mineral prospecting and mining in Washington State. Draft February 1998. Olympia, Washington.

WDFW. 2003. Design of road culverts for fish passage. Washington Department of Fish and Wildlife. 2003 edition. Olympia, WA. 112 p. Available online at: http://wdfw.wa.gov/publications/00049/wdfw00049.pdf

WDOE (Washington Department of Ecology). 2009. Resource Manual for pollution prevention in marinas. Water Quality Program, Publication #9811, Olympia, Washington.

WDOE. 1986. Recommended interim guidelines for the management of salmon net-pen culture in Puget Sound. WDOE, Olympia, Washington.

Webster, J.R., S.W. Golladay, E.F. Benfield, D.J. D'Angelo, and G.T. Peters. 1990. Effects of forest disturbance on particulate organic matter budgets of small streams. J. N. Am. Benthol. Soc. 9:120-140.

Weiss, C. and F. Wilkes. 1974. Estuarine ecosystems that receive sewage wastes. Pp. 71-111 in: H.T. Odum, B J. Copeland, and E.McMahan, eds., Coastal Ecological Systems of the United States. The Conservation Foundation, Washington, D. C. Vol. III.

Weitkamp, L.A. and M.V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. Fisheries Oceanography 17: 380-395.

Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-24, 258.

Welch, D.W. 1995. Upper thermal limits on the oceanic distribution of Pacific salmon (*Oncorhynchus* spp.) in the spring. Can. J. Fish. Aquat. Sci. 52:489-503.

Welty, J., T. Beechie, K. Sullivan, T. Hyink, R.E. Bilby, C.W. Andrus, and G. Pess. 2002. Riparian aquatic interaction simulator (RAIS): A model of riparian forest dynamics for the generation of large woody debris and shade. Forest Ecology and Management 162(2-3):299-318.

Wemple, B.C., J.A. Jones, and G.E. Grant. 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon. Water Resour. Bull. 32:1195-1207.

Wertheimer, A.C. 1997. Status of Alaska salmon. Pp. 179-197 in: D.J. Stouder, P.A. Bisson, and R.J. Naiman, eds. Pacific salmon and their ecosystems: Status and future options. Chapman and Hall, Inc., New York.

West, C., L. Galloway, and J. Lyon. 1995. Mines, stormwater pollution, and you. Mineral Policy Center, Washington, D.C.

Westbrook, C.J., D.J. Cooper and B.W. Baker. 2006. Beaver dams and overbank floods influence groundwater-surface water interactions of a Rocky Mountain riparian area. Water Resources Research 42: 1-12.

WFWC (Washington State Fish and Wildlife Commission). 1997. Policy of Washington Department of Fish and Wildlife and Western Washington Treaty Tribes Concerning Wild Salmonids.

Wheeler, A.P., P.L. Angermeier, and A.E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. Reviews in Fisheries Science 13(3):141-164.

Wickett, W.P. 1962. Environmental variability and reproduction potentials of pink salmon in British Columbia. In: N. J. Wilimovsky, ed., Symposium on pink salmon, pp. 73-86. H. R. MacMillan lectures in fisheries, Univ. British Columbia, Vancouver.

Wilber, D.H. and D.G. Clarke. 2001. Biological effects of suspended sediments: A review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management 21:855-875.

Williams, G.D. and R.M. Thom. 2001. Marine and estuarine shoreline modification issues: White paper submitted to the Washington Department of Fish and Wildlife, Washington Department of Ecology, and Washington Department of Transportation.

Williams, R., M. Krkosek, E. Ashe, T.A. Branch, S. Clark, P.S. Hammond, E. Hoyt, D.P. Noren, D. Rosen, and A. Winship. 2011. Competing conservation objectives for predators and prey: estimating Killer whale prey requirements for Chinook salmon. Plos One **6**.

Williams, R.W., R.M. Laramie, and J. Ames. 1975. A catalog of Washington streams and salmon utilizationCVolume 1, Puget Sound Region. Wash. Dep. Fish., Olympia.

Williams, T.H., E.P. Bjorkstedt, W.G. Duffy, D. Hillemeier, G. Kautsky, T.E. Lisle, M. McCain, M. Rode, R. G. Szerlong, R.S. Schick, M.N. Goslin, and A. Agrawal. 2006 Historical population structure of coho salmon in the Southern Oregono/Northern California Coasts evolutionarrily significant unit. NOAA Technical Memorandum NFMS-SWFSC-390.

Williams. R. 1983. Releases of coho salmon into the Upper Willamette River, Oregon. Information Report Number 83-3. Oregon Department of Fish and Wildlife, Research Development Section, Corvalis, OR. February 1983.

Willis, R.A. 1954. The length of time that silver salmon spent before death on the spawning grounds at Spring Creek, Wilson River, in 1951-52. Fish. Comm. Oregon Res. Briefs 5:27-31.

Wilson, P.C. 2010. Water quality notes: Water clarity (turbidity, suspended solids, and color). Soil and Water Science Department, University of Florida, Gainesville, Florida.

Winans, G.A., D. Viele, A. Grover, M. Palmer-Zwahlen, D. Teel, and D. Van Doornik. 2001. An update on genetic stock identification of Chinook salmon in the Pacific Northwest: test fisheries in California. Reviews in Fisheries Science 9(4):213-237.

Wingfield, J.C., K. Hunt, C. Breuner, K. Dunlap, G.S. Fowler, L. Freed, and J. Lepson. 1997. Environmental stress, field endocrinology, and conservation biology. P. 95-131 in: J.R. Clemmons and R. Buchholz, eds. Behavioral approaches to conservation in the wild. Cambridge University Press, London.

Wipfli, M. S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests. Canadian Journal of Fisheries and Aquatic Sciences 54: 1259-1269.

Wissmar, R.C. and C.A. Simenstad. 1998. Variability of estuarine and riverine ecosystem productivity for supporting Pacific salmon. Chapter 6. Pp. 253-301 in: G.R. McMurray and R.J. Bailey (eds.), Change in Pacific Northwest Coastal Ecosystems. Proceedings of the Pacific Northwest Coastal Ecosystems Regional Study Workshop, August 13-14, 1996, Troutdale, Oregon. NOAA Coastal Ocean Program, Decision Analysis Series No. 11. NOAA Coastal Ocean Office, Silver Spring, MD. 342 p.

WMOA. 1995. An agreement concerning the use of treated wood in aquatic areas. Memorandum of Agreement between Washington Department of Ecology and Washington Department of Fish and Wildlife.

Wolter, C. and R. Arlinghaus. 2003. Navigation impacts on freshwater fish assemblages: The ecological relevance of swimming performance. Reviews in Fish Biology and Fisheries 13(1):63-89.

Wolter, C., R. Arlinghaus, A. Sukhodolov, and C. Engelhardt. 2004. A model of navigation-induced currents in inland waterways and implications for juvenile fish displacement. Environmental Management 34(5):656-668.

Wright, D.G. and G.E. Hopky. 1998. Guidelines for the use of explosives in or near Canadian fisheries waters. Fisheries and Oceans Canada.

Wright, S.G. 1968. Origin and migration of Washington's Chinook and coho salmon. Washington Department of Fisheries, Information Booklet No. 1, 25. Washington Department of Fisheries, Research Division, Olympia.

Wright, S.G. 1970. Size, age, and maturity of coho salmon in Washington's ocean troll fishery. Wash. Dep. Fish., Fish. Res. Papers 3(2):63-71.

WSCC (Washington State Conservation Commission). 2002. Salmonid habitat limiting factors water resource inventory areas 33 (lower) and 35 (middle) Snake watersheds, and lower six miles of the Palouse River. Available: http://www.scc.wa.gov/index.php/288-WRIA-33-34-35-Snake-River-Watershed/View-category.html.

Wu, Y.G., S.M. Bartell, J. Orr, J. Ragland, and D. Anderson. 2010. A risk-based decision model and risk assessment of invasive mussels. Ecological Complexity 7: 243-255.

Wurl, O. and J.P. Obbard. 2004. A review of pollutants in the sea-surface microlayer (SML): A unique habitat for marine organisms. Marine Pollution Bulletin 48:1016-1030.

WWPI (Western Wood Preservers Institute). 2011. Best management practices for the use of treated wood in aquatic and wetland environments. Vancouver, Washington. 36 p.

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

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18: 487-521.

Young, G.A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. No. NAVSWC-MP-91-220. Naval Surface Warfare Center, Silver Spring, MD.

Yousef, Y.A. 1974. Assessing effects on water quality by boating activity. U.S. Environmental Protection Agency Environmental Protection Technology Series, EPA-670/2-74-072, Orlando, Florida.

Yousef, Y.A., W.M. McLellon, and H.H. Zebuth. 1980. Changes in phosphorus concentrations due to mixing by motorboats in shallow lakes. Water Research 14(7):841-852.

Zedler, Joy. 2005. Ecological restoration: guidance from theory. San Francisco Estuary and Watershed Science. 3(2) http://escholarship.org/uc/item/707065n0.

Zelo, I. and D. Helton. 2005. Removal of grounded, derelict or abandoned vessels as site restoration. In Abandoned Vessel Program Conference Proceedings-International Oil Spill Conference 2005, May 15-19, Miami Beach, Florida.

Zelo, I., M. Overfield, and D. Helton. 2005. NOAA’s Abandoned Vessel Program and Resources and Under Sea Threats project - Partnerships and Progress for Abandoned Vessel Management. In Abandoned Vessel Program Conference Proceedings-International Oil Spill Conference 2005, May 15-19, Miami Beach, Florida.

Ziemer, R.R. and T.E. Lisle. 2001. Hydrology. In River Ecology and Management, Lessons from the Pacific Coastal Ecoregion. Pages 43-68 in R.J. Naiman, and R. E. Bilby. Springer-Verlag, New York, New York, NY.

7. TABLES

Table 1. 4th field hydrologic units designated as EFH for each of the three species of Pacific Coast salmon and the impassable dams that form the upstream extent of EFH in those units.

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
17020005	Chief Joseph	WA	X	X		Chief Joseph Dam
17020006	Okanogan	WA	X			
17020007	Similkameen	WA	X			
17020008	Methow	WA	X	X		
17020009	Lake Chelan	WA	X			
17020010	Upper Columbia- Entiat	WA	X	X		
17020011	Wenatchee	WA	X	X		
17020012	Moses Coulee	WA	X	X		
17020015	Lower Crab	WA	X			
17020016	Upper Columbia-Priest Rapids	WA	X	X		
17030001	Upper Yakima	WA	X	X		Keechelus Dam Kachess Dam (Kachess River)
17030002	Naches	WA	X	X		Rimrock Dam (Tieton River)
17030003	Lower Yakima	WA	X	X		
17060101	Hells Canyon	OR/ID	X			Hells Canyon Dam
17060102	Imnaha River	OR/ID	X			
17060103	Lower Snake-Asotin	OR/WA/ID	X	X		
17060104	Upper Grande Ronde River	OR	X	X		
17060105	Wallowa River	OR	X	X		
17060106	Lower Grande Ronde	OR/WA	X	X		
17060107	Lower Snake-Tucannon	WA	X	X		
17060108	Palouse River	WA	X			
17060110	Lower Snake River	WA	X	X		
17060201	Upper Salmon	ID	X			
17060202	Pahsimeroi	ID	X			

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
17060203	Middle Salmon-Panther	ID	X			
17060204	Lemhi	ID	X			
17060205	Upper Middle Fork Salmon	ID	X			
17060206	Lower Middle Fork Salmon	ID	X			
17060207	Middle Salmon-Chamberlain	ID	X			
17060208	South Fork Salmon	ID	X			
17060209	Lower Salmon	ID	X			
17060210	Little Salmon	ID	X			
17060301	Upper Selway	ID	X	X		
17060302	Lower Selway	ID	X	X		
17060303	Lochsa	ID	X			
17060304	Middle Fork Clearwater	ID	X	X		
17060305	South Fork Clearwater	ID	X	X		
17060306	Clearwater	WA/ID	X	X		
17060308	Lower North Fork Clearwater	ID	X			Dworshak Dam
17070101	Middle Columbia-Lake Wallula	OR/WA	X	X		
17070103	Umatilla	OR	X	X		McKay Dam (McKay Creek)
17070105	Middle Columbia-Hood	OR/WA	X	X		
17070106	Klickitat	WA	X	X		
17070306	Lower Deschutes	OR	X	X		
17080001	Lower Columbia-Sandy	OR/WA	X	X		Bull Run Dam #2
17080002	Lewis	WA	X	X		
17080003	Lower Columbia-Clatskanie	OR/WA	X	X		
17080004	Upper Cowlitz	WA	X	X		
17080005	Cowlitz	WA	X	X		
17080006	Lower Columbia	OR/WA	X	X		
17090001	Middle Fork Willamette	OR	X			

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
17090002	Coast Fork Willamette	OR	X			Dorena Dam
17090003	Upper Willamette	OR	X	X		
17090004	McKenzie	OR	X	X		Cougar Dam[1]
17090005	North Santiam	OR	X	X		Big Cliff Dam[2]
17090006	South Santiam	OR	X	X		
17090007	Middle Willamette	OR	X	X		
17090008	Yamhill	OR	X	X		
17090009	Molalla-Pudding	OR	X	X		
17090010	Tualatin	OR	X	X		
17090011	Clackamas	OR	X	X		
17090012	Lower Willamette	OR	X	X		
17100101	Hoh-Quillayute	WA	X	X		
17100102	Queets-Quinault	WA	X	X		
17100103	Upper Chehalis	WA	X	X		
17100104	Lower Chehalis	WA	X	X		
17100105	Grays Harbor	WA	X	X		
17100106	Willapa	WA	X	X		
17100201	Necanicum	OR	X	X		
17100202	Nehalem	OR	X	X		
17100203	Wilson-Trask-Nestucca	OR	X	X		
17100204	Siletz-Yaquina	OR	X	X		
17100205	Alsea	OR	X	X		
17100206	Siuslaw	OR	X	X		
17100207	Siltcoos	OR		X		

[1] Cougar Dam is a barrier to coho salmon only. Chinook salmon are trapped and hauled above the dam.

[2] Big Cliff Dam is a barrier to coho salmon only. Chinook salmon are trapped and hauled above the dam.

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
17100301	North Umpqua	OR	X	X		
17100302	South Umpqua	OR	X	X		
17100303	Umpqua	OR	X	X		
17100304	Coos	OR	X	X		
17100305	Coquille	OR	X	X		
17100306	Sixes	OR	X	X		
17100307	Upper Rogue	OR	X	X		Lost Creek Dam
17100308	Middle Rogue	OR	X	X		Emigrant Dam
17100309	Applegate	CA/OR	X	X		Applegate Dam
17100310	Lower Rogue	OR	X	X		
17100311	Illinois	CA/OR	X	X		
17100312	Chetco	CA/OR	X	X		
17110001	Fraser	WA	X	X		
17110002	Strait Of Georgia	WA	X	X	X	
17110003	San Juan Islands	WA		X		
17110004	Nooksack	WA	X	X	X	
17110005	Upper Skagit	WA	X	X	X	Gorge Lake Dam
17110006	Sauk	WA	X	X	X	
17110007	Lower Skagit	WA	X	X	X	
17110008	Stillaguamish	WA	X	X	X	
17110009	Skykomish	WA	X	X	X	
17110010	Snoqualmie	WA	X	X	X	Tolt Dam (S. Fork Tolt River)
17110011	Snohomish	WA	X	X	X	
17110012	Lake Washington	WA	X	X		Cedar Falls (Masonry) Dam (Cedar River)
17110013	Duwamish	WA	X	X	X	
17110014	Puyallup	WA	X	X	X	
17110015	Nisqually	WA	X	X	X	

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
17110016	Deschutes	WA	X	X		
17110017	Skokomish	WA	X	X	X	
17110018	Hood Canal	WA	X	X	X	
17110019	Puget Sound	WA	X	X	X	
17110020	Dungeness-Elwha	WA	X	X	X	
17110021	Crescent-Hoko	WA	X	X		
18010101	Smith River	CA/OR	X	X		
18010102	Mad-Redwood	CA	X	X		Robert W. Matthews Dam
18010103	Upper Eel	CA	X	X		Scott Dam
18010104	Middle Fork Eel	CA	X	X		
18010105	Lower Eel	CA	X	X		
18010106	South Fork Eel	CA	X	X		
18010107	Mattole	CA	X	X		
18010108	Big-Navarro-Garcia	CA	X	X		
18010109	Gualala-Salmon	CA	X	X		
18010110	Russian	CA	X	X		Coyote Valley Dam (E. Fork Russian R.) Warm Springs Dam (Dry Cr.)
18010206	Upper Klamath	CA/OR	X	X		Keno Dam
18010207	Shasta	CA	X	X		Dwinnell Dam
18010208	Scott	CA	X	X		
18010209	Lower Klamath	CA/OR	X	X		
18010210	Salmon	CA	X	X		
18010211	Trinity	CA	X	X		Lewiston Dam
18010212	South Fork Trinity	CA	X	X		
18020104	Sacramento-Stone Corral	CA	X			
18020111	Lower American	CA	X			Nimbus Dam
18020115	Upper Stony	CA	X			Black Butte Dam

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
18020116	Upper Cache	CA	X			Capay Dam[3]
18020125	Upper Yuba	CA	X			
18020126	Upper Bear	CA	X			Camp Far West Dam
18020151	Cow Creek	CA	X			
18020152	Cottonwood Creek	CA	X			
18020153	Battle Creek	CA	X			
18020154	Clear Creek-Sacramento River	CA	X			Keswick Dam (Sacramento R.), Whiskeytown Dam (Clear Creek)
18020155	Paynes Creek-Sacramento River	CA	X			
18020156	Thomes Creek-Sacramento River	CA	X			
18020157	Big Chico Creek-Sacramento River	CA	X			
18020158	Butte Creek	CA	X			
18020159	Honcut Headwaters-Lower Feather	CA	X			Feather River Fish Barrier Dam
18020161	Upper Coon-Upper Auburn[4]	CA	X			
18020162	Upper Putah	CA	X			Monticello Dam
18020163	Lower Sacramento	CA	X			
18040001	Middle San Joaquin-Lower Chowchilla[5]	CA	X			Buchanan Dam (Chowchilla River), Bear Dam (Bear Creek), Owens Dam (Owens Creek) Mariposa Dam

[3] Capay Dam was selected as the upstream extent of EFH because it was identified as a complete barrier by NMFS biologists and is located in the vicinity of the historical upstream extent of Chinook salmon distribution.

[4] Natural "lower falls" are downstream of any artificial barriers that would meet the criteria for designating them as the upstream extent of EFH; therefore, the upstream extent of EFH within this HU is at the "lower falls".

[5] EFH for Chinook salmon in the Middle San Joaquin- Lower Chowchilla HU (18040001) and Lower San Joaquin River HU (18040002) includes the San Joaquin River,

4th Field Hydrologic Unit Code	Hydrologic Unit Name	State(s)	Chinook	Coho	PS Pink	Impassable Dam(s)
18040002	Lower San Joaquin River[5]	CA	X			
18040003	San Joaquin Delta	CA	X			
18040007	Fresno River	CA	X			Hidden Dam
18040008	Upper Merced	CA	X			Crocker-Huffman Diversion Dam
18040009	Upper Tuolumne	CA	X			La Grange Dam (Tuolumne R.)
18040010	Upper Stanislaus	CA	X			Goodwin Dam
18040011	Upper Calaveras	CA	X			New Hogan Dam
18040012	Upper Mokelumne	CA	X			Camanche Dam
18040013	Upper Cosumnes	CA	X			
18050001	Suisun Bay	CA	X			
18050002	San Pablo Bay	CA	X	X		San Pablo Dam (San Pablo Cr.)
18050003	Coyote	CA	X	X		LeRoy Anderson Dam
18050004	San Francisco Bay	CA	X	X		
18050005	Tomales-Drake Bays	CA	X	X		Nicasio Dam (Nicasio Cr.) Peters Dam (Lagunitas Cr.)
18050006	San Francisco Coastal South	CA		X		
18060015	Monterey Bay[6]	CA		X		Newell Dam (Newell Cr.)

its eastern tributaries, and the lower reaches of the western tributaries. Although there is no evidence of current or historical Chinook salmon distribution in the western tributaries (Yoshiyama et al. 2001), the lower reaches of these tributaries could provide juvenile rearing habitat or refugia from high flows during floods as salmon migrate along the mainstem in this area.

[6] EFH for coho salmon in the Monterey Bay HU does not include the sections south of the Pajaro HU (18060002).

Table 2. 4th field hydrologic units where salmon distribution was not based on Streamnet (2013), Calfish (2013) or NOAA (2005a; 2005b).

4th Field HU Code	Hydrologic Unit Name	Source	
		Chinook	Coho
17020008	Methow	N/A	Fulton 1970
17020011	Wenatchee	N/A	Fulton 1970
17060103	Lower Snake-Asotin	N/A	Fulton 1970
17060104	Upper Grande Ronde River	N/A	Fulton 1970; Childs 2003
17060105	Wallowa River	N/A	Fulton 1970; Childs 2003
17070306	Lower Deschutes	N/A	Seals and French 2012
17090004	McKenzie	N/A	Fulton 1970: Williams 1981
17090006	South Santiam	N/A	Fulton 1970; Williams 1981
18010104	Middle Fork Eel	Williams et al. 2006	Brown and Moyle 1991; Williams et al. 2006
18010108	Big-Navarro-Garcia	NMFS 2005	N/A
18010109	Gualala-Salmon	Bjorkstedt et al. 2005	N/A
18050002	San Pablo Bay	Leidy et al. 2005	Leidy et al. 2005
18050003	Coyote	NMFS 1998; Leidy et al. 2007	Leidy et al. 2005; Spence et al. 2005
18050004	San Francisco Bay	NMFS 1998; Leidy et al. 2007	Brown and Moyle 1991; Leidy et al. 2005; Spence et al. 2005
18050005	Tomales-Drake Bays	Ettlinger et al. 2012	N/A
18060001	San Lorenzo-Soquel	N/A	Brown and Moyle 1991; Spence et al. 2011; April 2, 2012 77 FR 19552
18060002	Pajaro River	N/A	No reliable data to support current or historical use by coho salmon

Table 3. Major prey items for Chinook salmon, coho salmon, and PS pink salmon by life stage and habitat. Prey type is highly dependent on fish size, micro- and macro-habitat, season and year. See text for more detailed information on diets.

Species	**Juvenile - freshwater**	**Juvenile- estuarine**	**Juvenile- marine**	**Sub-adult/Adult**
Chinook salmon	insects (Diptera, Ephemeroptera)	insects (Diptera, psocoptera), epibenthic crustaceans (copepods), planktonic crustaceans (decapod larvae, euphausiids. gammarid amphipods, copepods), annelid worms (polychaetes), fish (clupeids, osmerids)	fish, planktonic crustaceans, insects	fish, planktonic crustaceans
Coho salmon	insects (Diptera, Ephemeroptera)	insects, epibenthic crustaceans, planktonic crustaceans, polychaetes, fish	fish, planktonic crustaceans	fish, planktonic crustaceans
Puget Sound pink salmon	insects, epibenthic crustaceans, planktonic crustaceans	epibenthic crustaceans, planktonic crustaceans, insects	planktonic crustaceans, planktonic molluscs	fish, planktonic crustaceans

Key References: Fresh et al. 1981; Higgs et al. 1995; Wipfli 1997; Schabetsberger et al. 2003; Gonzales 2006; Olegario 2006; Sweeting et al. 2007; Macneale et al. 2010; Bollens et al. 2010; Duffy et al. 2010; Sanderson et al. in preparation.

Table 4. Chinook salmon habitat use by life-history stage. See key to abbreviations and EFH data levels on the next page.

Stage - EFH Data Level[1]	Duration or Age	Diet/Prey	Season/Time	Location	Water Column	Bottom Type	Oceanographic Features	Other
Eggs EFH Data Level 0-4	50-130 d	Non-feeding stage; eggs consumed by birds, fish, and mammals.	Late summer, fall, and winter	Intragravel in stream beds	20-80 cm gravel depth; 15-700 cm water depth	Medium to course gravel	NA	DO < 2 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C, optimum 5-14 °C; Water velocity 15-190 cm/s
Larvae (alevins) EFH Data Level 0-4	50-125 d until fry emerge from gravel	Non-feeding stage; Alevins consumed by birds, fish and mammals	Fall, winter, and early spring	Intragravel until fry emergence	20-80 cm gravel depth; 15-700 cm water depth	Medium to course gravel	NA	DO < 2 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C, optimum 5-14 °C; Water velocity 15-190 cm/s
Juveniles (freshwater) EFH Data level 0-4	days-yrs	Insect larvae and adults, plankton (e.g., Daphnia)	Year-round, depending on race	Streams, lakes, sloughs, rivers	0-120 cm	Varied	NA	DO lethal at <2 mg/l, optimum at saturation; Temperature 0-25 °C, optimum 12-14 °C; Salinity < 29 ppt
Juveniles (estuary and oceanic) EFH Data Level 0-3	6-months to 2 yrs	Estuary: insects, copepods, polychaetes euphausiids, amphipods decapod larvae, fish, squid, crabs,	Estuary and Ocean: year-round	BCH BAY, IP, ICS, OCS	P, N, SD/SP 30-80 m preferred depth	All bottom types	Estuarine, littoral then more open water, UP, F, CL, G	DO lethal at <2 mg/l, optimum at saturation; Temperature 0-26 °C, optimum 12-14 °C; Salinity sea water
Adults EFH Data Level 0-2	2-8 yrs of age from egg to mature adult	Fish, squid, euphausiids, amphipods, and copepods, decapods	Spawning: July-Feb. Non-spawning: Year round	Oceanic to nearshore migrations, spawn in freshwater	P, N, SD/SP	NA	Different stock groups have specific oceanic migratory patterns	DO Preferred >5 mg/l, optimum at saturation; Temperature 0-26 °C; optimum <14 °C

Primary sources: Healey 1991. Bjornn and Reiser 1991. Myers *et al*. 1998. NOAA 1990. Fisher and Pearcy 1995. Spence *et al*. 1996. Aitkin 1998. McCullough et al. 2001; Kaeriyama et al. 2004. Beamer et al. 2005. Brennan et al. 2004. Sweeting et al. 2007. Daly et al. 2009. Duffy et al. 2010.

1 Not all habitats have been sampled

KEY FOR TABLES 2, 3, AND 4.

EFH Data Level

0 No systematic sampling has been conducted for this species and life stage; may have been caught opportunistically in small numbers during other surveys.

1 Presence/absence distribution data are available for some or all portions of the geographic range.

2 Habitat-related densities are available. Density data should reflect habitat utilization, and the degree that a habitat is utilized is assumed to be indicative of habitat value.

3 Habitat-related growth, reproduction, or survival rates are available. The habitats contributing the most to productivity should be those that support the highest growth, reproduction, and survival of the species (or life-history stage).

4 Habitat-related production rates are available. Essential habitats are those necessary to maintain fish production consistent with a sustainable fishery and a healthy ecosystem.

Location where found (in waters of these depths)

BAY - nearshore bays, give depth if appropriate (e.g., fjords)
BCH - beach (intertidal)
BSN - basin (>3,000 m)
IP - island passes (areas of high current), give depth if appropriate
ICS - inner continental shelf (1-50 m)
LSP - lower slope (1,000-3,000 m)
MCS - middle continental shelf (50-100 m)
OCS - outer continental shelf (100-200 m)
USP - upper slope (200-1,000 m)

Where found in water column

D - demersal (found on bottom)
N - neustonic (found near surface)
P - pelagic (found off bottom, not necessarily associated with a particular bottom type)
SD/SP - semi-demersal or semi-pelagic if slightly greater or less than 50 percent on or off bottom

Bottom Types

M - mud	S - sand	R - rock
SM - sandy mud	CB - cobble	C - coral
MS - muddy sand	G - gravel	K - kelp

SAV - subaquatic vegetation other than kelp (e.g., eelgrass).

Oceanographic Features

UP - upwelling	G - gyres	F - fronts
CL - thermo-or pycnocline	E – edges	

Other

U=Unknown
NA=not applicable

Table 5. Coho salmon habitat use by life-history stage. See key to abbreviations and EFH data levels at Table 4.

Stage - EFH Data Level[1]	Duration or Age	Diet/Prey	Season/Time	Location	Water Column	Oceanographic Features	Other
Eggs EFH Data Level 0-4	50 days at optimum temperatures	Non-feeding stage; eggs consumed by birds, fish and mammals	Fall/winter	Streambeds	Intragravel; water depth 4-35 cm	NA	DO < 2 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C; optimum 4.4-13.3 °C; Substrate 2-10 cm with < 12% fines (<3.3 mm), optimum <5% fines; Water velocity 25-90 cm/s
Larvae (alevins). EFH Data Level 0-4	100 days at optimum temperatures	Non-feeding stage; Alevins consumed by birds, fish and mammals	Winter/spring	Streambeds	Intragravel; water depth 4-35 cm	NA	DO < 3 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C; optimum 4.4-13.3 °C; Substrate 2-10 cm with < 12% fines (<3.3 mm), optimum <5% fines; Water velocity 25-90 cm/s
Juveniles (freshwater) EFH Data Level 0-4	1-2 yrs, most (>90%) 1 yrs	Aquatic, terrestrial, and estuarine invertebrates, eggs, fish	Rearing - all year Migration - spring and fall	Streams, lakes, BAY (estuaries)	Water depth 0-122 cm in streams	NA	DO lethal at <2 mg/l, optimum at saturation; Temperature 0-25 °C; optimum 12-14 °C; Salinity < 29 ppt; Water velocity 5-30 cm/s
Juveniles (estuarine) EFH Data Level 0-3	0-2 yrs	Insects, copepods, euphausiids, amphipods, crab larvae, fish	Rearing – winter, spring, summer, Migration - all year	BCH, BAY	Pelagic	NA	Temperature <15 °C
Juveniles and adults (marine) EFH Data Level 0-	16 months (except precocious males)	Epipelagic fish (herring, sand lance) and marine invertebrates (copepods, euphausiids, amphipods, crab larvae)	Rearing – winter, spring, summer Migration - all year	BCH, ICS, MCS, OCS, USP, BAY, IP	Pelagic	UP, CL, F; migration influenced by currents, salinity, and temperature	Temperature <15 °C

1 Not all habitats have been sampled

Stage - EFH Data Level[1]	Duration or Age	Diet/Prey	Season/Time	Location	Water Column	Oceanographic Features	Other
Adults (freshwater) EFH Data Level 1-2	up to 2 months	Little or none	Migration - fall Spawning - fall, winter	Rivers, streams, lakes		NA	

Primary Sources: Shapovalov and Taft 1954; Sandercock 1991; Bjorrn and Reiser 1991; Weitkamp *et al*. 1995; Spence *et al*. 1996; Aitkin 1998; McCullough et al. 2001; Brodeur et al. 2007; Weitkamp et al. 2008; Daly et al. 2009.

Table 6. Pink salmon habitat use by life stage. See key to abbreviations and EFH data levels with Table 4.

Stage - EFH Data Level[1]	Duration or Age	Diet/Prey	Season/Time	Location	Water Column	Bottom Type	Oceanographic Features	Other
Eggs EFH Data Level 0-4	90-100 d	Non-feeding stage; eggs consumed by birds, fish and mammals	Late summer, fall, and winter	Intragravel in stream beds	15-50 cm depth in gravel; water depth 10-15 cm	Medium to course gravel	NA	DO < 2 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C, optimum 4.4-13.3 °C; Water velocity 20-140 cm/s
Larvae (alevins) EFH Data Level 0-4;	100-125 d, fry emerge and migrate quickly from stream	Non-feeding stage; alevins consumed by birds, fish, and mammals	Fall, winter, and early spring	Intragravel until fry emergence	15-50 cm depth in gravel; water depth 10-15 cm	Medium to course gravel	NA	DO < 3 mg/l lethal, optimum > 8 mg/l; Temperature 0-17 °C, optimum 4.4-13.3 °C; Water velocity 20-140 cm/s
Juveniles EFH Data Level 0-3	2 yrs	Pteropods, amphipods, crab larvae,, euphausiids, copepods, , amphipods, fish squid	Estuary: spring, summer Ocean: year-round	BCH BAY, IP	P, N; migration influenced by currents, salinity, and temperature	All bottom types	Estuarine, littoral then open water; UP, F, CL, E; migration may be influenced by surface currents, salinities and temperatures	DO <2 mg/l lethal, optimum at saturation; Temperature 0-26 °C, optimum 12-14 °C; Salinity sea water; School with other salmon and Pacific sandfish
Adults EFH Data Level 0-2	2 yrs of age from egg to mature adult	Fish, squid, euphausiids, amphipods, and copepods	Spawning: Aug-Dec	Oceanic to nearshore migrations	P, N	NA	Different regional stock groups have specific oceanic migratory patterns	DO lethal at <3 mg/l, optimum at saturation; Temperature 0-26 °C, optimum <14 °C; Migration timing for different regional stock groups varies; earlier in the north, later in the south

Primary sources: NOAA 1990; Bjornn and Rieser 1991; Heard 1991; Higgs et al. 1995; Spence *et al*. 1996; Aitken 1998; Boldt and Haldorson 2003; Cross et al. 2005; Bollens et al. 2010.

1 Not all habitats have been sampled

Table 7. Summary of fishing activities that potentially affect EFH. CK=Chinook salmon; CO=coho salmon; P=PS pink salmon.

Fishing Activity	Habitat Type		
	Freshwater	**Estuarine**	**Marine**
Roundhaul gear		CK, CO, P	CK
Pot/trap		CK, CO, P	CK
Bottom trawl			CK
Mid-water trawl			CK
Long lines			CK
Carcass removal	CK, CO, P		
Vessel impacts	CK, CO, P	CK, CO, P	CK, CO, P
Harvest of prey species		CK, CO, P	CK, CO, P
Marine debris	CK, CO, P	CK, CO, P	CK
Derelict gear	CK, CO, P	CK, CO, P	CK
Shellfish harvest		CK, CO, P	
Recreational fishing	CK, CO, P	CK, CO, P	CK, CO, P

8. FIGURES

Figure 1. Overall geographic extent of EFH for Chinook salmon, coho salmon, and Puget Sound pink salmon

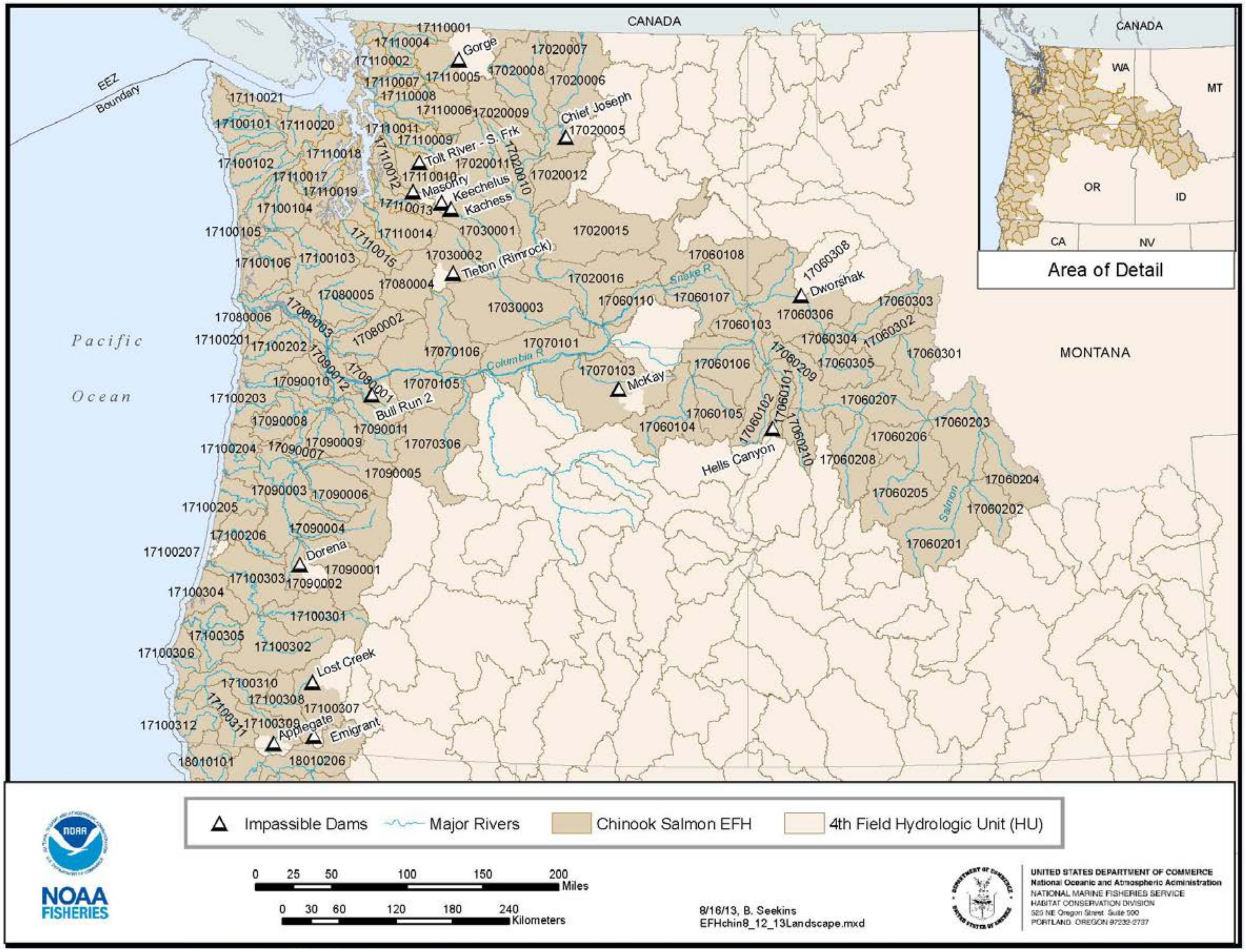

Figure 2. Chinook salmon EFH in Washington, Oregon, and Idaho. EFH designations are based on the USGS 4th field hydrologic units.

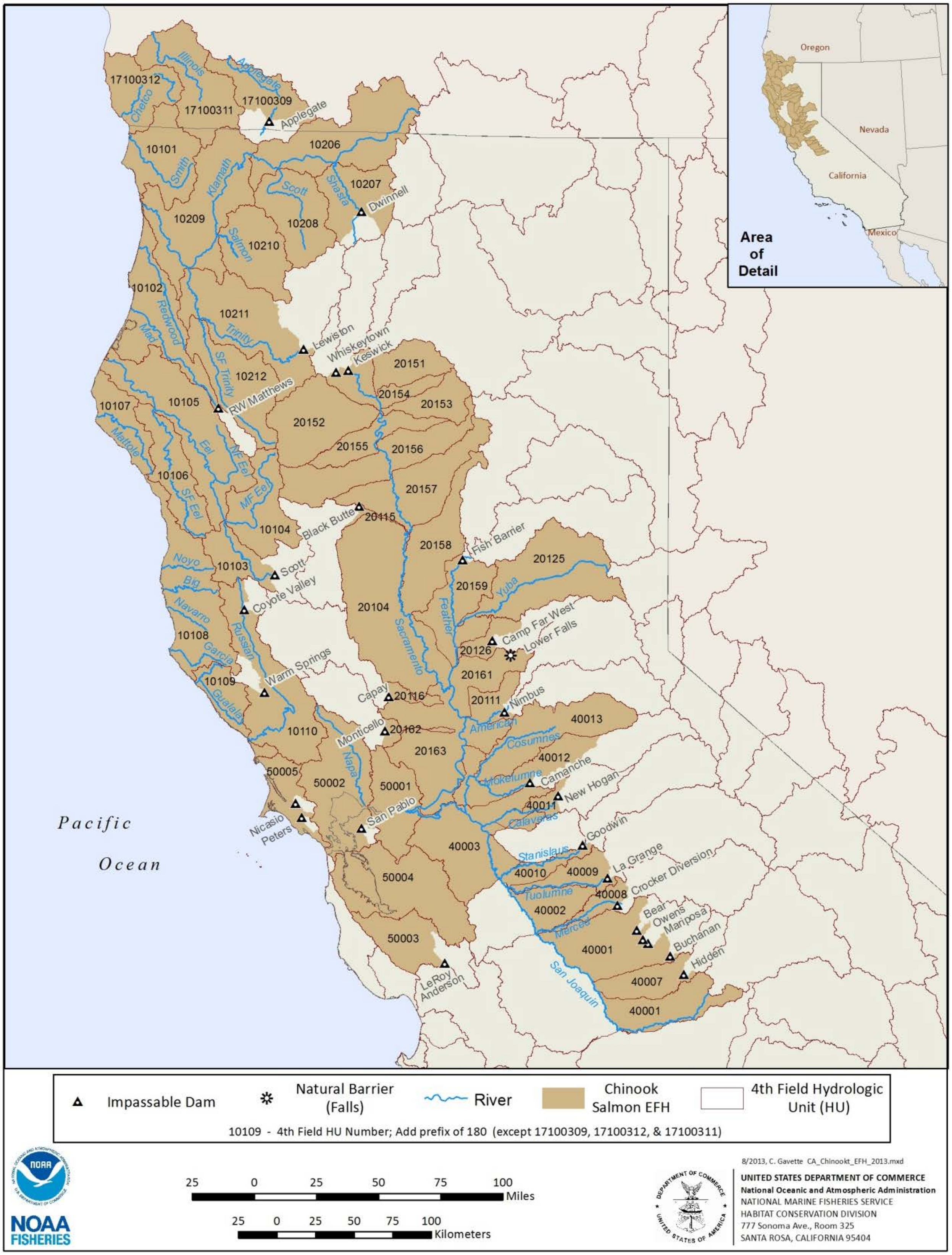

Figure 3. Chinook salmon EFH in California. EFH designations are based on the USGS 4th field hydrologic units.

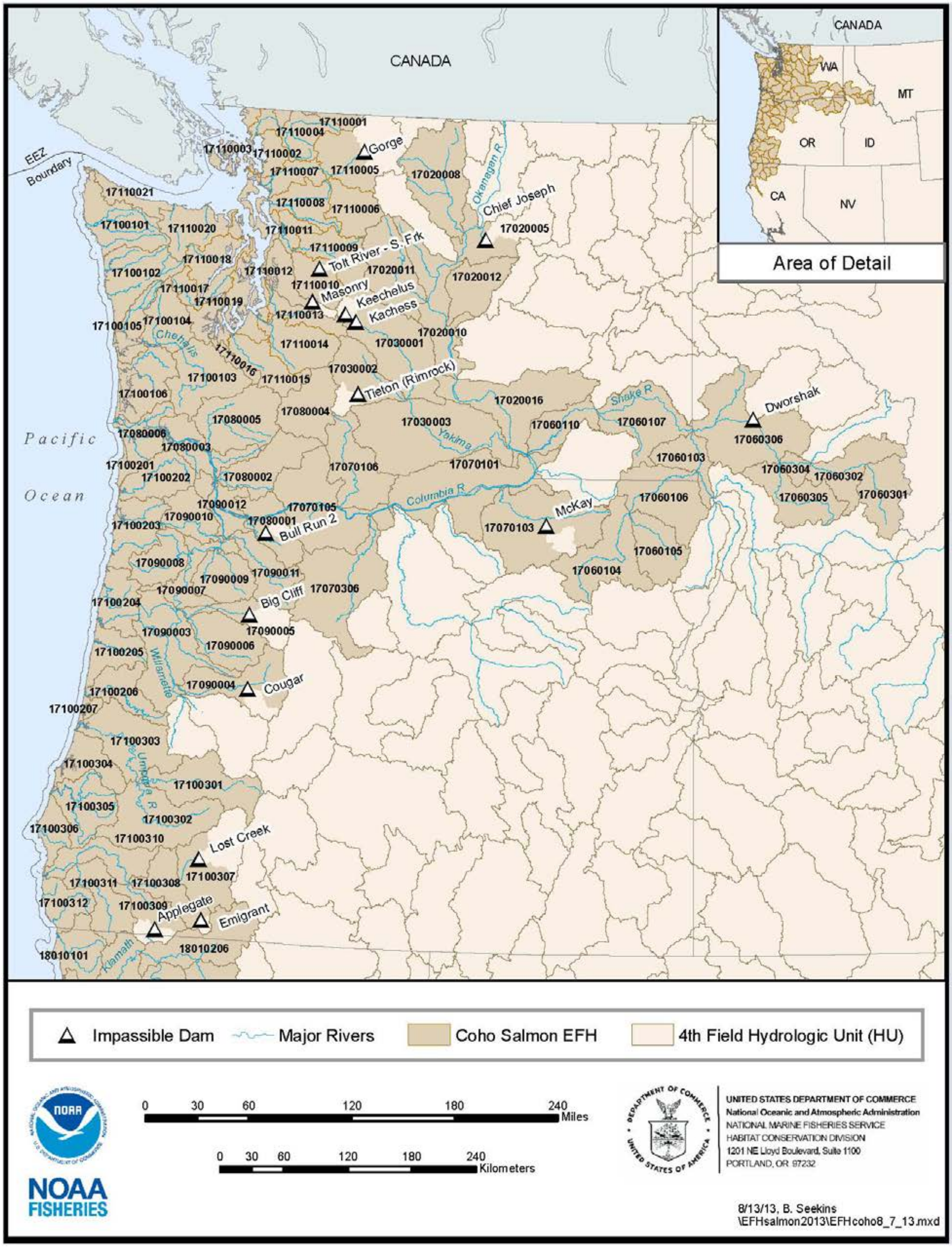

Figure 4. Coho salmon EFH in Washington, Oregon, and Idaho. EFH designations are based on the USGS 4th field hydrologic units.

Figure 5. Coho salmon EFH in California. EFH designations are based on the USGS 4th field hydrologic units.

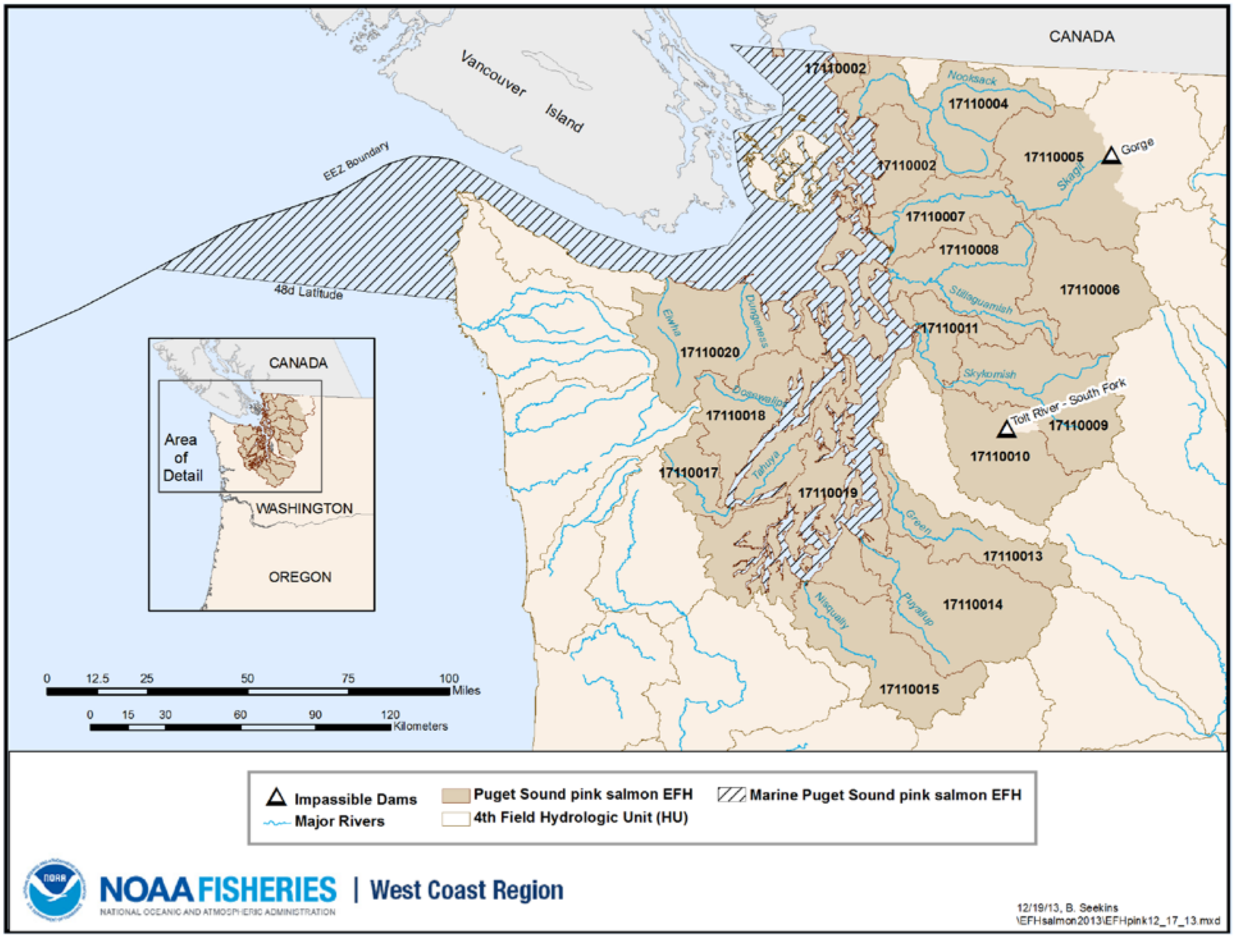

Figure 6. Puget Sound pink salmon EFH. EFH designations are based on the USGS 4th field hydrologic units.