10 Data Gaps

The activity-specific white papers prepared for WDFW in 2006 and 2007 identified data gaps in two ways:

- data gaps identified for specific "mechanisms of impact"(i.e., missing information on the impacts from construction and maintenance, hydraulic and geomorphic modifications, riparian vegetation modification, aquatic vegetation modification, water quality modifications, and ecosystem fragmentation on HCP species, and

- data gaps identified for specific activities and sub-activities.

In addition, there are several data gaps related to the general lack of knowledge of the more obscure HCP species. These gaps include:

- the extent of utilization of nearshore areas by species like green and white sturgeon and steelhead.

- the dependence of some species on both riparian and aquatic vegetation, such as Pacific lamprey and sturgeon.

- Survival and fitness following physical disturbance, handling, and relocation-related dispersal (e.g., to what degree does the unintentional dispersal of freshwater mussels limit density-dependent reproductive success).

10.1 Data Gaps Identified for Specific Mechanisms of Impact

10.1.1 Construction, Maintenance and Operations

10.1.1.1 Noise

Data on the effects of exposure to sound from pile driving on specific fish or invertebrates are few, and although the few studies completed provide some information about exposures to pile-driving sounds, there is little that can be definitively concluded (Hastings and Popper 2005). Hastings and Popper (2005) stress that because monitoring data show that sound pressure levels do not necessarily decrease monotonically with increasing distance from the pile, it is important that received sound levels be measured in future experiments to develop exposure metrics that correlate with mortality and different types of damage observed in fish exposed to pile driving. Hastings and Popper (2005) conclude that it is important to initiate experimental studies that start with basic questions about the effects on fishes from exposure to pile-driving sounds. Recommended studies from Hastings and Popper (2005) are presented in Table 10. Two data gaps are particularly significant: the cumulative impact of sound to fish and the effects of noise on the behavior of fish and the consequent impact to species survival and recovery.

Table 10-1. Research Questions on the Impact of Pile Driving on Fishes (Hastings and Popper 2005)

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

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

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

Specific data gaps on the sound sensitivity of fish and shellfish were identified:

- The sound sensitivity of primitive fishes (such as lamprey) is currently unknown.
- Hearing capacities of other HCP species and the effects of increased underwater noise on hearing is unknown.
- Effects on heart, kidneys, and other highly vascular tissue due to construction are unknown.
- Although studies have identified elevated hearing thresholds in response to engine and other white noises for cyprinid fishes (which are hearing specialists), data are needed on hearing and on how fish react to temporary, chronic, and cumulative anthropogenic noises caused by vessels, construction, and other sources.
- Effects of underwater noise on mollusks in general are a data gap. The sound sensitivity of the Olympia oyster is currently a data gap, and the effects of related sound stressors are unknown.
- No research has been identified regarding the effects of lower intensity, continuous underwater noise on invertebrates. However, operational noise is typically associated with sound pressures well below levels that have been observed to cause injury in shellfish, suggesting that HCP invertebrate species would not be subject to these effects. Because HCP invertebrates with the potential for stressor exposure are either filter feeders or grazers and are essentially non-motile, these species are unlikely to be subject to auditory masking effects that would limit their ability to sense predators and prey. Some potential may exist for disturbance induced interruption of feeding behavior, but more research on this subject is necessary to definitively determine this and this subject is considered a data gap.
- It is important to develop information on ambient noise levels for particular areas, because ambient noise levels influence the area of effect (attention to ambient), and fish reaction to sound likely varies depending on the "loudness" of ambient conditions.

10.1.1.2 Vessel Activities and Nearshore Structures

Relatively little is known about the potential impacts of vessel activities on potentially covered species. Although some work has been done with respect to turbidity, much of the research to date has focused on freshwater environments.

- More work is needed with respect to impacts of smaller vessels on turbidity in estuarine and marine environments.
- Much work is also needed to assess the noise impacts of small vessels operating at varying speeds, so that noise levels specific to conditions created by a particular project can be estimated.

- Potential impacts of small vessels on eelgrass and aquatic vegetation are not well known, and more work is needed to support impacts to these resources.

- Haas et al. (2002) recommends determining thresholds of disturbance for epibenthic communities affected by varying degrees of vessel activity.

- No literature was identified describing the potential impacts of vessel activities with respect to artificial light.

- Additional data gaps include the effects of temporary shading associated with vessel operations during construction of overwater structures or installation of non-structural piling. However, in general vessels required for the construction of overwater structures and installation of non-structural piling operate during the approved in-water work window, which minimizes potential impacts associated with shading.

- Additional data gaps relate to the operation of commercial and recreational vessels which may be moored at an overwater structure or non-structural piling, and may occur at various times of year and therefore affect covered species.

- Information specific to facility operation and vessel activities is needed to address temporary, chronic, and cumulative impacts on HCP species.

Grounding, anchoring, and prop wash are forms of direct disturbance from vessel activity. Grounding, anchoring, and prop wash are likely to cause effectively permanent alteration of substrate characteristics and the aquatic vegetation community. While numerous studies have documented the effects of grounding, anchoring, and prop wash on habitat, direct assessments of the impacts on species have not been studied for most HCP species and remain a data gap. These include temporary, chronic, and cumulative impacts on HCP species in marine, riverine, and lacustrine environments.

Previous white papers prepared in conjunction with WDFW, WSDOT, and Ecology on overwater structures (Nightingale and Simenstad 2001a; Carrasquero 2001) identified significant gaps on the subject of ambient light modifications and effects on habitat along marine shorelines. Specifically, these gaps included further exploration to:

(1) determine the conditions for and the significance of avoidance of shoreline structures by migrating juvenile salmon;

(2) measure the effects of using artificial lights in under-pier environments to avoid interference with natural ambient light patterns in shallow nearshore habitats;

(3) further quantify the effects of overwater structures on salmonid prey resource abundance; and

(4) develop a scientifically based approach to determine cumulative impact thresholds.

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

The question of cumulative effects of HPA-permitted structures has yet to be addressed. There is still a need for a scientifically based cumulative assessment tool to guide the design and placement of structures. This assessment should include steps to:

(1) develop a landscape-scale model of shoreline processes that create and maintain biological habitats;

(2) develop assessment indices for identifying ecological responses to structures within the context of the model;

(3) identify landscape-level subunits, such as shoreline drift cells (sectors); and

(4) identify landscape elements in terms of connectivity and homogeneity using the fundamental definitions of corridors, matrices, patches, and other landscape attributes.

Although effects of HPA-permitted structures on the behavior of salmonids and their prey resources have been studied, similar effects on other HCP species can only be inferred from these findings, as the majority of these species have not been the focus of the studies to date.

10.1.1.3 Construction/Maintenance Dredging

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

Although the physics of turbidity generation can be calculated, adequate data do not exist to quantify the biological response in terms of threshold sediment dosages and exposure durations that can be tolerated by each of the HCP species. Numerical modeling simulations of dredging-related suspended sediment plume dynamics need to be correlated with field and laboratory studies to further identify information needs on each of the HCP species. In marine environments, existing data indicate that responses to suspended sediments are highly species-specific, with some species having lethal effects at several hundred parts per million (ppm) in 24 hours and others having no effect at concentrations above 10 parts per trillion (ppt) for 7 days. Studies on East Coast species have identified lethal suspended concentration levels, and Newcombe and Jensen (1996) developed a predictive model for defining lethal and sublethal fish injury threshold levels for suspended sediment concentrations. However, threshold studies (single-event as well as cumulatively) are lacking for the temporary impacts of suspended sediment levels specific to dredging in Pacific Northwest marine, lacustrine, and riverine environments (Nightingale and Simenstad 2001a).

The following information needs are also considered data gaps:

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

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

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

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

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

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

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

10.1.1.4 Ambient Light Modifications and Artificial Light

Species-specific sensitivity to ambient light modification is a data gap for most HCP species.

- Ambient light modification is a likely stressor for many species in nearshore lacustrine environments and may also pose risk in marine environments. However, as juvenile sockeye salmon and steelhead are more typically found farther from shore, the effects of shading are less clear; therefore, the impact potential in the marine environment is uncertain.

- Information is needed on the temporary, chronic, and cumulative impacts of ambient light modification on HCP species in marine, riverine, and lacustrine environments.

- Extensive gaps exist in our understanding of how artificial light impacts aquatic organisms. Impacts to fish resulting from artificial light are often related to changes in nighttime behaviors such as migration, activity, location (Nightingale and Simenstad 2001b), and potentially schooling behavior in juvenile salmonids (Ali 1959, 1962, in Simenstad et al. 1999).

- Further studies on the qualitative effects of predator/prey relationships associated with artificial light, and investigations focused on the consequences of behavioral changes in aquatic organisms in a natural environment, are necessary to better understand the impacts associated with nighttime artificial light.

10.1.1.5 Channel Dewatering and Handling Fish and Shellfish

Few studies have compared the susceptibility of various fish and macroinvertebrate species to different types of handling techniques. More information comparing the susceptibility to injuries associated with these types of techniques is needed to identify potential take for these species. Training and minimum qualifications for personnel performing fish capture and handling (particularly electrofishing) are also needed to define standard protocols that would minimize risk of take.

Most of the studies on the effects of fish handling have been performed on electrofishing. Electrofishing effects have been conducted on adult fish greater than 12 inches in length (Dalbey et al. 1996). The relatively few studies that have been conducted on juvenile salmonids indicate that spinal injury rates are substantially lower than they are for large fish. Only a few recent studies have examined the long-term effects of electrofishing on salmonid survival and growth (e.g., Ainslie et al. 1998, Dalbey et al. 1996).

Little research has been conducted on the effects of dewatering and fish capture and handling on nonsalmonid HCP species. Injury frequencies reported for specific species are highly variable among and often within investigations and sometimes appear to be contradictory. Differences in rates and degree of injury, especially between investigations, are often difficult to attribute to species, fish size, fish condition, environment (including water conductivity and temperature), field intensity, or other current or field characteristics. Still, most existing data support Salmonidae as the fish taxon most susceptible to electrofishing injury (Snyder 2003).

More directed research is necessary to understand the risk of take resulting from channel dewatering and fish handling.

Exposure of the giant Columbia River limpet and great Columbia River spire snail to work area dewatering is possible, but sensitivity to this stressor is a data gap so the potential for take is unknown.

10.1.2 Hydraulic and Geomorphic Modifications Data Gaps

Finlayson (2006) identified five areas where additional research pertaining to physical nearshore processes is needed:

(1) characterizing the role of historical morphology;

(2) identifying tide-level controls on littoral phenomena;

(3) further development of existing littoral transport models;

(4) improved characterization of the role of extreme events in shaping low-energy, mixed-sediment beaches; and

(5) further testing and adaptation of numerical wave models for fetch-limited environments.

No research has been conducted to study submarine and intertidal groundwater n Puget Sound. It is clear from work elsewhere that such flows are crucial in sustaining nearshore ecosystems (Gallardo and Marui 2006); however, their role on the nearshore environment throughout Puget Sound is virtually unknown (Finlayson 2006).

10.1.2.1 Channel Hydraulics

Some studies that address the effects of HPA-permitted structures on habitat features such as scour or sediment composition, and studies that address the effects of changes in habitat features on potentially covered species exist. There are few case studies demonstrating quantitative impacts on animals or their habitat. The existing studies are often of limited use because they focus on "legacy" effects, i.e., impacts that occurred because of practices that are rarely, if ever, authorized under current regulations.

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

10.1.2.2 Littoral Drift

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

10.1.2.3 Substrate Modifications

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

- **Cutting-edge technique effectiveness assessments**. Current practical knowledge exists to protect shoreline areas through the implementation of innovative (cutting-edge) engineering alternatives. These cutting-edge alternatives can provide the desired degree of infrastructure protection while restoring physical processes, habitat features, and/or ecological functions. Unfortunately, while technically feasible, the effectiveness of these techniques has not been fully tested through the implementation of prototype projects.

- **Peer-reviewed monitoring of constructed restoration efforts**. Habitat restoration activities have been undertaken in many nearshore settings throughout western Washington over the last 30 years. While some have been large and monitored (Cheney et al. 1994; Carney et al. 2005), most have a tendency to be for small properties with no monitoring. Even when monitoring has been performed, it is generally used more as a design tool, rather than to evaluate the efficacy of the restoration activities to restore the targeted species (Carney et al. 2005).

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

10.1.3 Riparian Vegetation Modifications Data Gaps

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

10.1.3.1 Marine Riparian Vegetation Modifications

Although the functions of freshwater riparian vegetation have been identified for riverine systems, exploring and defining the functions of marine riparian vegetation are ongoing. There is reason to believe that marine riparian vegetation provides similar functions to riparian vegetation adjacent to freshwater habitats; however, the extent and nature of those functions are not fully understood (Desbonnet et al. 1995; NRC 2001; Brennan and Culverwell 2004). The following information needs are outstanding:

(1) understanding the specific nature and function of riparian habitat elements along marine shorelines;

(2) the dependence of HCP species on riparian marine and freshwater habitat functions;

(3) the dependence of HCP species on marine allochthonous inputs; and

(4) the cumulative and synergistic effects of riparian and shoreline removal.

10.1.4 Aquatic Vegetation Modifications Data Gaps

HCP species-specific data gaps with regard to aquatic vegetation include the following:

- Dependency of Pacific and river lamprey as well as northern abalone on aquatic vegetation.
- Effect of diminished habitat complexity due to aquatic vegetation modification on the giant Columbia River limpet and California floater (mussel).
- Of the potentially covered species, current data have shown a clear and consistent dependence on freshwater aquatic vegetation only for the Olympic mudminnow, although it is expected that freshwater aquatic vegetation is important for other potentially covered species as well, which is why this is identified as an important information gap.

10.1.4.1 Marine and Estuarine Aquatic Vegetation

Numerous significant data gaps preclude a clear understanding of how human activities cumulatively impact aquatic vegetation in marine and estuarine waters. Relatively little work has been done on macroalgae. For eelgrass, the following gaps are particularly significant (Jones and Stokes 2006):

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

10.1.4.2 Freshwater Aquatic Vegetation

It is not known at what point the cumulative impact of HPA-permitted activities on aquatic vegetation becomes significant to most potentially covered freshwater species. Most of these species are thought to be affected by the loss of aquatic vegetation through indirect impact pathways that could vary from one location to another. To assess the relative merits of aquatic plant conservation and mitigation measures, the importance of aquatic vegetation in different systems and for all of the potentially covered species needs to be better understood.

10.1.5 Water Quality Modifications Data Gaps

There is still much work to be done to understand the impacts of suspended sediment and turbidity on potentially covered species. Most of the reviewed literature discussed impacts only with respect to salmonid species. Many of the studies were conducted in the laboratory in the absence of complex interactions that occur in natural systems. While the laboratory work is useful for describing interactions around which a study has been designed, additional field data would help to verify laboratory-derived conclusions. In addition, many data gaps that were identified by Bash et al. in 2001 still appear to be gaps. This includes:

- a lack of background water quality data for most waters in Washington,
- exposure thresholds for sublethal effects,
- the effects of short-term sediment pulses,
- species responses to varying sediment particle sizes and shapes, or patches of increased turbidity, including responses to reduced light,
- The effects of turbidity and suspended sediment on freshwater and marine HCP species and habitats,
- the effect of fine sediment deposition on hyporheic mechanisms, and
- how these affect habitat quality and quantity.

This information would help in estimating the potential impacts of aquatic projects by providing a more comprehensive impact analysis in the context of existing conditions and species response thresholds to suspended sediment exposure.

A particular data gap is how HCP species are affected by resuspension and transport of contaminated sediments (Michelsen et al. 1999). Many data gaps exist with respect to the potential for treated wood applied to aquatic settings to impact potentially covered species. Information is needed regarding creosote-treated wood effects on fish and shellfish in riverine and lacustrine environments. The chronic and cumulative effects of copper-treated wood in marine, riverine, and lacustrine environments are a data gap. Little work has been done to evaluate the potential impacts of treated wood applications in large projects on water quality and sediment and dose responses of potentially covered species to PAH and metals concentrations in water and sediment (Poston 2001). Poston (2001) reported a lack of knowledge on bioaccumulation and pathways of exposure of potentially covered species to PAHs and metals, as well as microbial and physical degradation processes of PAHs and metals. These processes are still not well described in the literature. Recent work has called into question the reduction in PAH leaching rates achieved by current BMPs for creosote treatment (Poston 2001). This information would allow for better estimates of take.

10.1.6 Ecosystem Fragmentation Data Gaps

10.1.6.1 Habitat Effects on Species

One of the biggest gaps in the literature is information that directly relates habitat changes to fish productivity (Bolton and Shellberg 2001). This information is difficult to collect because multiple factors may simultaneously influence the overall productivity and survival of fish species. However, this type of information is crucial to understand to minimize impacts on HCP species from HPA-permitted activities.

Although it is recognized that lost-opportunity impacts must be mitigated to achieve no loss of habitat (WDFW 2003), currently there are no tools for universal and consistent application of the concept.

10.2 Data Gaps Identified for Specific Activities and Sub-Activities

10.2.1 Bank Protection Data Gaps

There is an overall need for controlled, hypothesis-based studies directed at documenting and understanding the biological impacts of bank protection structures and activities to estuarine, marine, and freshwater ecosystems, particularly the effects associated with the structures both before and after impacts occur. Most current knowledge is based on anecdotal observations after the fact or those collected intuitively over time. Specific study needs include:

- Studies on the magnitude of the loss of salmonid food resources caused by bulkheading.
- Studies developing quantitative, comparative understanding of the effectiveness and habitat impacts of hard versus soft bank protection approaches/technologies.
- Information on long-term and cumulative habitat effects or relative benefits to biota for biotechnical approaches.
- Studies quantifying construction-related impacts related to specific bank protection activities (such as turbidity).
- Studies developing information on bank/shoreline morphology related to bank structures, such as:
    - Accurate estimates regarding the rate of marine beach erosion and accretion in the presence of bank structures, including both seasonal and long-term effects.
    - Effect of marine bulkheads specific to wave reflection and erosion of the upper beach.
    - Role of marine log structures in attenuation of energy at the shore.
    - Role of marine log bank protection structures in recruiting and retaining sediment and naturally occurring driftwood.

  - Differences in sediment transport at unarmored versus armored shorelines/banks and in areas with and without naturally occurring wood debris.

- Basic understanding of nearshore and bank ecosystem functions (e.g., roles of marine riparian vegetation, impact of LWD reductions ecosystem-wide); this will help to support the rationale for installing, leaving undisturbed, or enhancing certain existing natural shoreline features.

- More specific information on migration and movement requirements of non-salmonid potentially covered species related to banks and bank protection structures; most research has focused on salmonids in this regard.

- Studies investigating effects of bank protection on predation, feeding behavior, and prey production for covered species; very few studies document the links between specific bank protection types and behavior/diet of shoreline-associated species.

- Studies investigating linkages between bank protection project impacts and the context in the watershed and nearby upland systems.

- Information on how changes in habitat opportunity or capacity change with addition of bank protection and whether and how these affect biological resources on a landscape scale.

- Predictive cumulative impact tools that model the potential effect of armoring on specific sites as well as systems. A possible approach is to focus on floodplain disconnection by using historical aerial photography. Photo-interpretation of bank protection structure locations and corresponding side channel and high-flow channels at each time step could provide insight on the relationship between those parameters as well as stream length (as an indicator of amount of habitat available). Potentially, such an analysis could demonstrate whether disconnection of key sediment sources or river reaches had an inordinate impact on floodplain connectivity.

- Maps and updates based on existing databases and inventories that:

  - Illustrate historical and current channel and/or shoreline alignments

  - Determine/prioritize critical areas for protection or restoration

  - Identify ecosystems that are most at risk to cumulative impacts.

- Monitoring studies (short- and long-term) confirming that BMPs and conservation measures have had the desired effect

- Objective, post-project evaluations to maximize opportunities to learn from past experience and improve upon future design

- Summary/collection of information on process and outcome for use of adaptive management related to bank protection
- System for tracking and evaluating impacts on watershed level

Schmetterling et al. (2001) noted four areas where research on construction and maintenance of shoreline protection is lacking:

(1) quantifying the habitat availability and quality of riprap;

(2) correlation of the effects of riprap banks on salmonid density in the absence of other dependent variables such as diking, channelization, and watershed land use;

(3) comparative studies on the use of riprap and alternative "soft" techniques, such as the integration of natural materials; and

(4) the cumulative effects of numerous bank-hardening projects at the watershed level.

10.2.2 Channel Modifications Data Gaps

The cumulative impacts of multiple bank protection projects on channel processes and morphology is a significant data gap.

10.2.2.1 Dredging

Although the sources of turbidity generation due to dredging are well known, the connection of this source to a measurable biological response is a crucial data gap. Adequate data do not exist to quantify the biological response in terms of threshold sediment dosages and exposure durations that can be tolerated by various organisms. The existing data indicate that responses to suspended sediments are highly species-specific, with some species having lethal effects at several hundred parts per million (ppm) in 24 hours and others having no effect at concentrations above 10,000 ppm for 7 days. Studies on east coast species have identified lethal concentration levels, and Newcombe and Jensen (1996) have developed a predictive model for defining lethal and sublethal fish injury threshold levels for suspended solids concentrations in streams and estuaries. However, threshold studies for the temporary impacts of suspended sediment levels specific to aquatic environments in the Pacific Northwest are lacking. Additionally, although dredging of drainage channels for agriculture is widespread throughout the state, the extent of the impacts and effects on HCP species remains essentially undocumented.

Data regarding benthic recolonization after dredging is limited and only suggested one vector (i.e., invertebrates burrowing up through sediments) to explain significantly higher benthic invertebrate recolonization after dredge disposal. Additional studies have likely been completed to provide a clearer understanding of effects from dredge disposal.

10.2.2.2 Gravel Mining and Scalping

Although considerable advances have been made in the understanding of fluvial geomorphology and aquatic and riparian ecology in recent decades, there are still relatively few studies directly addressing the impacts of gravel mining in its various forms (e.g., wet and dry pit mining, bar scalping) and ecological restoration after mining. Most of the case studies of the geomorphic effects of mining have involved large extraction rates over a decade or more, resulting in large, measurable changes in channel form (Norman et al. 1998). Studies of long-term, indirect, and cumulative effects of mining up the food chain stand as a data gap. Such studies designed to measure mining-induced changes would require the collection of baseline data, which is seldom performed prior to gravel mining activities.

Food-web impacts of gravel mining are not well understood. Predation on juvenile salmon by introduced warm water species (such as those that thrive in the artificial habitats created by floodplain pits) has been documented in California, but no such studies are known to have been undertaken in Washington. The food-web implications of disrupting or eliminating shallow gravel riffle habitats, and reducing the abundance of large woody debris in the channel as a consequence of instream mining, have not been directly measured in the field.

10.2.2.3 Sediment Capping

When compared with dredging, sediment capping is a relatively new practice and consequently there are a number of data gaps concerning the impacts on HCP species. Nearly all of the literature regarding sediment capping is oriented toward the physical and biogeochemical properties of sediment caps and the impact of capping on benthic macroinvertebrates. Consequently, data gaps exist concerning the use of capped areas as fish nesting and foraging habitat. Despite this data gap, insight into how capped areas may be used by fish can be found by reviewing the information which exists regarding fish colonization of nourished beach habitat.

There is substantial anecdotal evidence that forage fishes use placed materials for spawning. For instance, a beach nourishment project in Silverdale Waterfront Park continues to be used by surf smelt. Shorelines cut into man-made fill in Commencement Bay have also been designated forage fish spawning areas (Penttila 2007). Developing this anecdotal evidence into a peer-reviewed article should be a target of future research considering the novelty and applicability of the work to both beach nourishment and sediment capping projects.

Additional studies regarding cap longevity would also be useful. As more sediment caps are applied and studied, our knowledge of how capping materials and techniques affect project longevity will improve. With this knowledge, a more accurate assessment of impact on biota can be made.

There is substantial evidence that invertebrate communities can rapidly recolonize an area after sediment capping, but all of this research has been conducted in marine waters. Capping of nutrient-laden sediments in small lakes practiced primarily in Japan (see Palermo et al. 1998) may have different impacts on invertebrates. Lateral recolonization, which has been found to be a factor in marine waters (Qian et al. 2003), may occur more rapidly near tributary inlets, but as of yet there is no evidence to indicate that recolonization would occur at different rates in marine, lacustrine, or riverine environments.

10.2.2.4 Channel Creation and Alignment

Restoring the ecological integrity of rivers, streams, and tidal channels requires an understanding of pre-disturbance conditions at the time of earliest Euro-American settlement in the mid-19th century. Unfortunately, documentation of these conditions is limited. Archival investigations, field studies, and geographic information systems and remote sensing analyses (such as those undertaken by the Puget Sound River History Project at the University of Washington) are needed to understand the historical landscape to address regional problems of resource management, restoration, and planning.

Straightening and dredging of drainage channels for agriculture is widespread throughout the state but remains essentially undocumented in its extent or impacts. The need for additional studies of this common practice stands as a data gap for channel creation and alignment.

10.2.3 Fish Passage Structures Data Gaps

Data gaps specific for fish passage structures include:

- Knowledge of the movement patterns of HCP species at different life-history stages relevant to the definition of design flows for fish passage.

- Understanding of the situational limits of different design approaches (e.g., stream simulation).

- Passage requirements of nonsalmonid HCP species and knowledge of the behavioral and physiological limits on the swimming ability of HCP species, sufficient to guide definition of hydraulic design criteria.

- Upstream movement requirements of HCP invertebrate species: The freshwater HCP invertebrate species vary in terms of the mechanisms they use to influence dispersal in flowing water environments appropriate for the fish passage activity type. Unionid mussels rely on host-fish species to disperse their parasitic larvae to upstream environments. These species have also been shown to disperse upstream for short distances by crawling along the bottom using their muscular foot and byssal thread attachments (Vaughan 2002). Other HCP invertebrate species, such as the giant Columbia River limpet and great Columbia River spire snail, crawl along hard substrates and are theoretically capable of navigating upstream for short distances. The degree to which fish passage subactivity types may help or hinder these dispersal mechanisms and the ramifications for population health are an area requiring additional study.

10.2.3.1 Culverts

In WAC 220-110-070 as well as in current design guidance documents (e.g., Bates et al. 2003), assumptions are made to define the period of year during which fish passage is required, based on the species that are expected to inhabit a stream. Many culverts present only a temporary barrier to fish passage or are barriers to juvenile and resident fish only. However, the significance of such barriers on fish movement in the field has not been thoroughly investigated, particularly where the occurrence and timing of fish movement are poorly understood. There are gaps in knowledge regarding the movement patterns of various salmonid species and life-history stages (particularly of resident and juvenile anadromous salmonids) in small stream channels. Nonsalmonid species are less well understood in many cases. Finally, there are key data gaps relative to the design requirements necessary for structures that maintain performance over time.

With regard to the migration requirements of fish, it is known that volitional movement can vary greatly among species, lifestages, habitats, seasons, and years (Gowan et al. 1994; Kahler and Quinn 1998; Kahler et al. 2001). Research on several critical fish passage related topics is currently in progress or has recently been completed. However, it may be difficult to translate this information into meaningful guidance because the research is typically focused on a single species and may not adequately reflect the requirements of a broad range of HCP species; therefore, a number of related uncertainties may remain.

The combined effects of culvert length, material selection, and the utility of baffles and similar elements lead to significant uncertainty when applied across a broad range of species. For example, the role of boundary layer turbulence is known to affect the ability of fish to pass through culverts, but the specifics of these effects are poorly understood and considered to be a data gap in an earlier white paper (Kahler and Quinn 1998). Subsequent to Kahler and Quinn’s (1998) review, research on the role of boundary layer turbulence has been studied by examining the swimming performance and behavior of juvenile salmon in test beds (Pearson et al. 2006). Research has demonstrated that juvenile salmonids are able to navigate culverts at higher average flow velocities than would be expected from standard swimming performance curves (Kahler and Quinn 1998; Pearson, Southard et al. 2006; Powers and Bates 1997). They do so by exploiting low-velocity zones in the turbulent boundary layer and other areas of hydraulic complexity. The ability of other fish species to similarly exploit these low-velocity zones in many cases is poorly understood. This creates the potential to over- or underestimate the passage requirements of nonsalmonid fish species.

Despite this directed research, several additional data gaps on issues relevant to design guidance remain (Bates et al. 2003; Pearson et al. 2006). Relatively few data are available on the passage requirements of smaller nonsalmonid fish species, such as dace and chub. While Katopodis (1992) has noted that swimming performance tends to be generally similar across species relative to size when grouped by swimming physiology, this may not fully account for the effects of hydraulic complexity in the passage environment. The flow conditions that constitute an appropriate upper design flow limit for juvenile fish passage are poorly understood for most HCP fish species, as well as other aquatic and semi-aquatic species. The movement of aquatic invertebrates and their passage requirements have received even less study (Vaughan 2002) and are a data gap for the HCP invertebrate species exposed to this activity type.

Current WDFW guidance emphasizes the use of "geomorphic designs" for new and replacement culverts (specifically, structures designed following the no-slope and the stream-simulation options). The intent of these designs is to produce a culvert that allows a broader range of geomorphic processes to function across a broad range of channel types. In the case of the no-slope option, the range of slope and sediment transport conditions over which it can provide effective fish passage remain uncertain. This is particularly true in higher gradient systems and systems with less-mobile bed conditions. It is generally intended for use in low-gradient systems with higher rates of sediment transport.

The development of stream simulation criteria and design procedures is recent. Most of the experience with the method is in mountainous streams. Uncertainties remain about the efficacy of specific criteria and design guidance across a broad range of channel types and hydro-geographic regions. Additional research would fine tune the criteria and guidance, broaden the application, and inform designers of appropriate criteria for unique situations.

Even fish passable culverts may impose ecosystem fragmentation effects on terrestrial and amphibian wildlife species. This may potentially result in indirect ecosystem-level effects on HCP species that are complex and difficult to predict. Even in the absence of complete understanding, it can generally be assumed that designs that promote more natural migration and dispersal behavior are desirable over those that produce barrier conditions. Ongoing research on this subject at the U.S. Forest Service may produce information that will improve guidance in the future (Bates et al. 2008).

10.2.3.2 Fish Ladders/Fishways

Additional study of the factors influencing passage of nonsalmonid HCP fish species is necessary to develop improved design criteria. For example, knowledge of juvenile fish jumping ability is necessary to design for the maximum allowable hydraulic jump (i.e., vertical drop) within a fishway. In this regard, recent research on juvenile coho salmon jumping ability has determined that jump heights exceeding 2.5 times the fish length block passage of a high percentage of individuals (Pearson et al. 2005). This information provides useful design guidance for salmonids, but these findings may not apply to nonsalmonid species. For example, recent research has documented low Pacific lamprey passage efficiency through fish ladders in the Columbia River system, but the specific fishway design factors that support or limit successful passage are unclear (Moser et al. 2002).

10.2.3.3 Roughened Channels

Roughened channels are outwardly simple structures, but in reality the design parameters required to construct a channel that will function as intended over time are demanding and complex. Improper design may lead to unintended perturbations in hydrologic, geomorphic, and riparian conditions that can cause a number of undesirable indirect effects on HCP species. Definitive design guidance for this type of structure is currently lacking and must be considered a data gap.

10.2.3.4 Weirs

Impacts from fish passage weirs are in many cases similar to those for small dams, which have been well documented and a topic of research for decades. In general, there are no major data gaps that exist. However, little research on the hyporheic zone has been conducted in highly altered and degraded fluvial systems (Bolton and Shellberg 2001). While the physical effects of weirs on the environment are well understood, there is a lack of information on the impacts from weirs on specific HCP species. When combined with limited understanding of species-specific migration behavior, a lack of knowledge of the physiological and behavioral passage limitations of all potentially affected HCP species presents the likelihood of unforeseen undesirable consequences. This further suggests that definitive guidance is lacking for the design of structures that function as intended across all species.

10.2.3.5 Trap and Haul

The effects of alteration of migratory corridors on subject fish species is an area of limited but increasing study. Alteration of migratory corridors may have unintended effects on homing selectivity that are undesirable for long-term evolutionary fitness; therefore, this is an area deserving of further study.

10.2.4 Fish Screens Data Gaps

Key data gaps remain in the following general areas:

1. Knowledge of the movement patterns of HCP species at different life-history stages relevant to the development of design and operational guidance for fish screens is a data gap. This is relevant to fish screen operation, but it encompasses an issue driven more so by water removal from the system. Essentially, fish screens can impose operational effects only when an intake or diversion is active, meaning that both fish screen design and managing the timing of water withdrawals are two available tools to limit adverse effects on HCP species. A better understanding of the range of species and life-history stages likely to occur, as well as the timing of their occurrence, is necessary to select the most appropriate screen design.

2. Knowledge of the behavioral and physiological limits on the swimming ability of HCP species, sufficient to guide definition of screen design criteria, particularly for nonsalmonid species is a data gap. Available data show that screen effectiveness may vary by species, depending on factors such as swimming physiology, behavior, sensitivity to bypass entrainment, the unintended effects of stimuli that might be used to guide them toward or away from intakes, and other factors. Fish screens designed to protect salmon may also be effective at protecting fish species with similar swimming physiology, but may not be protective for weaker-swimming species such as juvenile lamprey (Close et al. 1998). Most screen research in Washington State has focused on protection of salmonids, resulting in criteria that may not provide adequate protection for other native species. However, at least some research is available on the response of nonsalmonid

species to fish screens. Better understanding of the tradeoffs between screen function and species protection will allow for more effective design and operational guidance.

3. Useful design criteria across the range of environment types and conditions where screens are employed are lacking. While uniform design guidance would be desirable, the bulk of available research indicates that it is impractical to develop guidance applicable for all environments and uses. The factors that determine the most appropriate screen design for a given situation are highly dependent on both the type of withdrawal (intake or diversion) and site-specific conditions. For example, an effective screen design for an agricultural diversion must consider a number of competing factors, such as the diversion flow rate, flow conditions and variability of the source body, the expected volume of naturally transported debris that must be cleared or passed, and the swimming physiology and sensitivity of the full range of HCP species that occur in the affected environment. This presents a complex set of demands that are not easily addressed by uniform design guidance. This suggests a need for a broader set of assessment steps that can be used to develop site-appropriate designs.

4. Clear demonstrations that fish screens are an effective tool for protecting the productivity and diversity of HCP species (relative to other conservation measures) are lacking. It is not clear that fish screens provide a conservation benefit for all species and all circumstances. While the issue of fish entrainment in industrial and power plant water intake systems is effectively mitigated by fish screens (Goodyear 1977; Hadderingh 1979; Taft and Mussalli 1978; Travnichek et al. 1993), the effectiveness of off-channel screen designs has been less well studied in agricultural applications. Moyle and White (2002) and Moyle and Israel (2005) conducted a broad review of published literature and found that despite policy directives dictating the widespread implementation of fish screens on agricultural diversions, relatively few studies have attempted to evaluate their effectiveness at maintaining or increasing population abundance and productivity. The literature suggests that this lack of evaluation is typical throughout the western United States, despite millions of dollars spent annually on fish screen installation and maintenance (Moyle and Israel 2005). While it can be argued that these studies are unnecessary because the conservation benefits are clear, it may be useful to consider more directed study to identify and prioritize the diversions with the greatest impact on fish populations, and to determine which types of screens provide the best protection for HCP species likely to be exposed.

5. Effects of off-channel diversions when the area between the point of diversion and the screen are quickly dewatered at the end of irrigation season are lacking. The magnitude of the negative effects are unknown. Lamprey are known to use these areas, and may be impacted by sudden dewatering. Effects might be mitigated by an incremental reduction of flow over a number of days and salvage of fish from residual pools.

10.2.4.1 Fish Screen Operations – Entrainment and Impingement

Entrainment and impingement risk is a subject of continuous and ongoing research as fish screen design advances. Despite a large body of existing research, much of the information necessary to protect the broad range of HCP species potentially exposed to screens from these stressors remains unknown. For example, the bulk of available research has focused on fish with subcarangiform swimming physiology (side-to-side undulation of the posterior one-third to one-half of body length), a characteristic of most, but not all, HCP fish species. This research provides the primary base of information on swimming performance used to guide design. However, design criteria based on these data are not likely to provide adequate protection for weaker-swimming fish, specifically lampreys, with anguilliform swimming physiology (eel-like full body undulation). Even for well-understood species such as salmonids, several factors such as species, age class (i.e. size), condition, and water temperature can influence swimming performance in ways that are relevant to design. Sensitivity to injury or other adverse effects also varies between species. For example, Zydlewski and Johnson (2002) evaluated fish screens designed for anadromous salmon protection and found that while juvenile bull trout were frequently impinged on the screen, they were able to escape and were effectively passed downstream without apparent injury or adverse effects. In contrast, Swanson et al. (2005) and White et al. (2007) found that even limited screen contact caused stress and injury sufficient to lead to delayed mortality in delta smelt.

Many design criteria in common use today are based on untested theories (Bates 2008). Design criteria that should be subjected to further research and scrutiny include the following:

- The relationship between screen mesh size and approach and sweeping velocity for balancing debris-clearing effectiveness against impingement and entrainment risks
- The efficacy of widely used sweeping velocity parameters for guiding various HCP fish species and life-history stages across screens and into bypass systems
- Effects of nonuniform approach velocity on impingement risk
- Use of turbulence, light, sound, and other mechanisms to deter or guide fish
- Efficacy of various cleaning mechanisms relative to different types of debris (e.g., hydraulic eddy cleaners), and related risks to HCP species
- Investigation and development of new cleaning technologies, such as vortex separators, to continuously clear sediment from screen bays
- Optimization of bypass configuration for fish collection and flow management
- Appropriate bypass depths and velocity for fish protection and water management
- Screening designs for planktonic larval life stages including effects of impingement, handling, and release.

10.2.4.2 Fish Screen Design Effects on Hydraulic and Geomorphic Modifications

While fish screens are expected to have relatively modest hydraulic and geomorphic effects in comparison to the flow control structure (or other activity types) associated with the related water intake or diversion system, additional data and analysis describing the hydraulic processes affected by certain types of fish screens are desirable. Screen designs of potential concern include large, permanent in-channel structures capable of altering local hydraulic and geomorphic conditions in riverine, marine, and lacustrine environments. In certain circumstances, off-channel structures may also cause undesirable effects. Specifically, screens that require a significant component of remaining instream flow to operate a bypass system may cause hydraulic and geomorphic effects by encouraging vegetation encroachment. Additional research to identify the types of stream channels sensitive to these effects may be desirable.

10.2.4.3 In-Channel Screens

In-channel or end-of-pipe screen systems are relatively simple in design in comparison to off-channel structures, and their effects are more broadly understood. Data gaps related to this subactivity type primarily concern uncertainty about the presence of HCP species with sensitive life-history stages (e.g., small size, planktonic or weak swimming) that cannot be effectively protected by current fish screen designs. For example, flow and velocity requirements necessary to draw various life-history stages of salmon into bypass systems are not well known. Although current designs seem to be effective, they are not likely optimized for either fish passage or flow management because of a lack of empirical data.

This uncertainty can be addressed only by amassing available site-specific data or conducting the necessary research to understand the timing and distribution of sensitive life-history stages in relation to the desired operating parameters of the water intake system. This understanding can be used to set operational limits as necessary to overcome limitations in screen performance.

Guidance criteria for the siting, design, and operation of infiltration gallery screens are currently lacking. Additional research should be conducted to determine if this technology has practical utility and, if so, to identify appropriate uses and develop design criteria.

For additional information, see Rychetsy and Card (2000).

10.2.4.4 Off-Channel Screens

The off-channel screen subactivity type encompasses a number of screen designs that range from relatively simple to complex. The design requirements for these structures are highly site specific. Although generalized guidance can provide some basis for selecting an appropriate design, site-specific assessments and research are necessary to develop these designs fully.

A number of data gaps have been identified that–when addressed–could improve both the general guidance for species protection and an understanding of the limitations of certain screen designs. These include:

- ***Passage-related effects of fish screen designs:*** The potential for certain types of off-channel fish screens, specifically those with integrated bypass channels, to create attraction flows that unintentionally delay adult migration has been identified as an issue of concern from a design perspective by WDFW (2001a). However, empirical data necessary to provide clear design guidance on this subject are currently lacking. Similarly, screens with bypass channels must produce adequate sweeping flows to avoid delaying downstream migrant salmonids. While sweeping flow requirements are fairly well understood for salmonids and some other fish species, the needs of some HCP species (e.g., lamprey) appear to be less clear.

- ***Upstream movement requirements of HCP invertebrate species:*** The freshwater HCP invertebrate species vary in terms of the mechanisms they use to disperse in flowing water environments. The degree to which fish screens may help or hinder these dispersal mechanisms and the ramifications for population health are an area requiring additional study.

- ***The ecosystem fragmentation effects of screens:*** Certain off-channel fish screen designs may affect upstream and downstream fish passage by delaying migration, or imposing unintended selection pressures on affected populations. Water withdrawals may also affect the transport of organic material and woody debris. Fish screens with bypasses provide a conduit for some of the debris to return to the river. The extent of these effects, particularly the cumulative effects of multiple screens distributed across the landscape, are not clear. This is an area that could benefit from additional research. Given the site-specific nature of these effects, however, it may be difficult to produce results that lead to broadly applicable guidance.

10.2.5 Flow Control Structures Data Gaps

10.2.5.1 HCP Species-Specific Information

Besides the extensive research on salmonids, there is a general lack of information regarding the effects that flow control structures may have on most other HCP fish species. An exception is that several studies have been conducted examining sturgeon and dams. During a detailed literature review, little information on impacts on invertebrates was found.

10.2.5.2 Dams

Impacts from dams have been well documented. Dams have been a topic of research for decades. Minor data gaps are as follows:

- little research on the hyporheic zone has been conducted in highly altered and degraded fluvial systems (Bolton and Shellberg 2001). As the understanding of these processes increases, studies will likely begin to focus more on the effects of land use and other human activities on surface–groundwater interactions.

- The effects of dam removal on aquatic species, their habitats, and ecological processes represent a data gap. Although there have been several studies on the ecological impacts of dam removal (Bednarek 2001), there is a general lack of post-removal data to document these changes. More specifically, dam removal data to date have focused on smaller dams, so the actual impacts from a large dam removal are often inferred. The future removal of two dams on the Elwha River (Washington) represents an opportunity to study the impacts of a large-scale dam removal.

10.2.5.3 Weirs

There is a lack on information on the impacts from weirs on specific HCP species.

10.2.5.4 Dikes and Levees

As with dams, little research regarding the hyporheic zone has been conducted in systems supporting dikes and levees. As the understanding of these processes increases, studies will likely focus on the effects of land use and other human activities on surface–groundwater interactions. In addition, while a number of studies document changes to habitat after construction of dikes and levees on the landward side of the structure, more information is needed with respect to in-channel changes.

10.2.5.5 Outfalls

Limited information is available on the hydraulic and geomorphic modifications of outfalls and intakes and their direct impact on fish and invertebrates. Information on the effects of outfalls on riparian and aquatic vegetation and ecosystem fragmentation is scarce. In general, most studies of outfalls are related to water quality modifications, and these impacts are well documented.

10.2.5.6 Intakes and Diversions

Limited information is available on the hydraulic and geomorphic modifications of intakes and diversions and their direct impact on fish and invertebrates. Information on the effects of intakes on riparian and aquatic vegetation, hyporheic flows, and ecosystem fragmentation is scarce.

10.2.5.7 Tide Gates

In a review of tide gate operations in the Pacific Northwest, Giannico and Souder (2005) failed to find studies that examined the effect of tide gates on juvenile fishes, reporting that this represents a large data gap in our understanding of how these structures influence fish populations. Specific information is lacking on migration patterns of species that use habitats where tide gates occur (Giannico and Souder 2005). If detailed information on the behavior and movements of HCP species were better understood, then tide gates could be better designed to allow for increased fish passage.

There is a potential for a loss of LWD as the result of a tide gate. However, there is little information about how tide gates alter LWD transport and recruitment, which represents a potential data gap. In marine ecosystems in general, the influence of LWD on primary productivity is somewhat unclear.

10.2.6 Habitat Modification Projects Data Gaps

10.2.6.1 Beaver Dam Removal/Modifications

There has been considerable research regarding the use of beaver dam habitat and similar backwater habitat by fish and invertebrates. However, there are no studies which have specifically monitored fish and invertebrate populations both before and after a beaver dam removal. Impacts on these species must be inferred from studies which have monitored the impacts of man-made dam removal projects on aquatic species. The impact of nonlethal beaver management strategies on pond habitat and fish passage is even less well understood. It is assumed that *(removing?)* these structures would have little impact on ecosystem dynamics while simultaneously controlling upstream flooding, but there have been no studies to support this assumption. There have been no studies on the impact of dam removal (beaver or otherwise) on any of the HCP invertebrate species.

10.2.6.2 Large Woody Debris Placement/Movement/Removal

The impact of LWD placement and removal is a thoroughly researched topic but there are several data gaps that still exist. The largest data gap regarding LWD placement/movement/removal is that little research on LWD in marine environments has been conducted.

- There has been little research on the importance of wood in supporting beach structure and connectivity between estuarine environments.

- Many shorelines in the Puget Sound area contain considerable wracked wood in the supertidal zone (Sobocinski 2003) which may serve to reduce shoreline erosion and protect the sediments which are the foundation for the shallow water habitat (Herrera 2005). Additional research is needed before the impact associated with wood modification on beaches can be assessed.

- In marine ecosystems, the influence of LWD on primary productivity is somewhat unclear. Supratidal food web dynamics are likely driven by both terrestrial and marine processes including (but not limited to) marine deposition of large wood. LWD along with wrack material and other organic debris can be a source for the detritus-based nearshore food web. Colonization of wrack by scavengers, infauna, and ultimately bacteria and diatoms, is an important process in maintaining energy exchange between the terrestrial and marine systems (Sobocinski 2003).

10.2.6.3 Spawning Substrate Augmentation

The impact of augmented salmonid spawning gravels on channel geomorphology and ecosystem dynamics is poorly understood. There have been a limited number of studies regarding the ecological ramifications of spawning substrate augmentations, despite the fact that it is frequently done. There is no information regarding the impact that added gravel may have on riparian flooding. Increased flooding of riparian areas could potentially benefit stream biota by providing increased habitat access and exporting additional food resources to the channel. Conversely, increased flooding could endanger man-made structures within the floodplain and potentially import organic material which could degrade the permeability of the augmented gravels.

The goal of spawning substrate augmentation is to create quality salmonid spawning habitat which will result in an increase in redd density and fry productivity and survival. The research to date has reported conflicting results as to whether gravel augmentation actually increases redd density. Additional research is needed to verify that augmented sites have a higher carrying capacity than unaltered sites. Research to date has indicated that benthic dissolved oxygen levels are higher in augmented gravels and that egg survivorship is elevated in augmented gravels (Merz and Setka 2004). Thus, even if redd density does not increase in a restored site, fry productivity and survival may still be improved.

The potential benefit of spawning substrate augmentation for invertebrates is unclear. It is evident that initially organisms with limited motility will be buried and will perish, and it is also clear that benthic organisms have the ability to rapidly recolonize augmented reaches (Merz and Chan 2005). Increased benthic dissolved oxygen will, in theory, benefit mollusks but there have been no studies that have identified a net benefit to invertebrate populations after gravel augmentation.

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

There has been a wealth of studies on the ramifications of in-channel habitat modification. Yet, due to the wide array of projects which are built in highly variable fluvial environments, the research results to date regarding the efficacy of such projects are mixed. The science of river restoration is constantly evolving and more studies are needed to quantify the effectiveness of projects built to the most rigorous and up-to-date standards. If indeed, these projects fail as frequently as projects built in years past (see Frissell and Nawa 1992; Merz and Chan 2005; Roni et al. 2002; Roper et al. 1998), then it can be assumed that channel rehabilitation efforts should be focused elsewhere (e.g. volume control, riparian restoration, off-channel habitat rehabilitation).

The most significant data gap related to in-channel and off-channel habitat modification is regarding the effect of the restoration on fish populations, because fish are mobile and are affected by impacts from outside the restored reach. Consequently, it is difficult to correlate alterations to a defined reach with fish population dynamics. Studies that monitor fish movement using different remote tracking technologies may be most useful in clarifying this issue. As tracking technologies improve, the question of habitat usage and restoration efficacy will be more definitively addressed.

10.2.6.5 Riparian Planting/Restoration/Enhancement

The research findings regarding fish response to riparian restoration are mixed. Increased riparian shading will reduce water temperatures (LeBlanc and Brown 2000; Opperman and Merenlender 2004) and this may benefit fish in thermally impacted reaches, but fish response to riparian vegetation planting/restoration has not been clearly defined. For instance, Bjornn et al. (1991) found that age-0 coho did not respond to either riparian vegetation removal or artificial cover creation in an Alaskan stream. Numerous researchers have monitored physical and macroinvertebrate response to riparian vegetation alteration (Fuchs et al. 2003; Sweeney et al. 2004; Teels et al. 2006; Wipfli 2005). These studies have found that partial riparian cover promotes the greatest macroinvertebrate abundance. It can be assumed that increased macroinvertebrate abundance will support a greater fish population, but more studies of fish response to riparian vegetation addition and removal are needed to definitively characterize the impact of riparian planting on fish.

There are no widely available studies regarding the impact of invasive vegetation removal on stream ecology. Vegetation removal can destabilize banks and increase stream temperatures. The removal of riparian invasives such as Himalayan blackberry is a common riparian restoration practice (Bennett 2007), and further studies are required to assess the impact of this and similar activities on both fish and invertebrates.

There is very limited information on marine riparian restoration efforts. Loss of riparian vegetation in marine environments has been identified as an important problem, but monitoring of marine riparian restoration efforts has not been done.

10.2.6.6 Wetland Creation/Restoration/Enhancement

The primary data gap regarding wetland creation is the impact of wetland creation on invertebrate species. It can be assumed that there will be no impact because in these types of restorations, habitat is not being degraded or eliminated but rather is being connected and/or augmented. Regardless, there is no available research to quantify the impact of riparian wetland creation/restoration on the HCP invertebrate species.

There is limited information as to what size riparian wetland would be most beneficial to the river-floodplain ecosystem. Most floodplain restorations are limited in scope and the resultant wetland is much less extensive then the natural historic wetland that once existed. Consequently, residence times are generally lower in restored versus natural riparian wetlands. There has been no research which has quantified how this lowered residence time may affect nutrient processing and carbon export from restored floodplains.

No studies have examined the impact of dike breaching on HCP fishes. Tidal flow over modified landscapes can produce fish traps, but this effect has not been described in the literature. The effects of nutrient loading from the inundation of former nutrient-rich (fertilized) agricultural lands have not been investigated.

10.2.6.7 Beach Nourishment/Contouring

There is substantial information about beach nourishment projects in exposed, sandy settings (Speybroeck et al. 2006). However, there is no peer-reviewed literature describing the restorative characteristics of beach nourishment projects for HCP fishes in coarse-clastic environments that are typical in Puget Sound (Shipman 2001). While there have been several reports of nourishment projects in Puget Sound (Gerstel and Brown 2006; Shipman 2001; Zelo et al. 2000), these “grey literature” reports have only cataloged the physical response of the beach to nourishment activities. These studies are useful for design purpose, but they have not addressed the core issue of whether nourished shorelines are actually used by species targeted by this activity (i.e., forage fishes).

Despite the lack of peer-reviewed work there is substantial anecdotal evidence that forage fishes do use placed materials for spawning. For instance, a beach nourishment project in Silverdale Waterfront Park, Kitsap County, continues to be used by surf smelt. Shorelines cut into man-made fill in Commencement Bay have also been designated forage fish spawning areas (Penttila 2007). Developing this anecdotal evidence into peer-reviewed articles should be the target of future research funding considering the novelty of the work and the large number of beach nourishment projects.

While there a number of peer-reviewed articles regarding the efficacy of beach nourishment in sandy settings (Speybroeck et al. 2006), none of these studies focus on the benefits or detriments to the HCP species. Many of the impacts that have been described in the literature relate to excess turbidity and deposition of fine sediments near nourishment project sites (Speybroeck et al. 2006; Wilber et al. 2003). It may be that these effects are less pronounced on the HCP species. The HCP species in the Pacific Northwest have adapted to environments where sediment concentrations are substantially higher than the tectonically benign east coast (Montgomery 2000).

There is essentially no information (peer-reviewed or otherwise) on the ecological impacts of beach nourishment on lakeshores. Only two peer-reviewed studies were found that examined the ecological impacts of freshwater beach nourishment. The results of these studies mirrored the work performed in the marine environment, with one study advocating nourishment for fish populations (Winfield 2004), while the other documented the loss of invertebrate species due to nourishment in the Great Lakes (Garza and Whitman 2004). Considering that numerous HPAs were authorized in 2006 alone for nourishment projects on lakeshores, more work is urgently needed on both the design parameters and ecological impacts of lakeshore nourishment projects.

10.2.6.8 Reef Creation

Much of the information collected in the Environmental Design of Low Crested Coastal Defense Structures (DELOS) program sponsored by the European Community is useful for identifying the impacts of reefs and the subsequent effects on fish and invertebrates. However, the relative lack of salmonids on the European continent limits the applicability of that work to the nearshore ecology of the Pacific Northwest.

The loss of fish that serve as food (forage fish) for salmonids has been studied, but relating the construction of an artificial reef to salmonid loss has not. Also, identifying the role that invasive species infestations (associated with the deployment of offshore rocky structures) can have on native species needs to be investigated (e.g., the abundance of urchins or macroalgae at the expense of salmonids).

The only research literature on freshwater reefs comes from the Great Lakes (Marsden and Chotkowski 2001; Meadows et al. 2005). However, it would be helpful to have a study similar to Marsden and Chotkowski (2001) to identify the ability of Washington freshwater reefs to attract invasive species.

There has been no work on the attraction of the HCP invertebrate species to artificial reefs.

10.2.6.9 Eelgrass and other Aquatic Vegetation Enhancement

Although eelgrass planting programs have been undertaken for nearly twenty years (Thom 1990), successful programs have only existed for a few years (Thom et al. 2005). Techniques and procedures for successful programs have been established (Thom et al. 2005); however, no program has yet to document the net gain to HCP species. The lack of data regarding the return of higher trophic species remains a large data gap.

10.2.7 Marinas and Terminals Data Gaps

In general, the thresholds for watershed and population size and the number of activities that must occur within a particular watershed to have a measurable cumulative impact are not yet established in the literature. These are needed to assess the effects of marinas/terminals on HCP species in a holistic approach.

In other regions of the United States, studies have documented the cumulative impacts on the nearshore environment (e.g., the Great Lakes [Meadows et al. 2005]. Impacts on numerous HCP species have been documented due to hydraulic and geomorphic modifications associated with marina development. Data and analysis describing the ecosystem processes affected by marina/terminal activities are needed.

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

10.2.7.1 Vessel Activities

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

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

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

Recent work specific to identifying the impacts of marinas and terminals on migrating juvenile salmon along marine and lake shorelines has begun to address these information needs.

10.2.8 Overwater Structures Data Gaps

10.2.8.1 Shading

Significant gaps and uncertainties remain in knowledge about the impacts of overwater structures and shading on the aquatic environment and biota (Nightingale and Simenstad 2001b; Carrasquero 2001). Some of these gaps are basic to understanding the ecology and life history of potentially impacted species, such as those defining the extent and ecological dependence of shoreline habitat use by certain biota.

Since the publication of the two WDFW white papers cited above, a few studies have been completed regarding shoreline habitat use of aquatic biota.

- Toft et al. (2004) reported on fish distribution, abundance, and behavior in nearshore habitats along the marine shoreline of the City of Seattle.
- Tabor et al. (2006) studied nearshore habitat use by juvenile Chinook salmon in the Lake Washington basin.
- Southard et al. (2006) studied conditions for, and the significance of, avoidance of shoreline structures by migrating juvenile salmon in *Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines*. This study supported other findings that identified shading of overwater structures as the mechanism for salmonid avoidance (Weitkamp 1982, Pentec 1997, in Nightingale and Simenstad 2001b; Shreffler and Moursund 1999) and recommended ways to minimize impacts of ferry terminals on juvenile salmonids.
- Haas et al. (2002) suggest that additional research is necessary to determine the thresholds at which epibenthic biota become affected by the shading of vegetation.

10.2.9 Shoreline Modification Data Gaps

10.2.9.1 Jetties

10.2.9.1.1 Marine Environments

Significant work has been performed on the various ways that shoreline modifications have altered the nearshore ecosystem, although much of this applies to shoreline hardening and human activities in general, not specific actions. Nearly all of the modifications associated with shoreline development can be attributed to jetties. Within this body of work, three areas have been identified that are relevant to the HPA process where data gaps remain:

- *Cutting-edge technique effectiveness assessments*. Current practical knowledge exists to protect navigational channels through the implementation of innovative engineering alternatives to jetties (e.g., engineered wood placement). These alternatives can provide the desired degree of infrastructure protection while restoring physical processes, habitat features, and/or ecological functions. The effectiveness of these techniques has not been fully tested through the implementation of prototype projects.

- *Peer-reviewed monitoring of constructed restoration efforts.* Habitat restoration activities have been undertaken in many nearshore settings throughout western Washington over the last 30 years. Some have been large and have included monitoring (Carney et al. 2005; Cheney et al. 1994), but most have a tendency to be carried out on small, private properties where no consistent monitoring of the project objectives has been calculated (Gerstel and Brown 2006). Even when monitoring has been performed, it has generally been used more as a design tool, rather than investigating the efficacy of the activities to restore the targeted species (Carney et al. 2005).

- *Cumulative impact studies*. Many other regions around the U.S. have established large interdisciplinary studies to document the cumulative impacts on the nearshore environment [e.g., the Great Lakes: (Meadows et al. 2005)]. Impacts on numerous HCP species have been documented due to hydraulic and geomorphic modifications associated with shoreline hardening in general.

10.2.9.1.2 Freshwater Environments

Because there are few jetties in fresh water, and likely few to be constructed due to the relatively weak demand for them, information on environmental impacts of jetties in fresh water on HCP species stands as a data gap.

10.2.9.2 Breakwaters

10.2.9.2.1 Marine Environments

There have been a large number of studies related to the hydrogeomorphic and ecologic impacts of breakwaters, mostly as a result of the Environmental Design of Low Crested Coastal Defense

Structures (DELOS) program sponsored by the European Community (Losada et al. 2005). The data collected as a part of the hydrogeomorphic portion of the program are relevant to projects in Washington State. The results that document the ecological transition from soft-substrate to hard-substrate communities are particularly relevant to rockfish and sculpin species, as well as the invertebrates. The relative lack of salmonids on the European continent limits the applicability of that work to the nearshore ecology of the Pacific Northwest.

The loss of fish that serve as food for the salmonids has been studied, but relating the construction of a single breakwater or artificial reef to salmonid loss has not. Identifying the role that invasive species infestations associated with the deployment offshore rocky structures can have on native species needs to be investigated (e.g., the abundance of urchins or macroalgae at the expense of salmonids).

10.2.9.2.2 Freshwater Environments

The only literature on freshwater breakwaters comes from the Great Lakes (Marsden and Chotkowski 2001; Meadows et al. 2005). Because there are few breakwaters in Washington in fresh water, and likely few to be constructed due to the relatively weak demand for them, information regarding any environmental impacts on HCP species stands as a data gap. It would be helpful to have a study like Marsden and Chotkowski (2001) to identify the ability of Washington freshwater breakwaters to encourage invasive species infestations.

10.2.9.3 Groins and Bank Barbs

10.2.9.3.1 Marine and Lacustrine Environments

There have been no systematic studies of the cumulative impact of groins, as they have not been built in large number for some time because of other legal restrictions (e.g., Clean Water Act, Coastal Zone Management Act, Shoreline Management Act, and city and county critical areas regulations).

Also absent are studies of the differing degree of impacts from different types of common modifications that would be equivalent to a groin or barb. Construction or repair of access stairways would clearly be less disruptive than construction of a groin that extended from above the ordinary high water mark (OHWM) to subtidal (in marine environments) or limnetic (in lacustrine environments) depths. However, there is essentially no peer-reviewed literature on the impact of these modifications on nearshore geomorphology, let alone nearshore ecology.

There is no literature that describes innovative engineering techniques related to alternative structures on the shoreline, most notably structural access to intertidal or lacustrine littoral areas of the shoreline.

10.2.9.3.2 Riverine Environments

In a literature review of the effects of riprap, by far the most common material used in groins and barbs, on salmonids in streams and rivers of the Western Unites States, Schmetterling et al. (2001) noted four areas where research on this subject is lacking:

(1) quantifying the habitat availability and quality of riprap;

(2) correlating the effects of riprap banks on salmonid density in the absence of other dependent variables such as diking, channelization, and watershed land use;

(3) comparative studies on the use of riprap and alternative "soft" techniques such as the integration of natural materials; and

(4) the cumulative and synergistic effects of numerous bank-hardening projects at the watershed level.