7.5 Riparian Vegetation and Large Woody Debris Modifications

Riparian zones form the transition between terrestrial and aquatic systems. Riparian/shoreline vegetation is an important component of freshwater, estuarine, and marine systems. It provides shade, streambank and shoreline stability, and allochthonous inputs. Riparian vegetation also influences groundwater conveyance and storage, and the condition and complexity of aquatic habitats (Knutson and Naef 1997; Murphy and Meehan 1991). Removal or disturbance of riparian/shoreline vegetation during construction or other activities permitted under HPAs can have several potential impacts to habitat and species in each of these systems, including:

1. Altered shading and altered air and water temperature regime *(caused by alteration of vegetation canopy cover and insulating effect of boundary layer condition created by riparian forest).*
2. Altered streambank/shoreline stability *(caused by degradation of riparian vegetation, loss of vegetative cover as well as root cohesion, and reduced resistance to erosive forces.)*
3. Altered allochthonous input *(caused by reduced inputs of leaf litter, woody debris, and terrestrial insects and other biota associated with riparian vegetation.)*
4. Altered groundwater/surface water interactions *(due to the influence of altered riparian vegetation on hyporheic zone function.)*
5. Altered water quality *(due to alterations to temperature and dissolved oxygen, and effects from altered sedimentation associated with altered stability.)*
6. Altered habitat conditions *(due to loss of large woody debris (LWD), recruitment sources and reduced bank stability leading to simplification of complex bank habitat.)*

These potential impact mechanisms and related ecological stressors are discussed below for marine and estuarine, riverine, and lacustrine environments. In general, the specific effects of different kinds of HPA-permitted projects on riparian vegetation are not discussed in detail. Research on the effects of alterations to riparian vegetation has concentrated on the impact mechanism rather than the activity that sets the impact mechanism in motion.

There are some general principles reflecting the expected impacts associated with HPA-permitted projects that alter riparian vegetation. The size and configuration of a project influences how much riparian vegetation is removed or disturberd. Projects onshore and parallel to the shoreline have the greatest chance of significantly impacting riparian vegetation. For example, installing some kinds of bank armoring may require removing riparian vegetation along the entire length of the project. Other bank armoring designs may require planting riparian vegetation. On the other hand, water crossing structures such as culverts or conduits may be installed or replaced with minimal disturbance to riparian vegetation. The magnitude of effect of other projects, such as overwater structures, marinas, terminals, bridges, and shoreline modifications, is likely to fall somewhere between the effects of installing hard bank armoring and conduit installation.

7.5.1 Altered Shading, Solar Input, and Ambient Air Temperature

7.5.1.1 General Effects: All Environments

Riparian vegetation provides shade, resulting in cooler water than areas without riparian vegetation. Cool water holds more dissolved oxygen than warm water. Many potentially covered fish and aquatic invertebrate species require cool and well-oxygenated water. Because fish are ectothermic (cold-blooded), their survival is dependent upon external water temperatures, and they will experience adverse health effects when exposed to temperatures outside their optimal range (USEPA 2003). Invertebrates, which are also cold-blooded, have a similar temperature dependence.

Direct effects of removing riparian vegetation include temperatures outside the optimal growth range for fish and invertebrate species. Increases in temperature can also result in mortality. An altered temperature regime may also directly affect fish by presenting seasonal thermal barriers inhibiting migration and access to habitat and prey.

Indirect effects of temperature change can include the alteration of food webs. Invertebrate species with parasitic life-history stages may be indirectly affected by effects to host fish species. Increased water temperatures may indirectly impact potentially covered species is by allowing expanded distributions and/or increased activity of warm-water piscivorous fish that may be potential predators to potentially covered species.

Knutson and Naef (1997) identified the following mechanisms for deleterious effects on fish and other aquatic organisms from changes in water temperature and dissolved oxygen associated with the removal of riparian vegetation:

- Inhibiting growth and altering metabolism
- Amplifying effects of toxic substances
- Increasing susceptibility to disease and pathogens
- Increasing potential risk of eutrophication through increased growth of bacteria and algae.

7.5.1.2 Ecosystem-Specific Effects: Marine and Estuarine

The influence of shade on nearshore water quality parameters such as temperature is not well established in marine environments. In general, seasonal air temperature conditions, winds, currents, stratification, and tidal exchange play more dominant roles in determining marine water temperatures (Brennan and Culverwell 2004). In marine and estuarine waters, shoreline vegetation is not likely to have much influence on marine water temperatures (Lemieux et al. 2004). In general, given the limited capacity for shade to influence water temperatures in the nearshore marine environment, the direct and indirect effects of this impact mechanism on most fish species are likely to be negligible. An identified data gap in the nearshore environment is the effect of the loss of shade for predation avoidance and other factors influencing fish survival.

However, shade may strongly influence temperatures in specific habitat types under specific circumstances, such as the upper intertidal zone, tidal pools, pocket estuaries, and other habitat types that become temporarily isolated or exposed by tidal dynamics. These systems can experience increased variability in temperature and microclimate conditions in the absence of protective shading. Microclimatic conditions in the upper intertidal zone are demonstrably influenced by riparian vegetation.

Temperature plays an important role in determining the distribution, abundance, and species' survival in the upper intertidal zone. Loss of riparian shade is correlated with increased substrate temperatures and reduced humidity, which in turn are indicative of increased desiccation stress (Rice 2006). Rice (2006) compared microclimate parameters at a bulkheaded Puget Sound beach with no overhanging riparian vegetation to those at an adjacent unmodified site with extensive riparian vegetation. He documented significant differences in light intensity, air temperature, substrate temperature, and humidity levels at the modified site. Differences in peak substrate temperatures were particularly striking, averaging nearly 20°F (11°C) higher at the modified site: 81°F (27.3°C) versus 61.7°F (16.5°C), respectively. This is a significant finding because temperatures and desiccation are major limiting factors for upper intertidal organisms including HCP forage fish species, specifically sand lance and surf smelt (Brennan 2004; Brennan and Culverwell 2004).

Although the influence and importance of shade derived from shoreline vegetation in the Puget Sound nearshore ecosystem is not well understood, it is recognized as a limiting factor to be considered and has prompted investigations to determine direct linkages between riparian vegetation and marine organisms. One such link is the relationship between shade and surf smelt. Surf smelt spawn at the highest tide lines at high slack tide near the water's edge on coarse sand or pea gravel. They incubate for approximately two to four weeks before hatching. Embryo development is temperature dependent, with marine riparian vegetation serving to maintain lower temperatures for fish that spawn in the summer during high-temperature periods (Penttila 2000). On the basis of a comparison of adjacent shaded and unshaded spawning sites sampled in northern Puget Sound, Penttila (2001) and Lemieux et al. (2004) found significantly higher egg mortality on unshaded beaches compared to those sites with intact overhanging riparian vegetation.

Sand lance, another potentially covered species that spawns in the upper intertidal zone, would presumably encounter similar impacts on egg survival when riparian vegetation is removed. The hypothesized mechanism causing the observed higher rate of mortality was increased egg desiccation due to longer periods of direct sun exposure at sites with insufficient riparian vegetation to provide shade and other favorable microclimate conditions. The findings of Rice (2006) comparing differences in microclimate conditions and surf smelt spawn survival on shaded versus unshaded beaches strongly support this hypothesis.

Anthropogenic changes in shoreline microclimate will change the intertidal incubating environment, potentially altering developmental rates or increasing physiological stress in fish embryos (Rice 2006). Considering the influences of temperature, moisture, and exposure on the diversity, distribution, and abundance of organisms that use upper intertidal zones, additional benefits of natural shading likely will be discovered as further investigations continue (Brennan and Culverwell 2004).

Invertebrates present in habitats that are temporarily isolated or exposed by tidal dynamics could potentially be directly affected by loss of shade and microclimatic effects resulting from riparian vegetation modification. In general, however, because shading from riparian vegetation does not likely affect water temperatures in the marine environment, impacts on aquatic invertebrates associated with this mechanism are anticipated to be negligible. For example, Olympia oysters are potentially directly affected by microclimate effects stemming from loss of shade due to riparian modification. However, this species tends to occur in the lower intertidal zone, below mean lower low water (MLLW) (Dethier 2006). As such, oyster colonies are not as influenced by riparian shade and are inundated for longer periods of time, meaning that the influence of riparian zone conditions on temperature and desiccation is far more limited.

7.5.1.3 Ecosystem-Specific Effects: Riverine

In riverine environments, removal of riparian vegetation as part of HPA-permitted projects affects water temperature through a number of mechanisms. The dominant mechanism is the effect of shading on solar radiation exposure.

Exposure to the sun's energy (due to a lack of riparian vegetation) causes an increase in water temperatures in summer when solar radiation exposure and ambient air temperatures are highest. The influence of shade on water temperature generally diminishes as the size of the stream increases because of the proportionally reduced area in which riparian vegetation can insulate against solar radiation and trap air next to the water surface (Knutson and Naef 1997; Quinn 2005; Poole and Berman 2001; Murphy and Meehan 1991, Bolton and Shellberg 2001. Increased stream temperatures can also cause a concomitant decrease in dissolved oxygen levels, an additional stressor with additive deleterious effects.

Riparian vegetation removal and alteration can cause surface waters to gain or lose heat more rapidly both by affecting local air temperatures and by increasing incident radiation and heat loss. (Quinn 2005; Bolton and Shellberg 2001; Poole and Berman 2001; Knutson and Naef 1997; Murphy and Meehan 1991). In winter, loss or degradation of the insulating capacity of riparian vegetation can decrease water temperatures and increase the incidence of ice scour.

In addition to the effects of shading, a broad array of research indicates that alterations of riparian vegetation can strongly affect temperatures even when adequate stream shading is still provided. Riparian vegetation restricts air movement, providing an insulating effect that regulates ambient air temperatures. Alterations of the riparian buffer width and vegetation composition can degrade this insulating effect, leading to greater variability in ambient air temperatures that in turn influence water temperatures (AFS and SER 2000; Bartholow 2002; Barton et al. 1985; Beschta 1991, 1997; Beschta et al. 1988;

Beschta and Taylor 1988; Brosofske et al. 1997; Brown 1970; Chen et al. 1992, 1993, 1995; Chen et al. 1999; Johnson and Jones 2000; Macdonald et al. 2003; May 2003; Murphy and Meehan 1991; Spence et al. 1996; Sridhar et al. 2004; Sullivan et al. 1990; Theurer et al. 1984; USFS et al. 1993). For example, Chen et al. (1995) found that maximum air temperatures at the margins of old-growth forest stands are elevated 3–29°F (2–16°C) relative to interior temperatures. Riparian buffer widths of 100–300 ft may be necessary to provide full ambient temperature regulation (AFS and SER 2000; Brosofske et al. 1997).

Numerous studies have documented the deleterious effects on fish species of changes in the temperature regime in freshwater stream systems (Poole et al. 2001; Sullivan et al. 2000). Water temperatures significantly affect the distribution, health, and survival of fish, especially salmonids. Alteration of the temperature regime in riverine systems due to the alternation of riparian vegetation is a well-documented stressor on native fish populations. Because fish are ectothermic (cold-blooded), their survival is dependent upon external water temperatures, and they will experience adverse health effects when exposed to temperatures outside their optimal range (USEPA 2003).

As stream temperatures rise, dissolved oxygen content decreases. Salmon, trout and other cold water fish, and many aquatic invertebrates require cool and well-oxygenated water, with a preferred temperature range of 40 to 58° Fahrenheit (F) (5.5 to 14.4° Celsius [C]), and dissolved oxygen levels of greater than 5 parts per million *(***need citation).* Selong et al. (2001) found that for age-0 bull trout, the upper lethal temperature is 70°F (20.9°C), and optimal growth occurred at 56°F (13.2°C); feeding declined significantly above 61°F (16°C). Also, a laboratory study showed that Dolly Varden displayed decreased appetite above 61°F (16°C), and temperatures were lethal above 68°F (20°C) (Takami et al. 1997).

It is useful to note that the effects of altered stream temperatures are not uniformly negative in all cases. For example, in light-limited streams, selective thinning of forests can have a positive effect on fish. In northern California, cutthroat and rainbow trout responded positively to increased light from riparian thinning through increased primary productivity that stimulated the food web (Wilzbach et al. 2005).

Several potentially covered invertebrate species would be impacted by the water conditions that could accompany freshwater riparian vegetation removal. In fresh water, the California floater and Western ridged mussels and the giant Columbia River limpet are all intolerant of low oxygen and high temperature conditions (WDNR 2006b) that can occur along shorelines lacking vegetation, although species profiles identified for this paper did not provide thresholds or ranges.

7.5.1.4 Ecosystem-Specific Effects: Lacustrine

Still-water systems, such as lakes or ponds, are subject to the same effects as those found in riverine and marine systems. As with both marine and riverine ecosystems, modifications to riparian vegetation in lacustrine systems can alter shading, solar input, and air temperature; alter allochthonous inputs; alter groundwater – surface water exchange, and alter habitat complexity. The dominant effect of vegetation removal is the loss of shading and increase in solar radiation exposure. These effects are generally less pronounced than those found in riverine systems, however, because lacustrine systems have a greater amount of unshaded surface area, large water volumes, and are often seasonally stratified, which can restrict water circulation. Little research has been conducted on the effect of riparian vegetation on lake temperatures. Lake surface area is usually dominated by shade-free open water zones, and thus the shaded margin does not have a large impact on overall lake temperatures (Lauck et al. 2005). As a result, riparian rehabilitation activities are not expected to alter lake temperatures. In lakes, water temperatures generally change gradually through the year with the seasons and show less change from night to day. However, loss of shading of nearshore littoral habitats can result in changes to water temperature of a sufficient magnitude to create thermal barriers for various fish species (Rice 2006; Carrasquero 2001), perhaps leading to changes in species composition.

7.5.2 Altered Streambank/Shoreline Stability

7.5.2.1 General Effects: All Environments

The root structure of riparian/shoreline vegetation resists the shear stresses created by moving water and thus retards bank cutting by streams, stabilizes streambanks and shorelines, maintains undercut banks along stream margins, and inhibits sediment from entering streams or marine shorelines by dissipating the erosive energy of flood waters, wind, and rain (Knutson and Naef 1997, Levings and Jamieson 2001; Brennan and Culverwell 2004, Waters 1995). Much of the scientific literature discusses the potential impacts of increased sediment as it relates to salmonids (Quinn 2005; Waters 1995; Furniss et al. 1991).

The bank instability that can result from the removal of riparian vegetation associated with bank protection structures can impact covered invertebrates as well as covered fish by elevating suspended solids concentrations and increasing the volume of fine sediments deposited.

The indirect effects on fish and invertebrates as a result of reduced shoreline stability relate to the increased probability of slope failures. Although slope failures occur naturally and are an important process that maintains proper substrate of adjacent beaches (Finlayson 2006), the immediate and unnatural impacts of riparian vegetation removal can adversely affect HCP species. These effects result from the increased turbidity of adjacent waters (Herrera 2006) and the potential burial of invertebrates.

7.5.2.2 Ecosystem-Specific Effects: Marine and Estuarine

Marine riparian vegetation clearly plays a role in stabilizing marine shorelines, particularly bluffs and steep slopes (Brennan and Culverwell 2004; Lemieux et al. 2004; Desbonnet et al. 1995; Myers 1993), but the specific mechanisms are not as well understood as they are in freshwater environments. The extent to which vegetation affects beach and slope stability varies depending on shoreline characteristics and the types of vegetation present (Lemieux et al. 2004; Myers 1993).

For marine shorelines, and particularly those in areas with steep and eroding bluffs, native vegetation is usually the best tool for keeping the bluff intact and/or minimizing erosion (Brennan and Culverwell 2004). On steeper slopes, marine riparian vegetation helps to bind the soils. Disturbing the face or toe of a bluff or bank may cause destabilization, slides and cave-ins (Clark et al. 1980, in Brennan and Culverwell 2004). Removal of the vegetation that helps to stabilize the face, or excavation along the face, increases the chance of slumping, which results in imperiled structures, lost land, a disruption to the ecological edge-zone, and increased sedimentation to the aquatic environment (Brennan and Culverwell 2004). On shorelines with shallower slopes, marine riparian vegetation dissipates wave energy, reducing erosion and promoting the accumulation of sediments.

Sedimentation and siltation impacts resulting from destabilized shorelines and bluffs can alter the ability of marine shorelines to support eelgrass beds (Finlayson 2006) and other marine littoral vegetation (Clark et al. 1980). This reduces habitat complexity, alters potential allochthonous inputs, and reduces the potential prey base available to the HCP species by inhibiting colonization by organisms upon which fish and invertebrates depend and altering the epibenthic assemblages upon which numerous fish species are dependent.

7.5.2.3 Ecosystem-Specific Effects: Riverine

In riverine environments, bank cohesion plays an important role in regulating channel width and substrate. The removal of riparian trees and understory can dramatically alter stream bank stability and the filtering of sediments from overland flow (Kondolf and Curry 1986; Shields 1991; Shields and Gray 1992; Simon 1994; Simon and Hupp 1992; Waters 1995), increasing erosion via wind, rain and current, and increasing inputs of fine sediment (Bolton and Shellberg 2001, Waters 1995).

By dissipating erosive energy, the root structure of riparian/shoreline vegetation resists the shear stresses created by flowing water and thus retards bank cutting by streams, stabilizes streambanks and shorelines, maintains undercut banks along stream margins, and inhibits sediment from entering streams (Knutson and Naef 1997, Levings and Jamieson 2001, Brennan and Culverwell 2004).

Increased delivery of coarse and fine-grained sediment to a river can affect water quality and habitat conditions. Slumping of unstable banks can bury eggs and larval fish, as well as HCP invertebrates. Although some specifics are known for marine invertebrate species (Hinchey et al. 2006), it is unknown what tolerance limits the HCP freshwater mollusks may have with respect to burial.

In addition to burial, increased sedimentation from destabilized banks can reduce or alter invertebrate habitat so that growth and fitness are reduced (or that the distribution of invertebrate species changes), and indirectly can trigger effects associated with food web alterations.

Much of the scientific literature discusses the potential impacts of increased sediment as it relates to salmonids. Increased sedimentation to streams or lakes can significantly affect the spawning success of salmonids (Quinn 2005; Waters 1995; Furniss et al. 1991). Increased sedimentation may also affect other HCP fish species, directly through gill damage or indirectly through impacts on their habitat.

7.5.2.4 Ecosystem-Specific Effects: Lacustrine

Riparian vegetation in lacustrine systems plays a similar role to that in marine, estuarine, and riverine systems, stabilizing shorelines against the erosive forces of wind-driven waves and boat wakes (Carrasquero 2001). The loss of riparian and emergent vegetation promotes shoreline erosion, creating an erosive cycle that further increases vegetation loss, with a resultant adverse effect on nutrient cycles. For example, loss of emergent vegetation can promote erosive cycles that preclude the recovery and reestablishment of such vegetation. Decreased emergent vegetation density results in altered sediment transport patterns. If sediments are not replenished, additional emergent vegetation loss can result, leading to additional shoreline erosion (Rolletschek and Kühl 1997).

7.5.3 Altered Allochthonous Input Including Large Woody Debris

7.5.3.1 General Effects: All Environments

In lakes, estuaries, and marine environments, riparian vegetation inputs contribute to habitat complexity and organic matter retention. Adjacent riparian vegetation is one source of woody debris. Woody debris provides essential cover for fish and invertebrate species, protection from currents, and foraging opportunities (Quinn 2005; Naiman et al. 2000; Knutson and Naef 1997; Murphy and Meehan 1991).

Removal of riparian vegetation for HPA-permitted projects diminishes externally derived (allochthonous) input into the aquatic environment, which can affect the prey base available to fish, the forage detritus available for benthic macroinvertebrates, future large woody debris (LWD) recruitment, and aquatic habitat complexity, diminishing the quality and complexity of habitat and species diversity of fish and benthic macroinvertebrates (Murphy and Meehan 1991).

7.5.3.2 Ecosystem-Specific Effects: Marine and Estuarine

The importance of allochthonous inputs of litter to marine ecosystems is apparent (Lemieux et al. 2004; Brennan and Culverwell 2004), although not as well documented as the linkages established for freshwater systems. Marine riparian vegetation is a known source of organic matter, nutrients, and macroinvertebrate prey items, and the recruitment of these materials is diminished when riparian vegetation is removed or modified (Lemieux et al. 2004; Spence et al. 1996; Maser and Sedell 1994; Williams et al. 2001; Brennan et al. 2004). The reduction of allochthonous inputs from riparian vegetation would inhibit nutrient inputs that contribute to the productivity of the intertidal food web and associated prey resources or forage base.

Allochthonous inputs of organic material and large wood from marine riparian systems have demonstrable effects on nearshore habitat conditions. In estuaries and marine environments, woody debris increases habitat complexity, affording cover for fish, protection from currents, and foraging opportunities (Quinn 2005).Woody debris also provides foraging, refuge, spawning and attachment substrate for aquatic invertebrates and algae in the marine/estuarine environment (Brennan and Culverwell 2004).

Driftwood and other LWD help build and maintain beach habitat structure in marine environments. LWD functions for beach stability include its contribution to roughness and sediment trapping as well as to inputs of organic matter, moisture, and nutrients that assist in the establishment and maintenance of dune and marsh plants.

There has been little research on the importance of wood in supporting beach structure and connectivity between estuarine environments. However, many shorelines in the Puget Sound area contain considerable wracked wood in the supratidal zone (Sobocinski 2003) which may serve to reduce shoreline erosion and protect the sediments which are the foundation for the shallow water environment. Riparian vegetation can help accumulate beach wrack by providing a complex surface to collect and retain loose marine debris.

Herrera (2005) described how multiple layers of LWD along a shoreline could provide effective energy dissipation, decreasing the amount of wave reflection during high water levels by increasing the roughness of the shoreline and by decreasing its slope relative to a vertical bulkhead. Because LWD is used in some marine soft-shore armoring applications to attenuate wave energy and lessen the potential for erosion, it is assumed that naturally occurring LWD on beaches would do the same, but this has not been empirically tested.

Marine shorelines modified by human activities tend to have less large woody debris and driftwood than unmodified beaches (Herrera 2005; Higgins et al. 2005). MacDonald et al.(1994) reported that shoreline armoring limited driftwood accumulation on a beach. Higgins et al. (2005) suggested that the mechanisms for the apparent reduction in LWD appeared to be the removal of adjacent riparian vegetation during and following placement of bank protection; reduced shoreline roughness at armored sites which causes more LWD to be transported away; and limited upper intertidal and backshore areas that allow for LWD deposition above tidal elevations that are routinely inundated.

LWD accumulations on beaches have been anecdotally correlated with increased distribution and suitability of spawning substrate for forage fishes (Herrera 2005), suggesting that the effects of LWD on sediment transport and distribution are meaningful from an ecological perspective.

Although little evidence has shown the direct impacts of the loss of large woody debris on HCP species on marine shorelines, differences in the survivability and diversity of lower trophic species near accumulations of woody debris on marine shorelines has been documented (Storry et al. 2006). Because one of the sources of LWD on marine shorelines is riparian vegetation, the loss of riparian vegetation would represent a loss of productivity on the upper foreshore and may partially explain the dramatic difference in supratidal productivity between modified and unmodified shorelines (Sobocinski 2003).

Recent studies indicate that for those salmonids known to be most dependent upon shallow marine nearshore habitats (i.e., Chinook and chum salmon, coastal cutthroat trout), insects derived from the terrestrial environment comprise major portions of their diets (Wipfli 1997; Levings and Jamieson 2001; Brennan et al. 2004; Brennan and Culverwell 2004; Toft and Cordell 2006). Stomach analyses of juvenile salmon have shown significant numbers of terrestrial insects, with higher numbers of insects found in those samples along marine shorelines with intact marine riparian vegetation (Sobocinski 2003). Vegetation modifications that reduce the abundance of terrestrial insects and/or reduce the likelihood of insect recruitment to the marine environment (e.g., removal of overhanging branches) are likely to result in localized reductions in the prey base available for these species.

7.5.3.3 Ecosystem-Specific Effects: Riverine

Riparian detritus and other allochthonous materials are the primary source of organic fodder in headwater streams, forming the basis for the food web (MacBroom 1998). Proximity of riparian vegetation provides terrestrial macroinvertebrates, which supplement the diets of fishes, and detritus such as leaves and branches, which provide food sources for benthic macroinvertebrates (Knutson and Naef 1997; Murphy and Meehan 1991; Bilby and Bisson 1998; Cummins 1980 (1975?)). As rivers increase in order and grow in size, these materials are processed and recycled by an increasing diversity of organisms (Vannote et al. 1980).

Removal of freshwater riparian vegetation as part of HPA-permitted projects would decrease the input of allochthonous materials to the nearby aquatic environment and food web, and diminish the ability of the system to support higher trophic organisms, including most of the freshwater HCP species. When the nutrients provided by riparian vegetation are altered, the net primary production of organic matter is affected, and the abundance and availability of prey resources for HCP species could be reduced (Bisson and Bilby 1998). Without allochthonous inputs, the forage detritus available for benthic macroinvertebrates is compromised, also diminishing habitat and species diversity of these prey items (Murphy and Meehan 1991). The grazing of organic material by macroinvertebrates such as caddisflies, stoneflies, and mayflies, is known to support the HCP salmon species (Hawkins et al. 1982; Murphy and Meehan 1991; Bilby and Bisson 1992), bull trout (Wydoski and Whitney 2003; Goetz et al. 2004), and sturgeon (Wydoski and Whitney 2003; Adams et al. 2002; Emmett et al. 1991). Although terrestrial and adult aquatic insects are important (Bjornn and Reiser 1991), juvenile salmon in streams have been found to be primarily supported by autochthonous organic matter (Bilby and Bisson 1992).

LWD promotes river-floodplain connectivity and thus the export of coarse particulate organic matter (CPOM) to the channel (Junk et al. 1989; Tockner et al. 1999). Floodplains have been shown to produce nutrient-rich organic matter (i.e., more live algae than decaying organic matter) which can serve as an import food resource for zooplankton (Muller-Solger et al. 2002; Schemel et al. 2004) and thus bolster aquatic food webs. Floodplains have been shown to act as nutrient sinks and carbon sources for adjacent channels (Tockner et al. 1999; Valett et al. 2005). The literature indicates that any activity which promotes the reconnection of once severed floodplain-channel pathways can be expected to have a net benefit for aquatic organisms (Crain et al. 2004; Schemel et al. 2004; Tockner et al. 1999). This is partially due to the fact that floodplains are vital for the transfer of energy (in the form of carbon) from terrestrial ecosystems to aquatic, especially in lowland river systems (Junk et al. 1989; Thoms 2003).

In streams, large woody debris (LWD) from riparian vegetation influences channel morphology and habitat complexity, retains organic matter, regulates the storage and transport of sediment, creates and maintains hydraulic complexity that contributes to fish habitat, and provides essential cover for fish (Knutson and Naef 1997; Murphy and Meehan 1991; Naiman et al. 2002; Quinn 2005). The removal of freshwater riparian vegetation limits the future input of woody debris as a habitat structure element and can limit habitat complexity, foraging opportunities, and predator avoidance (Schmetterling et al. 2001; Spence et al. 1996; Quinn 2005). Juvenile salmonid abundance in rivers in winter, particularly juvenile coho salmon abundance, is positively correlated to abundance of LWD (Hicks et al. 1991).

Riparian vegetation and LWD are important for bank-side habitat, providing shade, lower temperatures, and cover from predation. Radio-tagged cutthroat trout have been observed using pools associated with LWD for cover (Harvey et al. 1999). The use of submerged riparian vegetation during early development has been hypothesized to increase Columbia River white sturgeon recruitment (Coutant 2004).

Within channels, approximately 70 percent of structural diversity is derived from root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, or windthrow (Knutson and Naef 1997). In small streams, LWD is a major factor influencing pool formation in plane–bed and step–pool channels. Bilby (1984) and Sedell et al. (1985) found that approximately 80 percent of the pools in several small streams in southwest Washington and Idaho were associated with wood. In larger streams, the position of LWD strongly influences the size and location of pools (Naiman et al. 2002). In larger streams, LWD is typically oriented downstream due to powerful streamflow, which favors the formation of backwater pools along margins of the mainstem (Naiman et al. 2002). The hydraulic complexity created by LWD encourages the capture and sequestration of other allochthonous inputs, making these materials more available to the food chain through grazing and decomposition (Knutson and Naef 1997; Murphy and Meehan 1991; Naiman et al. 2002; Quinn 2005)

Woody debris increases the hydraulic roughness and impounds sediment behind logjams (Buffington and Montgomery 1999; Gippel et al. 1996; Harvey et al. 1987; Keller and Swanson 1979; Manga and Kirchner 2000; Montgomery et al. 1996; Shields and Gippel 1995). Local aggradation behind stable logjams can raise the bed-surface elevation of channels and increase the potential for floodplain inundation and lateral channel migration (Abbe and Montgomery 2003). Consequently, changes in wood loading and the age structure and composition of riparian forests can dramatically influence channel dynamics and the potential for lateral channel migration in unconfined river systems (Brummer et al. 2006).

Studies have shown that channels with LWD retain more bedload (Faustini and Jones 2003) and particulate organic matter (POM) (Cordova et al. 2007; Diez et al. 2000) than similar reaches without wood. Depending on channel form and wood size and orientation, LWD-induced pools and bars can occur upstream, downstream, and/or lateral to wood structures (Abbe and Montgomery 2003; Gurnell and Petts 2006; Kail 2003).

The presence of LWD within channels has been shown to promote floodplain connection during storm flow conditions by increasing flow resistance within the channel (Dudley et al. 1998). Increased channel roughness promotes backwater conditions which locally connect floodplain and channel habitat. LWD promotes floodplain connectivity by diverting flow into side channels (Abbe and Montgomery 1996; Brummer et al. 2006). Side channel and floodplain habitat that are connected to the mainstem create more accessible habitat for foraging and rearing, altering the composition and/or abundance of accessible food sources for HCP species.

The addition of wood to a channel will, depending upon the size, quantity, orientation, and channel dimensions, create a complex depositional environment. Studies by Stewart and Martin (2005) and Baillie and Davies (2002) have shown that LWD promotes in-channel sediment storage as the logs deflect flow and increase channel roughness. Large woody debris promotes heterogeneity in channel form by creating flow divergence and changing local base-level (Latterell et al. 2006). These processes lead to sediment deposition in both upstream pools and downstream eddies (Beechie and Sibley 1997). Both flow diversion and base-level increase will lead to increased floodplain connection and side channel activation/formation (lateral connectivity). Additionally, complex flow patterns will lead to increased flow through gravel bars, channel embankments, and riffles (vertical connectivity). LWD removal adversely affects ecosystem connectivity in the fluvial environment by reversing these effects. LWD removal has been shown to promote scour (Diez et al. 2000) leading to a drop in water surface elevation and lateral disconnection. LWD removal will also reduce flow resistance and simplify flow paths (Curran and Wohl 2003) which could lead to reduced hyporheic exchange.

LWD increases the abundance of and access to floodplain habitat (Young 1991). LWD-induced floodplain-channel connection is expected to augment allochthonous carbon budgets in restored channels. These improved conditions will in turn be beneficial to HCP species that occur in riverine environments affected by LWD, especially those which favor floodplain habitat (e.g. coho, sockeye, and Chinook salmon). Conversely, the removal of LWD may limit access to floodplain habitat is expected to decrease allochthonous carbon inputs and the storage and cycling of nutrient inputs to the stream channel, and impact those species which utilize these areas for foraging, rearing, and refuge.

Fish rely on habitat complexity for cover and refuge (Cederholm et al. 1997; Everett and Ruiz 1993; Harvey et al. 1999). Specifically:

- Bryant et al. (2007) have documented fish species such as Dolly Varden, coho, steelhead, and cutthroat trout utilizing complex habitats with LWD.

- In a study of Smith Creek in northwest California, Harvey et al. (1999) found that tagged adult coastal cutthroat trout moved more frequently from pools without LWD than from pools with LWD. They hypothesized that the habitat created by LWD attracts fish, and once fish establish territory within the desirable habitat, they remain there longer. Fausch et al. (1995) and others have criticized studies such as Harvey et al. (1999) because it is difficult to determine if increased abundance in treatment sites is due to increased populations or simply just concentrations of fishes that would have thrived equally well in other habitat.

- A study by Cederholm et al. (1997) on a tributary of the Chehalis River found that increasing habitat complexity by adding LWD caused an increase in winter populations of juvenile coho salmon and age-0 steelhead.

While no studies of LWD and HCP invertebrates were found, other studies have shown varying effects of LWD on invertebrates in rivers.

- LWD can serve as a substrate for algal growth (Bowen et al. 1998).

- In the Ohe River, Germany, Hoffman (2000) showed a intimate connection between all lifestages of the lepidostomatid caddisfly, *Lasiocephala basalis* and LWD.

- Hilderbrand et al. (1997) noted no change in macroinvertebrate populations following a wood addition experiment in Virginia.

- Spanhoff et al. (2006) noted a net negative impact of wood addition on stream macroinvertebrates.

- LWD can serve as macroinvertebrate habitat (Rolauffs et al. 2001; Warmke and Hering 2000)

7.5.3.4 Ecosystem-Specific Effects: Lacustrine

Lacustrine systems are dependent on allochthonous inputs from riparian systems, receiving this material directly through litter fall and windblown detritus from their own riparian areas, as well as allochthonous material transported into the system by rivers and streams. The importance of riparian vegetation to the lacustrine nearshore area has been documented by Scheuerell and Schindler (2004).

Several studies of lakes in Washington State have demonstrated a loss of both productivity and diversity in their food webs in the presence of human development (Scheuerell and Schindler 2004). Studies have identified large woody debris and emergent and riparian vegetation as crucial to the maintenance of lake productivity and food webs (Roth et al. 2007; Smokorowski et al. 2006). In areas of intense shoreline development where riparian vegetation has been thinned or removed, littoral coarse woody debris is greatly diminished or entirely absent (Francis and Schindler 2006).

The loss of productivity due to the lack or removal of LWD, in conjunction with other human activities (e.g., fishing), can initiate a collapse of piscivorous fish species in freshwater lakes (Roth et al. 2007). It can also reduce the amount of periphyton available for other lower trophic fishes and remove substrate suitable for HCP species (Smokorowski et al. 2006).

Coarse woody debris has been shown to be an essential habitat component for sockeye salmon in lakes and is important for the overall health of lacustrine shoreline ecosystems (Naiman et al. 2000). Sockeye salmon are the primary HCP species potentially affected by shoreline modifications along lakeshores. Lake shorelines represent crucial spawning habitat for sockeye (Burgner 1991; Scheuerell and Schindler 2004). Tabor et al. (2004, 2006) have documented the importance of small woody debris as habitat structure in Lake Washington, where it may provide important periodic refuge from predators for juvenile Chinook salmon.

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

7.5.4 Altered Groundwater/Surface Water Interactions

7.5.4.1 General Effects: All Environments

Alteration or removal of riparian vegetation would appreciably change the interface between plants, soil, and water on and near the bank surface. Riparian vegetation acts as a filter for groundwater, removing sediments and taking up nutrients (Knutson and Naef 1997).

Indirect impacts on HCP species from the reduction of groundwater–surface water interactions include increased nutrient loading, altered temperatures, and habitat changes. Any activity that affects riparian or nearshore areas will degrade the buffering capability of the terrestrial–aquatic ecotone. Numerous studies have shown that wide stream buffers are effective at attenuating nutrients (Feller 2005; Mayer et al. 2005), herbicides (Gay et al. 2006), and sediment loading (Jackson et al. 2001). Riparian vegetation retards overland flow, promotes infiltration, and assimilates shallow groundwater nutrients. When this vegetation is removed through any HPA-permitted activity, nutrients and pollutants will be more efficiently transported from upland sources to downgradient water bodies. Forested buffers can effectively remove nutrients in shallow groundwater. In a study of a forested buffer in Alabama, a 33-ft (10-m) buffer reduced the groundwater nitrate concentration by 61 percent (Schoonover and Williard 2003). In a subsequent study of a forested wetland buffer, a buffer averaging 125 ft (38 m) wide reduced the nitrate concentration by 78 percent and total phosphorus by 66 percent (Vellidis et al. 2003).

7.5.4.2 Ecosystem-Specific Effects: Marine and Estuarine

While less well studied, similar effects on groundwater – surface water exchange are likely to occur in marine systems as in riverine systems.

Bank armoring that requires the removal of riparian vegetation may lead to localized increases in substrate temperature due to the loss of cool groundwater flow (Penttila 2001). Riparian vegetation modifications can alter soil characteristics, infiltration rates, and groundwater transport that provides freshwater seepage to the intertidal zone. Alteration of these functions can directly reduce or eliminate rearing habitat for Olympia oysters and other marine organisms that use freshwater seeps along marine shorelines. These changes could also inhibit the suitability of marine shorelines for supporting eelgrass beds (Finlayson 2006). By affecting eelgrass habitat, these alterations could generate indirect food web effects for both invertebrates and fish.

7.5.4.3 Ecosystem-Specific Effects: Riverine

Riparian vegetation, in conjunction with upland vegetation, moderates stream flow by intercepting rainfall, contributing to water infiltration, and using water via evapotranspiration (Knutson and Naef 1997). Plant roots increase soil porosity, and vegetation helps to trap water flowing on the surface, thereby aiding in infiltration (Knutson and Naef 1997). Water stored in the soil is later released to streams through subsurface flows. Through these processes, riparian and upland vegetation help to moderate storm-related flows and reduce the magnitude of peak flows and the frequency of flooding (Knutson and Naef 1997). Riparian vegetation, the litter layer, and silty soils absorb and store water during wet periods and release it slowly over a period of months, maintaining stream flows during rainless periods (Knutson and Naef 1997).

The interface between flow within the hyporheic zone[1] and the stream channel is an important buffer for stream temperatures, so alteration of groundwater flow can affect stream temperature as well (Poole and Berman 2001). The magnitude of the influence depends on many factors, such as stream channel pattern, structure of the alluvial aquifer, and variability in the stream hydrograph (Poole and Berman 2001).

7.5.5 Altered Water Quality

7.5.5.1 General Effects: All Environments

Alterations to the water quality parameters of temperature and dissolved oxygen are discussed as a result of alterations to shading. See Altered Shading, Solar Input, and Ambient Air Temperature. Alterations to turbidity are discussed under Altered Streambank/Shoreline Stability.

Riparian zones are an ecotone between open water and terrestrial environments. Riparian vegetation retards overland flow, promotes infiltration, and assimilates shallow groundwater nutrients. When this vegetation is removed through any HPA-permitted activity, nutrients and pollutants will be more efficiently transported from upland sources to downgradient water bodies. Activities that affect riparian areas will also degrade the buffering capability of the terrestrial–aquatic ecotone. Once convoluted flow paths become simplified, the transfer of sediment, nutrient, and pollutants from terrestrial to aquatic systems increases. In theory, the restoration of riparian areas will decrease pollutant loading to the channel and benefit aquatic organisms.

Considerable research regarding riparian buffers and pollutant loading has been conducted and although the results have been mixed there has been a general trend observable in the data. Numerous studies have shown that wide stream buffers are effective at attenuating nutrients (Feller 2005; Mayer et al. 2005), herbicides (Gay et al. 2006), and sediment loading (Jackson et al. 2001).

Riparian buffer widths play an important role in determining the efficacy of a buffer at removing pollutants. Reviews of the literature have indicated that the most effective buffers are greater than 98 ft (30 m) in width (Hickey and Doran 2004) and this applies to all streams, including first order tributaries (Mayer et al. 2005). Riparian buffers which meet these criteria have been shown to remove as much as 95 percent of the influent total phosphorus (Hickey and Doran 2004). In lowland eutrophic systems this would serve as a net benefit to the aquatic ecosystem, especially in nutrient impacted lakes. In a study of a forested buffer in Alabama, a 33-ft (10-m) buffer reduced the groundwater nitrate concentration by 61 percent (Schoonover and Williard 2003). In a subsequent study of a forested wetland buffer, a buffer averaging 125 ft (38 m) in width reduced the nitrate concentration by 78 percent and total phosphorus by 66 percent (Vellidis et al. 2003).

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

7.5.5.2 Ecosystem-Specific Effects: Riverine

Reduced riparian buffer width can lead to decreased buffering capacity and an associated increase in pollutant and nutrient loading.

Dramatic increases in sediment and organic matter export occur immediately following removal or disturbance of LWD. These short-term direct impacts affect water quality parameters such as turbidity and dissolved oxygen levels, which in turn affect the viability of multiple lifestages of fish. These sedimentation impacts could also affect invertebrate distribution and fitness.

7.5.6 Altered Habitat Conditions

7.5.6.1 General Effects: All Environments

The removal of riparian/shoreline vegetation limits the future input of woody debris as a habitat structure element, and can limit habitat complexity, foraging opportunities, and predator avoidance in marine, estuarine, riverine, and lacustrine environments (Quinn 2005; Schmetterling et al. 2001; Spence et al. 1996).

Upland development has greatly reduced the amount of vegetation and nutrients available to the marine system. Such modifications have resulted in decreased abundance and taxa richness in both benthic and infaunal invertebrate and insect assemblages (Brennan and Culverwell 2004).

7.5.6.2 Ecosystem-Specific Effects: Marine and Estuarine

In marine environments, driftwood and/or large woody debris (LWD) from the riparian zone contributes to build and maintain beach habitat structure. Documented LWD functions for beach stability include its contribution to roughness and sediment trapping (Gonor et al. 1988; Brennan and Culverwell 2004) and to inputs of organic matter, moisture, and nutrients that assist in the establishment and maintenance of dune and marsh plants (Williams and Thom 2001). Eilers (1975) found that piles of downed trees in the Nehalem salt marsh (Oregon) trapped enough sediment to support vegetation, wherein marsh islands that trapped sedge seeds provided an elevated substrate for less salt-tolerant vegetation. Herrera (2005) suggested that driftwood at the top of the beach may also slow littoral drift and erosion by reducing wave energy and wave reflection energy and by creating pockets where larger sediment will accumulate. It has been suggested that estuarine wood can affect water flow and subsequent formation of bars and mudbanks (Gonor et al. 1988). The beneficial habitat structure functions of LWD along marine shorelines may be maximized if trees that fall perpendicular to beaches typically remain in place, as in the case of a study that found fallen trees tend to stay in place along Thurston County shorelines (Herrera 2005). The perpendicular alignment of LWD across the beach provides the LWD structure for the widest possible portion of the aquatic habitat, thus maximizing the potential area for sediment trapping and organic matter contributions.

The effects of modification of riparian vegetation on the structural habitat of fish have not been as well studied in marine systems as in freshwater environments. Sobocinski (2003) reports that food sources used by salmonids were directly related to the structural complexity provided by natural LWD-laden shorelines. Therefore, it is expected that the loss of such complexity will compromise salmonid food sources.

It is uncertain what role structural complexity plays in the life-history cycle of HCP invertebrate species, if any. In marine areas, Newcomb's littorine snail is found primarily in association with a narrow band of nearshore intertidal habitat that contains certain marsh plant species (Larsen et al. 1995); because detailed reproductive and habitat needs are not known, it might be conservatively assumed that Newcomb's littorine snail is subject to habitat loss or direct desiccation if riparian aquatic vegetation is impacted.

The removal or reduction of LWD in nearshore areas introduces the potential for direct impacts on fish and invertebrates via altered habitat suitability by reducing potential cover and stability of existing habitats. Indirect effects on habitat could include the reduced potential for development of future habitat.

7.5.6.3 Ecosystem-Specific Effects: Riverine

In riverine systems, riparian vegetation contributes to habitat complexity by maintaining bank stability, providing bank structure, and providing overhanging vegetation. Alterations of riparian vegetation are likely to affect habitat complexity in ways that are detrimental to HCP species. The quantity of woody debris in channels in the Pacific Coastal ecoregion has decreased over time as a result of various land use practices, including the removal of wood from rivers for navigation and fish passage, splash damming, and clearing of riparian trees (Bisson and Bilby 1998; Murphy and Meehan 1991; Jennings et al. 2003; Schindler et al. 2000; Abbe and Montgomery 2003; Montgomery et al. 2003; Collins et al. 2003).

A key mechanism by which riparian vegetation contributes significantly to habitat complexity in freshwater environments is by the input of woody debris (Naiman et al. 2002). LWD is a primary determinant of channel form in streams, creating pools and waterfalls and affecting channel width and depth (Bilby and Ward 1991; Bisson et al. 1987; Keller and Swanson 1979; Montgomery and Buffington 1993). ; Woody debris input in streams is important in controlling channel morphology, regulating the storage and transport of sediment and particulate organic matter, and creating and maintaining fish habitat (Abbe and Montgomery 2003; Collins et al. 2003; Jennings et al. 2003; Montgomery et al. 2003; Murphy and Meehan 1991; Naiman et al. 2002). Within streams, approximately 70 percent of structural diversity is derived from root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, or windthrow (Knutson and Naef 1997). Additionally, juvenile salmonid abundance in winter, particularly juvenile coho salmon, is positively correlated to abundance of LWD (Hicks et al. 1991). In a study of Smith Creek in northwest California, Harvey et al. (1999) found that tagged adult coastal cutthroat trout moved more frequently from pools without large woody debris than from pools with large woody debris. They hypothesized that the habitat created by wood attracts fish, and once fish establish territory within the desirable habitat, they remain there longer. A study by Cederholm et al. (1997) in a tributary of the Chehalis River found that wood additions caused an increase in winter populations of juvenile coho salmon and age-0 steelhead populations. A study by Everett and Ruiz (1993) also found that fish use complex environments and the structure of the LWD itself for cover and refuge.

In small streams, LWD is a major factor influencing pool formation in plane-bed and step-pool channels. Bilby (1984, in Naiman et al. 2002) and Sedell et al. (1985, in Naiman et al. 2002) found that approximately 80 percent of the pools in several small streams in southwest Washington and Idaho are associated with wood.

The position of LWD strongly influences the size and location of pools in larger streams, as well (Naiman et al. 2002). In larger streams, LWD is typically oriented downstream due to powerful streamflow, which favors formation of backwater pools along margins of the mainstem (Naiman et al. 2002).

The hydraulic complexity created by LWD encourages the capture and sequestration of other allochthonous inputs, making these materials more available to the food web through grazing and decomposition (Quinn 2005; Naiman et al. 2002; Knutson and Naef 1997; Murphy and Meehan 1991).

Sediment accumulated by woody debris in streams provides substrate for the establishment of early successional plant species that can mature into riparian vegetation. In the Pacific Northwest, LWD in riparian areas provides an important germination site for several conifer species. *(need reference.)*

Channel complexity promotes the retention of water and organic material. This retentiveness plays an important role in the fate of nutrients in the stream channel. In a study by Mulholland et al. (1985), it was suggested that leaf litter in streams promotes nutrient retention as the leaf pack acts as a substrate for nutrient-hungry microbes. Using solute injection techniques, Valett et al. (2002) found that phosphorus uptake in channels with high LWD volumes, frequent debris dams, and fine-grained sediments was significantly greater than in channels in younger forests without these characteristics. Corroborating this finding, Ensign and Doyle (2005) conducted phosphorus injections in streams both before and after the removal of LWD and coarse-particulate organic matter (CPOM) in the channels and found that phosphate uptake decreased by up to 88 percent after LWD removal. These studies show that channel complexity increases water retention and, through CPOM and LWD retention, provides a substrate for biofilm growth.

Numerous studies have reported fish use of complex cover composed of riparian vegetation, such as branches, root wads, and woody debris, which provides increased and diverse surface area and interstices for prey colonization and protection from predation. Particulate organic matter accumulated by LWD is an important food source for many stream-dwelling invertebrates. Addition of wood to channels causes increased abundance of macroinvertebrates and changes the species composition in that stream. Pools formed by LWD in streams are an important habitat for many species of stream fishes.

The use of submerged riparian vegetation during early development has been hypothesized to increase Columbia River white sturgeon recruitment (Coutant 2004). In another study, radio-tagged cutthroat trout were observed using pools associated with LWD for cover (Harvey et al. 1999). In addition, undercut banks are stabilized by riparian vegetation roots, which reduce the effects of erosion from streamflow. These undercut banks provide shade and lower temperatures, which are important for fish habitat and cover from predation (Angermeier and Karr 1984; Heggenes and Borgstrom 1988; Rowe et al. 2004). Therefore, significant reduction in riparian vegetation will affect species composition.

Riparian vegetation modifications can impose a number of stressors on fish and aquatic invertebrate species, with potentially detrimental effects on survival, growth, and fitness. For example, riparian modification can cause hydraulic and geomorphic changes in the stream channel due to reduced LWD recruitment and increased bank erosion.

Long-term indirect effects on fish and invertebrates associated with altered habitat complexity include a reduction or modification of prey base and related changes or reduction in foraging success, modified distribution and/or diversity of species within riverine systems, and decreased habitat suitability for various lifestages, resulting in decreased viability and reproductive success.

7.5.6.4 Ecosystem-Specific Effects: Lacustrine

In lakes, large woody debris provides cover and foraging opportunities for fish (Quinn 2005).

Altered habitat complexity in the form of a reduction of shoreline LWD and overhanging vegetation has been linked to removal due to human development (Francis and Schindler 2006). Loss of LWD has a number of effects on the health of the lake food web. Fish also respond to habitat characteristics resulting from the association of shoreline and riparian zone modification. In a study of Wisconsin lakes, the habitat characteristics most influenced by this association were depth, substrate size and embeddedness, and amount of woody vegetation and macrophytes (Jennings et al. 1999).

Tabor et al. (2004, 2006) have documented the importance of small woody debris as habitat structure in Lake Washington, where it may provide important periodic refuge from predators for juvenile Chinook salmon.

While the importance of riparian vegetation to the lacustrine nearshore area has been documented (Scheuerell and Schindler 2004), the role of emergent vegetation on the productivity of habitat has not been explored in detail in Washington waters or with regard to HCP species.

7.5.7 Activity-Specific Effects

7.5.7.1 Culverts

Culvert retrofit projects are likely to have little or no effect on riparian vegetation, as construction and maintenance work will be implemented from the existing roadway and will take place within the footprint of the existing structure. Removal and replacement projects may have more broad-reaching effects on riparian vegetation. In many cases, the work can be implemented from the existing road prism or channel modification, requiring little riparian disturbance. However, in some cases culvert removal or replacement may cause hydraulic and geomorphic modifications that affect riparian conditions in both upstream and downstream reaches more broadly. This is particularly likely to be true in situations where road-impounded wetlands are created as a result of backwater conditions. Draining of these impoundments may alter the relationship between the stream and riparian vegetation as the channel adjusts to the new gradient condition.

7.5.7.2 Water-Crossing Structures

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

7.5.7.3 Bank Protection

Bank protection structures such as bulkheads may cause a physical barrier between the bank and hyporheic flow and prevent exchange between the bank and aquatic ecosystem.

Marine shorelines that have been modified by human activities tend to have less LWD and driftwood than unarmored beaches (Higgins et al. 2005; Herrera 2005). MacDonald et al. (1994) also reported that shoreline armoring limited driftwood accumulation on a beach. Higgins et al. (2005) suggested that the mechanisms for the apparent reduction in LWD appear to be the removal of adjacent riparian vegetation during and following placement of the bank protection; reduced shoreline roughness at armored sites, which causes more LWD to be transported away; and limited upper intertidal and backshore areas that allow for LWD deposition above tidal elevations that are routinely inundated.

Because LWD is used in some marine soft-shore armoring instances to attenuate wave energy and lessen the potential for erosion, it is assumed that naturally occurring LWD on beaches would do the same, but this has not been empirically tested. Herrera (2005) describes how multiple layers of LWD along a shoreline could provide effective energy dissipation, decreasing the amount of wave reflection during high water levels, by increasing the roughness of the shoreline and by decreasing its slope relative to a vertical bulkhead.

7.5.7.4 Logging

Logging practices in northwestern Montana have been shown to decrease habitat complexity through the reduction of LWD inputs (Hauer et al. 1999).

7.5.7.5 Groins

Channel complexity promotes the retention of organic material. Groins typically simplify channel structure, causing a drop in complexity. Decreased nutrient retention will affect both local waterways and downstream receiving waters. Local waterways will be affected through the associated reduction in primary production, and receiving waters (which are primarily located in more nutrient-impacted lowland areas) will be affected through additional nutrient loading, which may lead to eutrophication.

7.5.7.6 Roughened channels

Construction of new roughened channels will have extensive effects on terrestrial vegetation. In contrast, alteration of an existing channel may require alteration of both riparian and aquatic vegetation for construction purposes. On this basis, the effects of riparian vegetation modification on HCP species as a result of roughened channel creation are expected to be relatively extensive.

7.5.7.7 Dredging

Impacts on habitat complexity from riparian vegetation loss and/or removal will be variable and will depend on the type and extent of dredging activities. Reductions in large woody debris loading to a riverine system from the loss of riparian functions (i.e., recruitment) may contribute to a loss of habitat complexity. Processes that homogenize habitat also diminish ecological health and habitat diversity (Jacobson 2006). The loss of large woody debris may result in the loss of pools and alterations of channel geometry.

Instream large woody debris may be disturbed or removed from the channel as part of dredging operations. In addition, the potential recruitment of large woody debris may be adversely impacted as a result of vegetation removal from channel banks and bars during construction access and staging.

7.5.7.8 Gravel mining

Gravel mining activities alter the distribution of riparian vegetation both directly through the removal or disturbance of riparian vegetation during mining activities and indirectly through the conversion of riparian areas to open pits. The loss of riparian vegetation caused by gravel mining can reduce the supply and retention of LWD.

7.5.7.9 Fish screens

Bankline in-channel screens and all off-channel fish screens pose some potential for riparian vegetation modification due to the fact that these types of screens may require a bypass system. Bypass systems typically take the form of a pipe or a constructed channel to return water to the stream system. The extent of riparian modification associated with bypass systems varies widely depending on the type of system and its extent. Some screen systems may employ a piped bypass that returns flow to the stream almost directly downstream of the diversion, requiring little additional riparian modification. Even longer bypass pipe systems installed by hand labor may have only minor effects on riparian vegetation. In contrast, due to the size of the diversion and local topography, some screen systems may employ constructed bypass channels of considerable length. In such cases, development of these channels may require extensive riparian modification. Assessing the extent of likely effects requires consideration of the scale and design of the screen system in question.

7.5.7.10 Tide Gates

Flow alterations from tide gates may redistribute LWD such that it concentrates in certain areas and is absent in others (Miller et al. 2001).

7.5.7.11 Beaver Dam Removal

Riparian and bank vegetation has been shown to act as a filter for polluted waters from upgradient sources moving through overland flow, interflow, and shallow groundwater pathways (Hickey and Doran 2004). The removal of beaver dams may be associated with reduced buffering capacity in downstream riparian zones. Reduced buffering capacity may lead to increased nutrient and pollutant loading to the channel.

The creation of a beaver dam impacts the riparian zone upstream of the dam. Inundation and clearing of vegetation by beaver results in the conversion of the terrestrial riparian zone into an aquatic system with minimal cover. In this way the riparian buffer upstream of the dam can be reduced by beaver activity. Beaver ponds create riparian wetlands. It has been shown that impoundments can increase riparian vegetation downstream of the dam by augmenting floodplain groundwater (Duke et al. 2007). Because beaver-created wetlands have rich organic soils, there is the potential for changes in nutrient levels to occur in the littoral areas of the pond (Cooper 1990).

Beaver dam removal and impoundment dewatering results in the creation of a stream reach which initially has little riparian vegetation. Until riparian vegetation becomes established after dewatering, there will be reduced vegetation adjacent to the channel and thus decreased direct delivery of organic material to the channel.

Nutrient-rich sediments from the benthos of the former impoundment (Ahearn and Dahlgren 2005) may be rapidly colonized with wetland vegetation and invasive species. The establishment of mature riparian stands may take years to decades (Auble et al. 2007), but dense stands of rapidly growing native and invasive plants such as *Typha* spp. (cattails) may provide channel shading in the short term. The removal of beaver dams will weaken the terrestrial-aquatic linkage and initially reduce allochthonous input from the riparian zone. Additionally, bank stability will be degraded until the channel adjusts and vegetation begins to grow and stabilize the banks. Riparian buffering capacity may increase as the former impoundment will serve as additional buffer area between the channel and upland pollution sources. It can be assumed that the removal of beaver dams which impound a large cross section of the floodplain will impact downstream riparian vegetation by altering hyporheic flow and thus will also reduce downstream allochthonous inputs.

Beaver actively recruit wood from the adjacent floodplain to augment their dams and build lodges (Collen and Gibson 2001). Beaver extirpation would eliminate this pathway for wood recruitment. The wood imported to the channel by beaver activity can serve as shelter for fishes (Cederholm et al. 1997), substrate for algal growth (Atilla et al. 2003), and habitat for macroinvertebrates (Clifford et al. 1993; Rolauffs et al. 2001).

Rolauffs et al. (2001) found that macroinvertebrate emergence was 3.2 and 5.5 times higher from a beaver dam than from the adjacent brook and pond areas, respectively. This indicates that not only are beaver ponds important for fluvial ecosystem functioning, but that the associated dam structures provide additional habitat benefits. Removal of beaver dams will, of course, eliminate those habitats created by both the pond and the dam.

While some beaver ponds have been shown to raise stream temperatures (Margolis, Raesly et al. 2001; Mcrae and Edwards 1994), a literature review by Pollock et al. (2003) noted that other studies have indicated that beaver ponds do not significantly affect temperature.

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

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

7.5.7.13 Riparian Planting/Restoration/Enhancement

One of the most common restoration practices is the restoration and planting of riparian environments. In some instances, invasive plants are removed from the riparian area and replaced with native vegetation. Increased shading caused by riparian canopy cover has both positive (LeBlanc and Brown 2000) and negative (Hetrick et al. 1998) ramifications for aquatic biota.

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

Increased shading from riparian plantings can decrease stream temperature by between 3.6 and 7.2^{o}F (2 and 4^{o}C) (Ebersole et al. 2003), which will benefit cold water species (Opperman and Merenlender 2004); conversely shading will decrease autotrophic production within the channel and possibly impact macroinvertebrate populations.

There is a growing body of literature indicating that riparian vegetation removal increases stream productivity. Canopy removal studies have indicated that macroinvertebrate populations increase after riparian vegetation is removed (Hetrick et al. 1998; Wipfli 1997). In headwater systems (which are generally oligotrophic), this increase in productivity is seen as a benefit to stream biota. Hetrick et al. (1998) studied riparian canopy removal in Eleven Creek, Alaska, and concluded that:

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

Findings such as these indicate that riparian plantings in headwater food limited reaches may be a detriment to juvenile fishes within the channel. In a similar study, Fuchs et al. (2003) found that streams flowing through newly logged forests in British Columbia (where the riparian zones were harvested within 5 years of the study) had nearly twice the macroinvertebrate biomass as those in unlogged or older logged sites, and a higher chlorophyll a concentration. In a study of open canopy and closed canopy patches by Zalewski et al. (1998), it was found that macroinvertebrate density was highest in mixed cover reaches which received both incident light and allochthonous input. Fish biomass followed the same trend, being lowest in heavily shaded areas and in open channels without riparian vegetation, but highest in ecotones of intermediate complexity.

Riparian buffer studies indicate that there are complex interactions between the channel and the riparian zone and that the ideal riparian environment may be a mix of closed canopy and open canopy patches (Zalewski et al. 1998). Riparian patch dynamics are vital to a healthy stream ecosystem. Riparian canopy provides shade and litter input, while open canopy patches are characterized by increased solar radiation, warm waters, and autochthonous production. A goal of riparian planting should be to increase the frequency of these habitat patches within degraded reaches with little canopy cover, while acknowledging that the increase in shading associated with riparian vegetation may locally decrease productivity within that patch.

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

7.5.7.14 Wetland Creation/Restoration/Enhancement

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

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

7.5.7.15 Beach Nourishment

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