8 Cumulative Impacts

The cumulative impacts[1] evaluated for the purposes of consultation under ESA are those effects of "future state or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation" (50 Code of Federal Regulations 402.02). The "reasonably certain" language regarding activities is too restrictive to meet this paper's objective of providing a general evaluation of cumulative effects of HPA-permitted activities. Therefore, a broader interpretation of cumulative effects is considered here. For the purposes of this paper, the cumulative impacts considered are the incremental impacts of individual projects considered in the context of other past, present, and reasonably foreseeable future actions.

Assessing cumulative impacts falls into the category of "an emerging science." No sources were identified that established quantified thresholds. However, the literature search identified numerous planning efforts throughout the country where cumulative impacts are identified as a topic to be addressed.

The Council on Environmental Quality (CEQ 1997) presents a simple typology of cumulative impacts where cumulative effects arise from single or multiple actions and accumulate in an additive or interactive manner. This typology and bank protection examples are presented in Table 8-1.

Table 8-1. Types and Examples of Cumulative Impacts

Cumulative Impact Type (CEQ 1997)	Example
Type 1. Repeated "additive" (*or deletion*) effects from a single project	A single bulkhead disrupts sediment transport and after each storm event sediment is transported from the downdrift beach section without being replaced. The deletion of sediment accumulates incrementally over time.
Type 2. Stressors from a single source that interact with biota to have an "interactive" (nonlinear) net effect.	A single bulkhead disrupts sediment transport as illustrated above and reflects wave energy that scours sediment from the beachfront along the bulkhead. The beach becomes coarser due to scour and lack of sediment resupply. Intertidal habitat is altered and no longer available for the benthic fauna such as

---

[1] Note to Reviewers: The content of this chapter is drawn from ten white papers prepared for WDFW in 2006 and 2007 on a variety of HPA-permitted activities. Because each of the original white papers discussed one category of activities, the discussion of "cumulative impacts" tends to be limited, emphasizing the effects of having several individual instances of a given activity in a particular area, (for example, the impacts of many bank armoring projects within a given reach.) The discussions do not necessarily discuss cumulative impacts in the broader sense, for example if bank armoring, overwater structures, water crossing structures, and habitat modifications were all permitted in a given area.

Cumulative Impact Type (CEQ 1997)	Example
	bivalves.
Type 3. Effects arising from multiple sources that affect environmental resources additively.	In addition to construction of a bulkhead, the riparian vegetation is removed. The bulkhead reduces the shore roughness and no longer retains LWD, and recruitment of LWD is lost due to clearing of the riparian vegetation. Shade provided by riparian vegetation is also lost, thereby increasing solar radiation and water temperature.
Type 4. Effects arising from multiple sources that affect environmental resources in an interactive (i.e., countervailing or synergistic) fashion.	Additional bulkheads are constructed due to concentration of wave energy from existing bulkhead or due to perceived threats increasing the length of protected shoreline. Effects accumulate in a linear manner to a threshold where habitat structure and composition are substantially changed, leading to an alteration of habitat processes and ultimately a shift in ecological function. This would be manifested in a reduction of habitat and loss of species richness.

This conceptual framework of cumulative impacts could be applied at a regional scale, where individual impacts could be quantified. However, due to the complexity of quantifying impacts and the lack of specific data, cumulative impacts are often assessed qualitatively. In the absence of a quantitative analysis of cumulative impacts, the following sections qualitatively describe the cumulative impacts of each impact mechanism.

Evidence increasingly indicates that the most devastating environmental effects are likely not the direct effects of a particular action, but the combination of individually minor effects of multiple actions over time (CEQ 1997).

Nightingale and Simenstad (2001b) specifically discussed the effects of overwater structures. However, much of their discussion is applicable to other types of HPA-permitted activities as well. They note that “The bathymetry of Washington's inland waters, that of a fjord surrounded by a narrow strip of shallow vegetated habitat, magnifies the need to protect the integrity and continuity of this limited area of nearshore habitat because of the concentrated zone of potential impact.” This is directly relevant to an ESA analysis, because it identifies the area where cumulative impacts will have a concentrated effect on habitat processes, structure and functions. In general, as the number of shoreline modification structures increases in a given area, impacts will accrue producing a net loss in vegetation production and a concomitant reduction in epibenthic and benthic nearshore habitat. The type and extent of each of these alterations depend on site-specific characteristics and structure types.

Nightingale and Simenstad (2001b) discuss cumulative effects on "rural and natural" as opposed to "urban industrialized" shorelines. For rural shorelines, the authors state that:

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

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

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

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

8.1 Cumulative Impacts Sorted by Mechanism of Impact

8.1.1 Cumulative Impacts Associated With Construction and Operations

8.1.1.1 Noise

Cumulative impacts associated with the construction activities of multiple projects could amplify the behavioral alterations or physical impacts that could occur as a result of individual projects. Cumulative noise impacts may result from the accumulation of exposure energy that fish receive from multiple pile drives (Popper et al. 2006), increased numbers of boats or boating use (Scholik and Yan 2001a), and increased use of construction equipment.

In speaking of cumulative noise impacts to marine mammals, Dr. Sylvia Earle, former chief scientist at NOAA, has stated that "each sound by itself is probably not a matter of much concern," but taken together, "the high level of [ocean] noise is bound to have a hard, sweeping impact on life in the sea" (Holing 1994, in Radle 2005). Applying this concept to the potentially covered species, the repeated occurrence of noise could prompt organisms to migrate away from an area. Conceivably, minor physical impacts associated with individual projects could become more severe if several projects in an area result in the same type of impact. Also, an organism or its habitat could be more vulnerable to physical damage due to the impacts of preceding activities.

Construction is only one of several sources of such noise; other major sources include large-vessel shipping traffic, military activities, and acoustic profiling for petrochemical and minerals exploration. However, the cumulative impacts of such noise sources on fish physiology and behavior are unknown at this time.

8.1.1.2 Artificial Light

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

8.1.1.3 Vessel Traffic

Cumulative impacts of vessel activities are not well characterized. Some potential cumulative impacts include the following:

- Cumulative impacts from vessel activities have been reported with respect to turbidity. Vessel traffic may cause extended periods of elevated turbidity as boat traffic collectively churns the water, slowing the settling of suspended sediment (Garrad and Hey 1988).

- Successive passes by vessels may accelerate shoreline erosion; recreational vessel traffic has been observed to cause boat wake-induced levee erosion at rates of 0.0004 to 0.009 inch (0.01 mm to 0.22 mm) per boat pass (Bauer et al. 2002).

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

- Because marinas serve multiple vessels, the underwater noise generated by boating activities (i.e., outboard motors) is cumulatively higher than at a single dock. If the marina is surrounded by a breakwater, the noise effect may be limited to the area of the marina. However, as a hub for boats traveling in and out, it would add to the total noise levels in the surrounding area. For shipping and ferry terminals, the potential for increased ambient noise levels, benthic disturbance, ambient light modifications, and water quality degradation is even greater due to year-round boat traffic and the size of the vessels using these facilities.

- Vessel traffic is associated with grounding, anchoring, and prop wash. Boat use will likely increase as the state population increases, resulting in disturbance of bottom substrates and vegetation generated by propeller wash.
- Cumulative effects from vessel traffic would be expected based on projections of future growth. In 1980, total ridership of Washington State Ferries was 16.7 million; by 2002, it increased by 50 percent to 25.1 million. These volumes are projected to continue to increase to 43.4 million riders by 2020 (WSDOT 2006b). Recreational vessel numbers and commercial vessel traffic have also increased, and this trend is expected to continue.
- Vessel type affects the potential impacts generated by boat traffic. WSDOT is currently in the process of evaluating the feasibility of several different vessel types to replace existing ferries at the Port Townsend and Keystone ferry terminals (WSDOT 2007).
- Sandstrom et al. (2005) found that vessel activities had a profound effect on species composition of aquatic plants, and Eriksson et al. (2004) found similar effects on fish species in areas of marinas and ferry boat routes compared to those areas without such boating traffic.

8.1.1.4 Channel Dewatering

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

Cumulative impacts of channel dewatering will most likely be associated with fish removal/exclusion methods, disturbance of the streambed, and modification of invertebrate habitat and consequent changes in species diversity. Although there are no available studies on the cumulative effects of temporary activities associated with channel dewatering, cumulative effects could result from the permitting of numerous dewatering activities within a watershed over a relatively short period of time.

The cumulative impacts on a particular species' population would depend on the number of concurrent projects at a watershed scale, as well as the population size of a given species. The cumulative impacts to fish populations resulting from multiple permitted activities within a watershed that require fish removal/exclusion could be measurable at the population scale depending on several factors, including watershed and population size. Fish removal/exclusion results in the capture and handling of fish, which can cause stress, harm, and mortality.

The threshold for watershed and population size and the number of activities that must occur within a particular watershed to have a measurable cumulative impact are not established in the literature.

Temporary losses of benthic macroinvertebrates are likely to occur as a result of dewatering associated with new construction or expansion of existing structures. Changes in the representative species assemblages as a result of changes in hydraulics and habitat conditions within affected reaches are also possible. The cumulative impacts of repeated channel dewatering efforts could lead to changes to benthic macroinvertebrate populations or species diversity that may lead to subsequent changes to fish populations or habitat occupancy.

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

8.1.1.5 Dredging

Analysis of cumulative effects of landscape-scale bathymetry modifications and changes to habitat structure should include the overall scope of dredging activities undertaken in the region. Understanding the scope of current dredging activities requires a breakdown and comparison of the areal extent of maintenance dredging undertaken annually compared to new project dredging, as well as the extent to which this dredging alters the nature of existing habitats in marine, riverine, and lacustrine environments. An analysis of the scope and nature of current dredging activities can lay the groundwork for assessing the long-term, cumulative effects that dredging activities can pose on existing ecosystem dynamics and the effects such changes may have on a variety of species.

The scope of such an assessment will vary depending on the environment type. For example, in marine environments an assessment might focus on the areal extent of dredging activities within each of the oceanographically distinct basins in Puget Sound, differentiating habitat impacts in terms of the depth, substrate composition, and bathymetric profile of the affected areas. In lacustrine habitats, the analysis might have a similar focus but would be limited to the individual lake. In riverine environments, a watershed-scale approach or a more targeted approach differentiating estuarine impacts may be appropriate.

8.1.1.6 Accidents

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

8.1.2 Hydraulic and Geomorphic Modifications

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

8.1.2.1 Urban Streams

Studies on the cumulative effects of increased impervious areas have focused on the effects of urbanization on the ecology of urban streams. The condition of urban streams is controlled by the altered timing and volume of water, sediment, nutrients, and contaminants resulting from the urbanized catchment (Bernhardt and Palmer 2007). The most noticeable determinant of channel change in urban watersheds is the increase in streamflow discharges (Booth and Henshaw 2001). Increased peak streamflows from urban development cause streams to incise deeper and wider channels (Booth 1990; Hammer 1972; Leopold et al. 2005). The consequence of this channelization is local bank failure, increase in sediment supply, and sediment deposition in lower gradient, downstream reaches (Booth 1990). Konrad (2000) examined urban watersheds in the Puget Lowland and found that urban development increased peak discharge magnitudes and decreased storm flow recession rates, causing "flashy" runoff conditions. Consequently, substrate reworking by flow was more frequent and extensive in urban streams than in suburban streams draining less-developed watersheds. Summer base flow was also suppressed relative to suburban streams. The ecological effects of urbanization on urban streams include species-poor assemblages of fish and invertebrates (Freeman and Schorr 2004).

8.1.2.2 Littoral Drift

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

8.1.2.3 Substrate Modification

Many HPA-permitted activities can result in substrate modification. The cumulative impacts of each component of substrate modification can lead to a reduction in the quantity and quality of habitat for potentially covered species. As noted by Quinn (2005), the incremental loss of spawning and rearing habitat has contributed to the declines in salmonid populations. Substrate modifications along marine shorelines have reduced the availability of suitable spawning habitat for surf smelt and sand lance. The cumulative impacts of these modifications are unknown; however, a crash in their populations could further impact salmonids and other piscivorous fish.

Among the potentially covered invertebrate species, Newcomb's littorine snail is particularly vulnerable to cumulative impacts of substrate modifications given the species' small geographic range (Grays Harbor and Willapa Bay) and specific habitat preference (*Salicornia virginica* marshes).

8.1.3 Shading

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

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

Fish feeding and migration abilities are closely linked to the ambient light environment. To the extent that under-dock environments block light transmission, they pose the risk of diminishing prey resources and triggering behavioral changes of HCP species. As these structures are typically in the shallow nearshore, the impacts on fish would likely be to the juvenile life-history stage. Following a study of ferry terminals in Puget Sound, Haas et al. (2002) reported that large overwater structures pose serious impacts on intertidal and subtidal nearshore habitats. These impacts include reduced benthic vegetation and decreased densities of epibenthic prey. Haas et al. (2002) concluded that the cumulative effects in densely population areas, such as Puget Sound, may be large. The extent to which this impact on prey availability is limiting to juvenile salmon is unknown. Haas et al. (2002) also identified extensive impacts of ferry terminals that pose habitat fragmentation effects.

8.1.4 Aquatic Vegetation

Aquatic vegetation is a fundamental structural component in marine, estuarine, and lake environments. Numerous species utilize the vegetation for cover, feeding, and spawning. The successive incremental losses of aquatic vegetation by multiple HPA-permitted projects could impact the species distributions and productivity. While aquatic vegetation may be resilient in recolonizing disturbed areas if suitable conditions are provided, the potential isolation of vegetation patches through the impacts of multiple projects could lead to the disappearance of the patch.

Existing structures will continue to modify ambient light conditions and subsequently aquatic vegetation via shading and turbidity. An increase in facilities or facility capacity and an overall increase in vessel traffic will likely magnify these impacts. Future construction of new facilities could result in the removal of existing aquatic vegetation, further affecting these resources.

8.1.4.1 Eelgrass and Macroalgae

The cumulative impact of structures that shade potential eelgrass habitat or otherwise inhibit growth would be a reduction in eelgrass coverage, as can be seen at individual structures (Nightingale and Simenstad 2001b). Large-scale eelgrass monitoring in the inland waters of Washington State (2000 through 2008 data set) indicates that the majority of eelgrass sites have no significant change, and that at sites with significant increases or decreases in eelgrass, the differences are small (Dowty et al., 2009). Preliminary data indicate downward trends may exist, but further analysis of data will be required to attribute significance to these results (personal communication, Dowty, 2009). However, because eelgrass coverage is affected by many variables in addition to the cumulative impacts of development, the results observed by Dowty et al. (2005) do not indicate a clear cause and effect of development on overall patterns of eelgrass coverage.

The real implications of cumulative changes in eelgrass distribution and cover are unclear, because it is not known how dependent many potentially covered species are on eelgrass. For instance, herring spawn on eelgrass, but there are extensive areas of eelgrass where no herring spawn, so changes in eelgrass cover alone would be a poor predictor of future herring spawning success. Similarly, young salmon forage extensively in eelgrass, but foraging habitat may not be a limiting factor for juvenile salmon in Puget Sound (Haas et al. 2002). Much human impact on eelgrass and macroalgae takes the form of habitat fragmentation, but although such fragmentation is in principle an adverse impact, it remains unclear just how that impact is delivered to affected species (Haas et al. 2002). Thus, our understanding of cumulative impacts on eelgrass and macroalgae is limited by major data gaps.

It has been documented that areas where eelgrass has been lost through direct disturbance or alteration of habitat conditions are sometimes colonized by other macroalgae species (Thom et al. 1994). This shift in aquatic vegetation would also be a shift in habitat structure, which could lead to a shift of fauna assemblages (Williams and Thom 2001). The shading of eelgrass beds that serve as important nursery habitat for many species can greatly affect numbers of marine biota within a region, including salmonids, crab, herring, and important epibenthic crustaceans. Pacific herring would be vulnerable to alterations in eelgrass distribution. Given the strong association of important fish prey resources with eelgrass, the shading out of eelgrass by numerous overwater structures poses a potential risk of reduced prey resources for fish, affecting fish populations.

8.1.4.2 Freshwater aquatic plants

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

8.1.5 Riparian Vegetation

Site-specific habitat functions are determined by whether an existing shoreline is in a relatively natural state or whether it is affected by urban development. Cumulative effects from additional HPA-permitted structures influence habitat functions. A natural environment that supports fish and shellfish spawning, rearing, and refugia is highly valuable from a biological perspective. Any alteration to that specific environment could influence the recruitment of fish and shellfish stocks in the larger ecosystem. As a result, the cumulative impact of structures along an ecologically intact shoreline could generate potentially significant cumulative effects.

In contrast, an urban, industrialized shoreline area may have, over a long period of time, lost its native vegetation and suffered major changes to its historical substrates. In that scenario, the addition of a new structure may pose a qualitatively different set of cumulative effects than the effects of the same new structure in a more natural environment.

Substantial loss and fragmentation of riparian habitat has occurred in the Puget Sound region over the last 100 years. Although empirical data are lacking to quantify the extent and quality of riparian habitat, existing data suggest that riparian areas within urbanized shoreline areas such as King County have been significantly altered (up to 100 percent) with upland development and increasing levels of urbanization (Brennan and Culverwell 2004). McClain et al. (1998) and Francis and Schnider (2006) described the process of urbanization in the Pacific Northwest as a trend that moves toward deforestation without replanting.

Although there have been numerous evaluations on the effects of large-scale removal of riparian habitat to aquatic habitats, few studies specifically address cumulative impacts from the localized removal of riparian and shoreline vegetation as part of the specific types of activities permitted by HPAs. It is expected that permitting multiple activities within a watershed can have cumulative impacts to riparian vegetation, including increased likelihood that the impacts will be measurable and thus more likely to have an adverse impact to aquatic species and habitat.

Such impacts may be more significant in smaller watersheds. The threshold at which a group of activities will have an adverse impact to aquatic species and habitat at the watershed scale cannot be quantified, because each watershed has unique characteristics, such as riparian/shoreline vegetation and the contribution such habitat makes to the quality of specific aquatic habitat.

Naiman et al. (2000) reports that although riparian communities are being managed for a wider-than-ever variety of ecological functions, riparian communities in heavily urbanized environments constrained by pavement are precluded from the full restoration of natural functions.

A major finding in a study of the cumulative effects of urbanization on 22 Puget Sound streams found that mature forested riparian corridors were effective in mitigating some of the cumulative effects of adjacent development. In riparian corridors found in highly urbanized areas, poor stream quality is common (May 1998).

8.1.6 Water Quality

8.1.6.1 Turbidity

The cumulative impacts of HPA-permitted projects on water quality appear to have more potential for significant impacts than the generally short-term impacts that may result from an individual project. When combined with the impacts of land uses, it is conceivable that species tolerances could be exceeded for temperature and dissolved oxygen, which would lead to mortality or displacement (avoidance).

Natural turbidity-causing events may vary greatly in magnitude and duration. Natural events are more likely to occur in an isolated fashion and affect different portions of the stream network at different times (Bash et al. 2001). This variation allows fish to use refuge areas that might otherwise be impacted by these events (Bash et al. 2001). Professional experience has shown that anthropogenic sediment disturbance is often different; such events are more likely to occur simultaneously in many scattered areas or in overlapping time frames across a watershed, causing secondary impacts and lingering effects with greater potential to affect larger portions of a stream network at any given time. In addition, anthropogenic disturbances may more frequently result in temporary barriers to fish movement, which could reduce the existence of or limit accessibility to refugia (Bash et al. 2001).

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

8.1.6.2 Altered Pollutant Loading

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

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

Studies have shown that marine areas with shoreline structures in areas with poor tidal exchange or freshwater areas with poor water circulation are characterized by higher concentrations of pathogens and PAHs than areas with elevated water circulation (Bordalo 2003), but there is no clear pattern indicating that shoreline modification structures consistently degrade water quality in every application.

8.1.7 Ecosystem Fragmentation

8.1.7.1 Habitat Loss

Disturbance of streambeds may result in loss of habitat. The significance of the loss depends on the size of the watershed, whether the loss is permanent or temporary, the amount of habitat cumulatively lost, and the significance of the habitat lost to the population (i.e., spawning, rearing, or migration habitat). The loss of streambed habitat could affect the prey base available for juvenile and adult resident fish species by reducing the abundance of benthic macroinvertebrates. Benthic macroinvertebrates, by definition, inhabit the stream bottom;

therefore, modification of the streambed will most likely have some effect on the benthic macroinvertebrate community (Waters 1995). Benthic macroinvertebrate populations generally recolonize disturbed areas quickly (within 45 days), but this recovery time may be extended when repeated disturbances occur (e.g., NMFS 2003).

Both permanent and temporary losses of benthic macroinvertebrates are likely to occur as a result of new construction or expansion of existing structures; changes in the representative species assemblages as a result of associated changes in hydraulics and habitat conditions within affected reaches are also likely. It is difficult to ascertain the cumulative impact of changes to benthic macroinvertebrate populations or species diversity and subsequent changes to fish populations or habitat occupancy that may result. Permanent loss of benthic macroinvertebrate numbers or a decrease in species diversity due to permanent loss of habitat will affect foraging opportunities for fish and could affect the population numbers within stream reaches; this may be measurable over time at the watershed scale depending on the size of the watershed and amount of habitat permanently lost.

8.1.7.2 Freshwater Habitat Accessibility

The cumulative impacts of reduced habitat accessibility can have significant impacts on the distributions of potentially covered species. The cumulative loss of access to floodplain and off-channel habitats can significantly reduce availability of required refuge, rearing, and spawning habitats. Such cumulative habitat accessibility losses would impact all freshwater species, but especially salmonids, lampreys, and Olympic mudminnow.

8.2 Cumulative Effects Sorted by Activity Type

8.2.1 Marinas, Terminals, Overwater Structures and Shoreline Modifications

As marina/terminal structures interact with other development in a given area, impacts accrue, producing a net loss in vegetation production and a concomitant reduction in epibenthic and benthic nearshore habitat. The type and extent of each of these alterations depends on specific site characteristics, structure types, design of the structures, and construction materials.

Marinas and large terminal structures produce cumulative effects by virtue of the fact that they contain multiple structures, operations and consequent impacts to shoreline processes functions. Marinas and terminals often include associated shoreline modifications such as breakwaters, jetties, or bank protection. Overwater structures (such as single family residential docks) may have direct and indirect localized effects on habitat, and multiple structures may produce cumulative effects similar to those from marinas and terminals. One study (Nightingale and Simenstad 2001b) specifically discusses the cumulative impacts of overwater structure construction.

8.2.1.1 Construction and Maintenance Activities

The WDNR Shorezone Inventory (2001) reports a total of 716 large marinas (i.e., over 100-foot slips) along Washington's marine shoreline. Several of the ferry terminals are currently slated for expansion or improvements, including: Anacortes, Bainbridge Island, Eagle Harbor, Edmonds, Mukilteo, Port Townsend, Keystone, and Seattle (Coleman Dock) (WSDOT 2007). It is also reasonable to assume that most of the other facilities in state waters will require at least some maintenance activities if not more substantial improvement activities in order to maintain operations.

8.2.1.2 Water Quality Modifications

Water quality impacts are dependent upon the level of use and design of the marina, terminal, or shoreline modification structure; the hydrography and geomorphology of the surroundings including the level of tidal exchange for structures located in marine areas; as well as proximity to other affected habitat.

Ferry terminals do not affect water circulation to the degree that marinas do, but both marinas and ferry terminals are associated with docks, shoreline protection structures, and elevated vessel activity. The cumulative impact of these facilities may be manifest through the increased occurrence and degree of usage of individual facilities. Increased dock usage levels can pose risks to water quality through the introduction of sloughing bottom paints, vessel engine exhausts, fuel spillage, overboard sewage discharge, paint and cleaning product contamination, and introduction of contaminants from automobile traffic and asphalted parking lots adjacent to a marina via stormwater (USEPA 2001).

8.2.1.3 Riparian Vegetation Modification

Marinas/terminals and associated shoreline modifications serve as transportation hubs and pathways for the movement of passengers and freight. As such, they require substantial impervious surface and encourage further shoreline development.

The Seattle-Tacoma area is an area of intense urbanization. The WDNR Shorezone Inventory (2001) reports that out of a total of 716 large marinas (i.e., over 100-foot slips) along Washington's marine shoreline, 41 percent are in this Seattle-Tacoma area. In contrast, out of the total of 3,000 miles of marine shoreline in Washington State, the Seattle-Tacoma shorelines represent less than 5 percent. In this particular area, marinas and ferry and terminal areas are typically denuded of riparian and shoreline vegetation.

8.2.2 Bank Protection, Stabilization and Shoreline Modifications

Literature reviews conducted by Canning and Shipman (1994), MacDonald et al. (1994), and Zelo et al. (2000) conclude that shoreline armoring does have cumulative effects and that while impacts of individual structures may not be substantial, the aggregate of several structures may be significant where littoral sediment supplies, transport, and beach substrate are altered. Reynolds (1983, in MacDonald et al. 1994) concludes that the cumulative effect of structural response to beach erosion is the escalation of engineered structures and the consequent loss of beach. Silvester (1977, in Gabriel and Terich 2005) found that the littoral energy applied to the sediment doubled in the presence of seawalls, which lead to increased scour downdrift. In this way, the cumulative effect of an incremental increase of seawalls would not necessarily be a linear addition of effects but could be interactive and synergistic.

The cumulative impacts of bank protection structures are particularly important because:

1. The structures are often constructed to counteract or curtail natural habitat-forming processes.

2. The shorelines of Washington State's water bodies are often lined with numerous small parcels that individually may produce only minor impacts, but cumulatively may be significant.
3. As noted by Nightingale and Simenstad (2001b), the bathymetry of Washington's inland marine waters is that of a fjord surrounded by a narrow vegetated habitat, which essentially concentrates the zone of impact.

8.2.2.1 Channel Processes and Morphology

The fact that bank protection projects typically work in direct opposition to natural channel processes results in the potential for significant cumulative impacts. As evidenced by the listing of several salmon populations as threatened or endangered under the ESA, significant habitat alterations, including bank protection, can cumulatively generate lasting impacts that have great implications for population viability.

8.2.2.2 Hydraulic and Geomorphic Modifications

Numerous studies throughout the world have documented the cumulative hydraulic and geomorphic impact of shoreline hardening and maritime activities on the coastal ecological communities (Byrnes and Hiland 1995; Guidetti 2004; Meadows et al. 2005; Penland et al. 2005; Wijnberg 2002). Because of the nature of these studies, they have not focused strictly on one activity type. The primary impacts addressed by these studies include the disruption of littoral processes as well as hardening of the shoreline and consequent coarsening of the substrate, although other maritime activities likely play a role as well (e.g., fishing) (Blaber et al. 2000; Guidetti et al. 2005). Although the notion of cumulative environmental impacts has been hypothesized to be important in the marine environment in Washington State (e.g., in Puget Sound [Gelfenbaum et al. 2006]), there have been no systematic, peer-reviewed studies that have investigated the phenomenon in Washington waters. Despite this lack of local data, the sum of work performed outside of Washington State documents a general pattern of ecological change due to the construction of shoreline protection structures. In particular, the switch from biological communities preferring soft substrates and relatively quiescent conditions to those preferring higher wave-energies and harder substrates is almost always identified (Guidetti 2004; Guidetti et al. 2005; Meadows et al. 2005). For the outer coast of Washington, the coast of California provides a relevant analog of patterns of ecological changes due to the construction of shoreline protection structures. Although development has been more recent, there has been some documentation of the general hardening of shorelines in California. For instance, Wasson et al. (2005) described the increased prevalence of coarse substrate-dependent (invasive) communities on shoreline works.

Although many of these locales are superficially different from Washington State, some of these studies are particularly germane to anthropogenic environmental degradation. In particular, the paraglacial landscape of the Great Lakes and the Adriatic Sea provide similar templates to the geomorphic variables responsible for nearshore change in the Puget Sound, the Strait of Juan de Fuca, and the large lakes of western Washington (Finlayson 2006). These areas have also been developed for a much longer time (in the case of the Great Lakes, hundreds of years; in northern Italy, millennia), such that the cumulative effect has been made much clearer. For instance, Bearzi et al. (2004) documented the historical loss of marine mammals in the Adriatic and attributed the loss to human activities (in general).

Although there are no known studies specific to the cumulative effects of modifications associated with the construction and operation of marinas, terminals or shoreline modifications such as jetties or groins, a few studies have documented the cumulative effects of bank hardening on the riverine ecology of large navigable channels.

- Riprap stabilization of one 15.5-mile (25-km) reach of the Sacramento River was cited as the primary cause of salmon decline in this river due to the loss of spawning gravels previously supplied from bank erosion (Buer et al. 1984; Shields 1991).
- In a comprehensive study of the historical decline of coho salmon smolt production in the lower Skagit River, Washington, Beechie et al. (1994) found that hydraulic modification from the combined effects of levee construction, bank hardening, and dredging accounted for 73 percent of summer habitat losses and 91 percent of winter habitat losses.
- The cumulative effects of bank hardening and historical removal of riparian forests throughout the lower Skagit River, Washington, have prevented wood recruitment from the natural processes of channel migration, thereby reducing the delivery of large wood to the estuary (Collins 2000). The loss of this wood can disrupt food webs for juvenile salmonids in estuarine marshes.
- Bank stabilization along 25 percent of the 99-mile (160-km) Garrison Reach of the Missouri River in North Dakota nearly eliminated the positive effect of riparian forest on the density of instream woody debris (Angradi et al. 2004).

8.2.3 Water Crossings

No studies that specifically address the cumulative impacts of water crossing structures were located. However, general discussions of cumulative impacts on channel hydraulics and substrates are pertinent.

8.2.3.1 Channel Hydraulics

Bates (2003) cites the importance of proper structure siting and land use practices for minimizing the cumulative impacts of culverts. Bates (2003) recommends as most effective those solutions that avoid the need for a water crossing structure, and states that impacts can be minimized by "consolidating water crossings; employing full-floodplain spanning bridges, by simulating a natural channel through culverts; or removing water crossings."

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

8.2.3.2 Substrate Modifications

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

8.2.4 Channel Modification

In general, as the number of channel modifications increases in a given area, impacts will accrue producing a net loss in riverine, lacustrine, and/or marine habitat. The type and extent of each of these alterations depends on specific site characteristics and the subactivity types.

8.2.4.1 Dredging

The cumulative effects of dredging have been documented by a number of studies (Byrnes et al. 2004; Cooper et al. 2007; Erftemeijer and Lewis 2006). These studies have documented that repeated dredging reduces the prevalence of seagrasses and macroinvertebrates; however, impacts on invertebrates conditioned for disturbance can respond quickly and recover significant populations of benthic invertebrates (Bolam and Rees 2003; Robinson et al. 2005). However, even in the most optimistic studies, the major cumulative impact of dredging is lower seabed productivity and diversity (Robinson et al. 2005).

Dredging from the lower Columbia River since at least 1904 has had cumulative effects on the sediment budget of the river and the littoral cell extending 160 km (100 miles) along the Pacific coast, from Point Grenville, Washington, to Tillamook Head, Oregon. The coast along this cell has experienced accelerated erosion, with recent coastal erosion in the Westport area alone costing $30 million in repairs (Kondolf et al. 2002).

8.2.4.2 Gravel Mining and Scalping

The greatest effects of instream gravel mining, bar scalping, and pit mining may be considered as cumulative because they may become obvious only over time and extend beyond the limits of the mining site itself (Kondolf 1997). Moreover, the effects of one mining activity may interact with nearby mining, yielding a net cumulative effect not apparent from a single mining action (Kondolf et al. 2002). Individually subtle effects of gravel mining can become more visible and serious through the propagation of channel incision upstream and downstream of such activities (often for distances of kilometers) on mainstem and tributaries and through the coalescing of incision effects.

Channel incision caused by the cumulative effects of gravel mining causes lowered alluvial groundwater tables, desiccation of riparian and floodplain vegetation, reduced channel-floodplain interactions, and the elimination of processes of channel migration and the consequent creation of habitat. Any extraction of gravel from the channel bed or floodplain interrupts sediment transport continuity and represents a net loss in the sediment transport budget, thereby inducing channel instability and reducing the volume of downstream bars (Dunne et al. 1981).

Because the direct and indirect effects of bar scalping are far-reaching, the cumulative effects of numerous bar-scalping operations can result in long-term habitat degradation. For example, Dunne et al. (1981) documented cases in which the current channel was abandoned and a former channel adopted following bar scalping. Bar scalping has also been shown to eliminate side channels, which are important habitats for juvenile salmonids (Pauley et al. 1989; Weigand 1991). Bar scalping on the Puyallup, Carbon, and White rivers from 1987 to 1988 reduced the mean side-channel riffle habitat area from 1350 to 930 cubic yards and mean side-channel glide and pool habitat area from 1550 to 0 yards at treatment sites, while the representative habitat areas increased or remained unchanged at control sites (Weigand 1991).

Small-scale extractions are often viewed as having only small, insignificant impacts. However, a small extraction on a small stream can take a large fraction of the annual sediment load, and multiple small extractions on a larger stream can add up to be equivalent to a large proportion of the total load. Even when the extractions are small, they can add up to have a significant cumulative effect on channel form, especially in small channels, where the sediment load would be naturally low (Kondolf et al. 2002).

8.2.4.3 Sediment Capping

Although numerous sediment capping projects are seldom performed in any one area, they are typically performed in marine and freshwater harbors that have been impacted by previous industrial activities. Sediment capping activities can therefore contribute to the cumulative effects of numerous, related types of industrial cleanup activities. These cumulative effects could include the loss of nearshore habitats, habitat fragmentation, and the displacement of endemic species as a result of large-scale modifications to substrate composition and bathymetry. Some of the cumulative effects of sediment capping can be observed from studies examining the cumulative effects of multiple beach nourishment projects. Beach nourishment involves the rapid deposition of large quantities of sand and because of this, the impacts associated with the work are similar to those impacts that are associated with sediment capping.

Peterson et al. (2006) documented the loss of benthic macroinvertebrates on a stretch of beach in North Carolina from a number of small beach nourishment projects. Several earlier studies have shown that invertebrates can be harmed by nourishment projects (Diaz et al. 2004; Peterson et al. 2006; Rakocinski et al. 1996), but Peterson et al. 2006 were the first to show that the cumulative damage could occur due to multiple ongoing projects, and overcome the rapid recolonization typical of invertebrates. This same process of reburial before invertebrate recolonization could occur if a sediment cap was successively maintained or if multiple caps were placed adjacent to one another.

8.2.4.4 Channel Creation and Alignment

Although numerous stream restoration and channel creation projects have been completed over the past decade, the cumulative effects of these projects has not been adequately assessed by the scientific community. In general, the cumulative effects of multiple channel creation and alignment projects that fall short of rehabilitating degraded conditions are likely to result in the loss of native habitat for many HCP species. For instance, the listing of several salmon populations as threatened or endangered under the Endangered Species Act has been linked to (among other things) the widespread loss of spawning and rearing habitat resulting from channel modifications throughout the region (Montgomery et al. 2003).

8.2.5 Fish Passage

Fish passage projects (with the exception of specific classes of weirs) are intended to improve the condition of fisheries resources by restoring fish passage to mitigate the effects of man-made perturbations on the environment. While the benefits of providing fish passage are clear and measurable, fish passage projects may produce unforeseen consequences.

The majority of the negative effects associated with fish passage activities occur as a result of two discrete impact mechanisms: construction and maintenance; and subsequent changes resulting in ecosystem fragmentation. Other impact mechanisms, such as hydraulic and geomorphic modifications and effects on aquatic and riparian vegetation, are expected to be minor in comparison. Construction-related effects are short term, while effects on ecosystem fragmentation are long term and more pervasive. Consequently, cumulative impacts associated with construction activities are unlikely to occur unless multiple projects are being constructed simultaneously and in proximity to each other. In contrast, the cumulative effects of altered fish passage and the upstream transport of allochthonous nutrients have significant potential for cumulative effects on ecosystem structure and function.

Restoration of access to historic habitats is widely recognized as a key element in strategies for the restoration of native aquatic fauna (Roni et al. 2002). However, it must also be recognized that fish passage projects may not equally restore full access to all migratory species that historically utilized the affected habitat. Projects intended to block upstream dispersal of non-native species may broadly affect the migration of nontarget species. The cumulative effects of these types of perturbations are twofold. First, altered passage conditions may impose selection pressures on HCP species, altering the genetic diversity of the affected population. Second, altering the range, abundance, and diversity of species able to access historic habitats is likely to alter the adaptive trajectory of the ecosystem in ways that are difficult to predict.

The cumulative effects of the fish passage projects are on balance expected to be beneficial to HCP species as a whole. However, some detrimental effects may occur as a result of the broad application of this activity type across the landscape due to the effects of stressors that are difficult to predict and/or assess.

8.2.6 Fish Screens

Fish screens are intended to minimize adverse effects from water withdrawals on aquatic species. Screening of diversion and intake structures has been broadly imposed as a matter of management policy across the landscape. This policy decision represents a defensibly precautionary approach to water resources management. While fish screens in many cases demonstrably reduce entrainment mortality, they may also impose unforeseen or unavoidable effects that must be considered.

The majority of the negative effects associated with fish screens occur as a result of construction and maintenance, and operations. Cumulative impacts by other impact mechanisms, such as hydraulic and geomorphic modifications, are expected to be minor in comparison. Construction-related effects are short term, while operational effects are long term but less intensive on an individual screen basis. Cumulative impacts associated with construction are unlikely to occur unless multiple projects are being constructed simultaneously and in proximity to each other.

Fish screens are a necessary impact minimization technology used to limit the effects of dams, diversions, and intake systems. When properly employed, they can reduce mortality caused by entrainment into intake and diversion systems. Such mortality can have significant implications for populations of many HCP species. From this standpoint, the positive impacts of fish screens outweigh the negatives. However, fish screens may impose some detrimental cumulative impacts when numerous screens are used across the landscape. The extent of these effects is difficult to predict and/or assess. Examples of potential cumulative impacts include:

- Delayed migration: Multiple off-channel screen systems arrayed along a stream corridor could conceivably significantly delay migration, presenting a number of adverse consequences. In the case of upstream migration, screens with accessible bypass channels and/or high-flow bypass discharges may cause confusion regarding the migratory corridor, slowing migration or attracting fish up blind channels. Upstream migrant juveniles may be repeatedly drawn into bypass systems and discharged downstream, slowing migration to desirable habitats. In the case of juvenile downstream migration, the bypass system must provide suitable sweeping flows to avoid fish delay at the bypass structure and loitering in the diversion.

- Delayed or modified dispersal: The dispersal of weak-swimming or planktonic fish and invertebrate larvae may be affected by the operation of fish screens. Organisms drawn into screen systems may be effectively bypassed and removed, but could be discharged to environments that are unfavorable for rearing, or dispersal to favorable habitats may be delayed by exposure to multiple screens.

- Nonlethal impingement, bypass entrainment: Juvenile fish may experience nonlethal impingement on in-channel and off-channel screen surfaces, followed by escape, or stress from entrainment through high velocity bypass systems and discharge to the stream channel. While the effects of temporary impingement or bypass entrainment from a single screen may be small, the combined effects of incremental migration delays, stress, and injuries from encountering many fish screens may be cumulatively significant.

- Effects of multiple screens on channel geometry and habitat complexity: In small streams, or in instances where bypass systems represent a significant component of stream length, off-channel screens incorporating bypass channels have the potential to exacerbate vegetation encroachment induced by changes in base flow conditions. This can in turn result in changes in channel geometry, flow velocity, substrate conditions, and resulting effects on habitat complexity in the affected bypass reach. Multiple off-channel screens distributed throughout a stream system present some potential for cumulative effects on channel form. These changes could have implications for the survival, growth, and fitness of HCP species.

Fish that are migratory or that are dependent on dispersal throughout the affected habitat types are most likely to experience cumulative impacts from fish screens. Anadromous and migrant resident salmonids are a prime example. The potential for entrainment-related losses of salmonids was a primary concern driving the widespread use of fish screens on agricultural diversions in the Columbia River basin and elsewhere. Most fish screens in Washington State are focused on avoiding adverse effects on salmon. Because of their migratory nature, however, salmon have the potential to be exposed to many fish screens throughout their life history. As such, they are likely to be exposed to impingement, migration delay, entrainment through bypass systems, and other related stressors several times. Individually, these stressors may not impose noticeable effects on survival, growth, and fitness, but the cumulative effects of multiple exposures could be significant.

Other HCP species potentially affected by the cumulative effects of fish screens include white sturgeon, mountain suckers, lamprey, and dace. Lamprey, suckers, and sturgeon are migratory species and are therefore potentially exposed to multiple fish screens during their life history. For lamprey, many screens designed to protect salmonids may not be adequately protective of weak-swimming amocoetes. Sturgeon larvae may depend on dispersal to nearshore and inundated riparian habitats for successful recruitment, exposing them to screen-related stressors. Fish screens may not provide adequate protection for these life-history stages. Dace, while not explicitly migratory, may depend on dispersal between suitable habitats to maintain population diversity. The cumulative effects of multiple fish screens could potentially limit the effectiveness of these dispersal mechanisms, affecting gene flow between populations and colonization of suitable habitats. Freshwater mussel species may be subject to cumulative indirect effects from cumulative effects on host fish distribution and abundance. Fish screens may block dispersal of some freshwater invertebrates.

In marine systems, fish screens may similarly help to limit entrainment-related losses. However, it is difficult to avoid entrainment of species with planktonic eggs and larvae, such as hake, cod, and Olympia oyster, when these life-history stages are present. These entrainment-related effects are more the result of intake operation than the effects of the screens, and better represent the cumulative effects of the flow control structure. However, these effects also reflect fish screen design limitations. Knowledge of planktonic egg and larval sensitivity to entrainment, and technologies suitable for limiting adverse effects, may not be available for all potentially affected HCP species. Currently available screening technologies are sensitive to biofouling and require consistent maintenance to remain effective.

This assessment of effects considers the effects of fish screens relative to a natural system baseline. The cumulative effects of fish screens are, on balance, likely to be of lesser magnitude than the impacts of multiple unscreened intakes and diversions. In a similar fashion, the cumulative effects of fish screens are likely to be small relative to the combined effects of multiple water withdrawals on habitat capacity and productivity.

8.2.7 Flow Control Structures

Flow control structures have cumulative effect ramifications. In general, as the number of flow control structures increases in a given area, impacts accrue that increase habitat loss, alter the flow regime, and shift the composition and diversity of species.

8.2.7.1 Dams

Cumulative effects from dams are well known. The presence of a dam alters stream temperatures, dissolved oxygen concentrations, nutrient loading, natural sediment transport, channel geometry, flow regime, habitat connectivity, and changes in species composition that result in cumulative impacts on HCP species. If only one of these impacts were realized, the impacts may be minor; however, taken in concert, these impacts can overwhelm some species and negatively affect their survival, growth, or fitness.

A series of dams on a given river or river system will compound difficulties for migrating species. For example, in a study on the Columbia River, only 3 percent of tagged Pacific lamprey reached the most upstream site of a series of 3 dams (Moser et al. 2002). However, 40–50 percent of them passed over the lower dams, indicating that as the number of structures increase, successful migration to the upper reaches of a watershed will decrease. In addition, declines in Columbia River salmon and steelhead were the result of cumulative impacts from nine hydropower dams on the mainstem, each contributing 2–20 percent of the overall loss (Williams and Thom 2001). From a geomorphic standpoint, a series of dams will compound sediment losses to downstream coastal systems, exacerbating beach loss and erosion. In terms of eutrophication, nutrient loading from several dams may lead to the development of low-oxygen zones in coastal areas.

In many cases, these cumulative impacts extend well beyond the location of the dam. For example, in the highly impounded Columbia River watershed, effects from dams high in the watershed will translate to the marine environment. On the Olympic Peninsula, the Elwha River dams are causing significant beach losses from sediment accumulation in reservoirs behind two large dams (DOI 1995).

8.2.7.2 Weirs

The cumulative effects from weirs on HCP species are similar to those described above for dams. However, these impacts are lessened due to the scale of weir projects and the fact that these are overflow structures with fewer impacts on the downstream water quality.

8.2.7.3 Dikes and Levees

Dikes and levees alter channel geometry, flow regime, and habitat connectivity, contributing to cumulative effects on HCP species. As with most flow control structures, the more levees constructed in a given area, the more fragmentation of the habitat will result. In addition, the presence of several dikes and levees in a watershed will compound the effects of flow changes downstream. For example, a given increase in flood flow from one channelized reach flowing into another such reach will increase the peak flood flows because there will be an increased amount of disconnected floodplain area. Normally, the floodplain would be able to absorb these flood flows and to minimize the downstream effects of peak flows.

8.2.7.4 Outfalls

Limited information is available regarding the cumulative impacts of hydraulic and geomorphic modifications associated with outfall structures. However, a string of poorly designed outfalls could easily starve a shoreline of sediment, just as groins have done in other parts of the world (Byrnes and Hiland 1995). If riparian vegetation is removed during the construction of an outfall, changes in temperature and solar input will be magnified as more such outfalls are placed within a watershed. Similarly, water quality degradation from a single outfall might be minimal;

however, the more outfalls that are located in a single stream reach, the more likely it is that impacts will occur on HCP species from metals toxicity, low oxygen, and exposure to organic pollutants.

8.2.7.5 Intakes and Diversions

As with outfalls, limited information is available regarding the cumulative impacts of hydraulic and geomorphic modifications associated with intakes and diversion infrastructure. Intakes have specific modifications that could have significant cumulative impacts. In particular, their design does not adequately account for the entrainment of spawn and drifting larvae along river system. This type of cumulative impact has been described in terms of large-scale hydropower planning in Europe (Larinier 1998). If riparian vegetation is removed during construction of an intake, changes in temperature and solar input will be magnified as more outfalls are placed within a watershed. In addition, as more diversions are located within a watershed, the more of an impact will occur on the downstream flow regime. An extreme situation could result in a completely dry channel from multiple diversions, which would make the river reach unusable for HCP species.

8.2.7.6 Tide Gates

Tide gates are often constructed in areas converted for agriculture. As a result, irrigation that routes diversions and runoff from fields through outfalls is likely. The cumulative effects from tide gates are similar to those for a dam. Because tide gates block migration and tidal flows, the more tide gates are present in a given area, the more impacts on HCP species would occur. These cumulative impacts translate to water quality modifications as well. Changes in salinity are a fundamental impact from the presence of a tide gate. The more tide gates there are in a system, the greater this impact will become. Changes in salinity are important to migration patterns and to provide suitable habitat for species that use these areas. In addition, metals toxicity from altered flow, oxidation of marsh soils, and changes in pH will be compounded if several tide gates are located within a given area.

Cumulative effects from saltwater intrusion into the riparian zone may also develop. In Australia, it was observed that saltwater seepage into the surrounding groundwater occurred. Depending on soil properties, this seepage was less than 33 ft to more than 262 ft (10 m to more than 80 m) from the impounded area (Johnston et al. 2005b). This saltwater intrusion could have a devastating effect on riparian vegetation, leading to increased bank failures, increased temperatures, and reduced nutrient cycling.

8.2.8 Habitat Modifications

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

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

8.2.8.1 Beaver Dam Removal/Modifications

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

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

8.2.8.2 Large Woody Debris Placement/Movement/Removal

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

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

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

8.2.8.3 Spawning Substrate Augmentation

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

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

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

8.2.8.5 Riparian Planting/Restoration/Enhancement

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

8.2.8.6 Wetland Creation/Restoration/Enhancement

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

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

8.2.8.7 Beach Nourishment/Contouring

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

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

8.2.8.8 Reef Creation

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

8.2.8.9 Eelgrass and Other Aquatic Vegetation Enhancement

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