INTRODUCTION

The quantity and quality of aquatic habitat present in any stream, river, lake or estuary is a reflection of the existing physical habitat characteristics (e.g. depth, structure, gradient, etc) as well as the water quality (e.g. temperature and suspended sediment load). There are a number of processes that create and maintain these features of aquatic habitat. In general, the key processes regulating the condition of aquatic habitats are the delivery and routing of water (and its associated constituents such as nutrients), sediment, and large woody debris (LWD). These processes operate over the terrestrial and aquatic landscape. For example, climatic conditions operating over very large scales can drive many habitat forming processes while the position of a fish in the stream channel can depend upon delivery of wood from forest adjacent to the stream. In addition, ecological processes operate at various spatial and temporal scales and have components that are lateral (e.g., floodplain), longitudinal (e.g., landslides in upstream areas) and vertical (e.g., riparian forest).

The effect of each process on habitat characteristics is a function of variations in local geomorphology, climatic gradients, spatial and temporal scales of natural disturbance, and terrestrial and aquatic vegetation. For example, wood is a more critical component of stream habitat than in lakes, where it is primarily an element of littoral habitats. In stream systems, the routing of water is primarily via the stream channel and subsurface routes whereas in lakes, water is routed by circulation patterns resulting from inflow, outflow and climatic conditions.

Human activities degrade and eliminate aquatic habitats by altering the key natural processes described above. This can occur by disrupting the lateral, longitudinal, and vertical connections of system components as well as altering spatial and temporal variability of the components. In addition, humans have further altered habitats by creating new processes such as the actions of exotic species. The following sections identify and describe the major alterations of aquatic habitat that have occurred and why they have occurred. These alterations are discussed as limiting factors.

Discussion of Habitat Limiting Factor Elements

Fish Passage Barriers

Salmon are limited to certain spawning and rearing locations by natural features of the landscape. These features include channel gradient and the presence of physical features of the landscape (e.g. logjams). Flow can affect the ability of some landscape features to function as barriers. For example, some waterfalls may be impassable at low flows, but then become passable at higher flows. In some cases, flows themselves can present a barrier, such as when extreme low flows occur in some channels; at higher flows fish are not blocked. Flow conditions may also allow accessibility to some anadromous salmonid species, while precluding access to others.

Throughout Washington, barriers have been constructed that have restricted or prevented juvenile and adult fish from gaining access to formerly accessible habitat. The most obvious of these barriers are dams and diversions with no passage facilities that prevent adult salmon from accessing historically used spawning grounds. Culverts are often full or partial fish passage barriers; delayed fish passage during certain flow conditions can be equally as detrimental as a total fish passage barrier. In addition, in recent years it has become increasingly clear that we have also constructed barriers that prevent juveniles from accessing rearing habitat. For example, dikes and levees have blocked off historically accessible side-channel rearing areas, and poorly designed culverts in streams have impacted the ability of juvenile salmonids to move upstream into rearing areas.

Functions of Floodplains

Floodplains are portions of a watershed that are periodically flooded by the lateral overflow of rivers and streams. In general, most floodplain areas are located in lowland areas of river basins and are associated with higher order streams. Floodplains are typically structurally complex, and are characterized by a great deal of lateral, aquatic connectivity by way of distributaries, sloughs, backwaters, side-channels, oxbows, and lakes. Often, floodplain channels can be highly braided (multiple parallel channels).

Properly functioning floodplains provide critical habitat. Aquatic habitats in floodplain areas can be very important for chinook and coho salmon juveniles that often over-winter and seek refuge from high flows in the sloughs and backwaters of floodplains. Floodplains also help dissipate water energy during floods by allowing water to escape the channel and inundate the terrestrial landscape, lessening the impact of floods on incubating salmon eggs. Floodplains also provide coarse beds of alluvial sediments through which subsurface flow passes. This acts as a filter of nutrients and other chemicals to maintain high water quality. Floodplains also provide an area for sediment deposition and storage, particularly for fine sediment, outside of the river channel, reducing the effects of sediment deposition and instability in the river channel.

Impairment of Floodplains by Human Activities

Large portions of the floodplains of many Washington rivers, especially those in the western part of the state, have been converted to urban and agricultural land uses. Many of the urban areas of the state are located in lowland floodplains, while land used for agricultural purposes is often located in floodplains because of the flat topography and rich soils deposited by the flooding rivers.

There are two major types of human impacts to floodplain functions. First, channels are disconnected from their floodplain. This occurs both laterally as a result of the construction of dikes and levees, which often occur simultaneously with the construction of roads, and longitudinally as a result of the construction of road crossings. This has: 1) eliminated off-channel habitats such as sloughs and side channels; 2) increased flow velocity during flood events due to the constriction of the channel; 3) reduced subsurface flows and groundwater contribution to the stream; and 4) simplified channels since LWD is lost and channels are often straightened when levees are constructed. Channels can also become disconnected from their floodplains as a result of down-cutting and incision of the channel from losses of LWD, decreased sediment supplies, and increased high flow events.

The second major type of impact is loss of natural riparian and upland vegetation. The natural riparian and terrestrial vegetation in floodplain areas was historically coniferous forest. Conversion of these forested areas to impervious surfaces, deciduous forests, meadows, grasslands, and farmed fields has occurred as floodplains have been converted to urban and agricultural uses. Riparian forests are typically reduced or eliminated as levees and dikes are constructed. Loss of vegetation on the floodplain reduces shading of water in floodplain channels, eliminates LWD contribution, reduces filtering of sediments, nutrients and toxics, and results in increased water energy during flood flows.

Elimination of off-channel habitats results in the loss of important habitats for juvenile salmonids. Side channels, sloughs and backwaters that are isolated from flooding impacts historically functioned as prime spawning habitat for chum, pink, and coho, and rearing and over-wintering habitat for chinook and coho juveniles. The loss of LWD from channels reduces the amount of rearing habitat available for chinook juveniles. Disconnection of the stream channels from their floodplain due to levee and dike construction increases water velocities, which in turn increases scour of the streambed. Salmon that spawn in these areas may have reduced egg to fry survival due to the scour. Removal of mature native vegetation from riparian zones can increase stream temperatures in channels, which can stress both adult and juvenile salmon. Sufficiently high temperatures can increase mortality.

Streambed Sediment

The sediments present in an ecologically healthy stream channel are naturally dynamic and are a function of a number of processes that input, store, and transport the materials. Processes naturally vary spatially and temporally and depend upon a number of features of the landscape such as stream order, gradient, stream size, basin size, geomorphic context, and hydrological regime. In forested mountain basins, sediment enters stream channels from natural mass wasting events (e.g. landslides and debris flows), channel bank erosion (particularly in glacial deposits), surface erosion, and soil creep. Natural input of sediment to stream channels in these types of basins occurs periodically during extreme climatic events such as floods (increasing erosion) and mass wasting. In lowland, or higher order streams, lateral erosion is the major natural sediment source. Inputs of sediment in these basins tend to be steadier in geologic time.

Once sediment enters a stream channel it can be stored or transported depending upon particle size, stream gradient, hydrological conditions, availability of storage sites, and channel type or morphology. Finer sediments tend to be transported through the system as wash load or suspended load, and have relatively little effect on channel morphology. Coarser sediments (>2 mm diameter) tend to travel as bedload, and can have larger effects on channel morphology as they move downstream, depositing through the channel network.

Some parts of the channel network are more effective at storing sediment, while other parts of the network are more effective at transporting material. There are also strong temporal components to sediment storage and transport, such as seasonal floods, which tend to transport more material. One channel segment may function as a storage site during one time of year and a transport reach at other times. In general, the coarsest sediments are found in upper watersheds while the finest materials are found in the lower reaches of a watershed. Storage sites include various types of channel bars and floodplain areas, and are often associated with LWD.

Effects of Human Actions on Sediment Processes

Changes in the supply, transport, and storage of sediments can occur as the direct result of human activities. Human actions can result in increases or decreases in the supply of sediments to a stream. Increases in sediment deposition in the channel result from increased erosion due to land use practices or isolation of the channel from the floodplain (due to presence of dikes or roads), which eliminate important off-channel storage areas for sediment and increase the sediment load beyond the transport capacity of the stream. In addition, actions that destabilize the landscape in high slope areas such as logging or road construction increase the frequency and severity of mass wasting events. Finally, increases in the frequency and magnitude of flood flows, and/or loss of floodplain vegetation, increase erosion. Increased erosion fills pools and aggrades the channel, resulting in reduced habitat complexity and reduced rearing capacity for some salmonids.

Increased total sediment supply to a channel increases the proportion of fine sediments in the bed, which can reduce the survival of incubating eggs in the gravel and change benthic invertebrate production.

Decreases in sediment supply occur in some streams, primarily as a result of disconnecting the channel from the floodplain. Dams typically block the supply of sediment from upper watershed areas while levees typically isolate the stream from natural upland sources of sediment. In addition, gravels are removed from streambeds to increase flow capacity (dredging) or for mineral extraction purposes. Reduction in sediment supply can alter the streambed composition, which can coarsen the substrate and reduce the amount of gravel substrate suitable for spawning.

In addition to affecting sediment supply, human activities can also affect the storage and movement of sediment in a stream. An understanding of how sediment moves through a system is important for determining where sediment will have the greatest effect on salmonid habitat and for determining which areas will have the greatest likelihood of altering habitats. In general, transport of sediment changes as a result of gradient, hydrology changes (water removal, increased peak flows, or altered timing and magnitude of peak flows), and isolation of the channel from its floodplain. Larger and more frequent flood flows move larger and greater amounts of material more frequently. This can increase bed scour and bank erosion, alter channel morphology, and ultimately degrade the quality of spawning and rearing habitat. Unstable channels become very dynamic and unpredictable compared to the relatively stable channels characteristic of undeveloped areas. Additional reductions in the levels of instream LWD can greatly alter sediment storage and processing patterns, resulting in increased levels of fines in gravels and reduced organic material storage and nutrient cycling.

Riparian Zone Functions

Stream riparian zones include the area of living and dead vegetative material adjacent to a stream. They extend from the edge of the ordinary high water mark of the wetted channel, upland to a point where the zone ceases to have an influence on the stream channel. Riparian forest characteristics in ecologically healthy watersheds are strongly influenced by climate, channel geomorphology, and where the channel is located in the drainage network. Large-scale natural disturbances (fires, severe windstorms, and debris flows) can dramatically alter riparian characteristics. These natural events are typically infrequent, with recovery to healthy riparian conditions for extended periods of time following the disturbance event. The width of the riparian zone and the extent of the riparian zone's influence on the stream are strongly related to stream size and drainage basin morphology. In a basin un-impacted by humans, the riparian zone would exist as a mosaic of tree stands of different acreage, ages (e.g. sizes), and species.

Riparian zone functions include providing hydraulic diversity, adding structural complexity, buffering the energy of runoff events and erosive forces, moderating temperatures, protecting water quality, and providing a source of food and nutrients. They are especially important as the LWD source for streams. LWD directly influences several habitat attributes important to anadromous species. In particular, LWD helps form and maintain the pool structure in streams, and provides a mechanism for sediment and organics sorting and storage upstream and adjacent to LWD formations. Pools provide a refuge from predators and high-flow events for juvenile salmon, especially coho that rear for extended periods in streams.

Effects of Human Activities on Riparian Zones

Riparian zones are impacted by all types of land use practices. Riparian functions are impaired by direct removal of riparian vegetation; by roads and dikes located adjacent to the stream channel; by road crossings, agricultural/livestock crossings, and timber yarding corridors that cross the stream channel; by unrestricted livestock grazing in the riparian zone; and by development encroachment into the riparian corridor. Further, riparian vegetation species composition can be dramatically altered when native trees are replaced by exotic species (e.g., shrubs, reed canarygrass), and where native coniferous riparian areas are converted to deciduous tree species. Deciduous trees are typically of smaller diameter than conifers and decompose faster than conifers, so they do not persist as long in streams and are vulnerable to being washed out by lower magnitude floods. Once impacted, riparian functions can take many decades to recover as forest cover regrows, and coniferous species colonize. It may take as long as 80-120 years to restore functional LWD contribution to the channel.

Changes to riparian zones affect many attributes of stream ecosystems. For example, stream temperatures can increase due to the loss of shade, while streambanks become more prone to erosion due to elimination of the trees and their associated roots. Perhaps the most important impact of riparian alteration is a decline in the frequency, volume, and quantity of LWD due to reduced recruitment from forested areas. Loss of LWD results in a significant reduction in the complexity of stream channels including a decline of pool habitat, which reduces the number of rearing salmonids. Loss of LWD affects the amount of both over-wintering and low flow rearing habitat, as well as providing a variety of other ecological functions in the channel.

Water Quantity

The hydrologic regime of a drainage basin refers to how water is collected, moved and stored. The frequency and magnitude of floods are especially important since floods are the primary source of disturbance in streams and thus play a key role in how channels are structured and function. In ecologically healthy systems, the physical and biotic changes caused by natural disturbances are not usually sustained, and recovery is rapid to pre-disturbance levels. If the magnitude of change is sufficiently large, however, permanent impacts can occur.

Alterations in basin hydrology are caused by changes in soils, decreases in the amount of forest cover, increases in impervious surfaces, elimination of riparian and headwater wetlands, and changes in landscape context. Hydrologic impacts to stream channels occur even at low levels of development (<2% impervious area) and generally increase in severity as more of the landscape is converted to from natural forest cover to more developed land uses.

Salmonid production is profoundly affected by water withdrawals for irrigation, industrial, and domestic use, including water transfers between basins. Removal of water, either directly from the stream channel or from wells that are in hydraulic continuity with stream flows, reduces the amount of instream flow and useable wetted area remaining for support of adult salmonid spawning and juvenile rearing. Reduction of instream flows also typically results in increased water temperature, often to levels that impair salmonid productivity. The relationship between the useable wetted area of a stream and stream flow varies between species and life stages. For example, juvenile coho prefer quiet water in pools for rearing, whereas juvenile steelhead prefer areas of faster water (Hiss and Lichatowich 1990). Streamflow limitations are typically greatest during the dry summer and early fall months when stream flows are lowest. In other instances stream flows may actually increase due to direct or indirect (irrigation ground water return flows) water transfers from other basins. In some instances peak flood flows may be transferred to basins that would otherwise not be affected by flood flows. These situations may increase the stream flow and useable wetted area for fish use, but the increased hydrology may cause channel bedload movement, bank erosion, loss of LWD, and other adverse habitat impacts that would not be experienced under the natural hydrology regime to which the channel is adapted.

Water Quality

Water quality affects productivity and survival of salmonids. There are several water quality parameters that affect salmonids, including water temperature, pH, dissolved oxygen, turbidity, nutrients, and toxic chemicals. Elevated water temperatures are typically associated with loss of mature riparian vegetation along the stream corridor, reduced instream flows during late summer resulting from water withdrawals, or from increased solar exposure to water impounded behind dams. Salmonids generally require a neutral pH; fish may be adversely affected by surface water with pH of 5.6 or less, and can also be adversely affected by high pH values (Spence et al. 1996). Dissolved oxygen levels are directly associated with water temperature, with saturation being higher in colder water. Turbidity refers to the presence of suspended sediment in the water column that may affect survival of eggs or fish. Stormwater runoff (particularly from roads), surface erosion, and increased streambank erosion are the main contributors of turbidity. Natural stream nutrient regimes have been altered. Natural nutrient cycling has been affected by low numbers of salmon carcasses due to reduced numbers of spawners returning to streams; by removal or alteration of riparian vegetation that reduces the entry of litter fall and invertebrates; by the lack of LWD in streams that slows the loss of nutrient sources from the stream; and by stormwater flows that flush available nutrients from the streams. In addition, hatchery salmon carcasses are often not returned to rivers and streams after the salmon are artificially spawned, reducing the cycling of marine-derived nutrients. Increased levels of nutrients result from stormwater runoff with high levels of nitrogen and phosphorus, and from failing septics and sewage treatment plant outfalls. High nutrient levels can lower dissolved oxygen levels in a waterbody. Public health districts regularly monitor for presence of fecal coliform bacteria. Elevated fecal coliform counts that do not meet Washington State water quality standards may result in closure of marine shellfish beds to harvest, but fecal coliform bacteria are not known to affect salmonid health or survival. However, elevated fecal coliform counts may be an indicator of other salmonid habitat problems (e.g., elevated nutrient levels, low dissolved oxygen, unrestricted cattle access to streams) in the watershed. There is far less water quality monitoring for presence of toxic chemicals. Sources of toxics of concern include toxic spills (e.g., oil, paint, pesticides.), runoff from roads/parking lots, exposure of the stream or marine water to treated wood, leaching of pesticides, and leaching of heavy metals.

Estuarine Habitat

Anadromous salmonids are affected by the freshwater habitat conditions described above, but are also affected by habitat conditions in the estuary, as well as in the ocean. Worldwide, few other habitats are so valuable for fish production and yet are so imperiled as estuaries. Estuaries include the area from the uppermost extent of tidal influence within the stream to the upper intertidal line on the delta face. Their abundant food supply, wide salinity gradients, and diverse habitats make these areas particularly valuable to anadromous fish for rearing, feeding, and osmoregulatory acclimation during transition between fresh water and marine habitats (Macdonald et al 1987). The vital role estuaries play in chum salmon ecology is well documented (Walters et al. 1978; Healy 1980A, Levy and Northcote 1982). Other species of salmonids that also inhabit estuaries, sometimes in high densities, include coho (Tschaplinski 1982, Mason 1974, Miller and Simenstad 1997, Nielsen 1994, Hiss 1994), sockeye (Healy 1980A), pinks (Hiss 1994), and chinook (Levy and Northcote 1982, Healy 1980A, Healy 1980B, Congleton et al

1981, Shreffler et al 1992). According to Levy and Northcote (1982), significant estuary rearing by chum and chinook fry on the Fraser River Delta extends even into tidal channels that are dewatered during normal low tides. In the Skagit River estuary, Beamer and LaRock (1998) found high densities of chinook, chum, and smelt inhabiting a salt marsh tidal channel (Browns Slough) that was not associated with any freshwater stream. Also found in Browns Slough were coho smolts and adult cutthroat trout engorged on smelt. Juvenile chinook have been documented in at least two Puget Sound estuarine salt marshes not associated with chinook spawning streams - Shine Creek on the Olympic Peninsula (Lichatowich 1993) and Seabeck Creek on the Kitsap Peninsula (Hirschi, personal communication). The spawning of Pacific herring, an important forage fish for salmonids, has been documented in Willapa Bay and Grays Harbor estuarine salt marshes, but the presence or importance of Pacific herring has not been assessed in Strait of Juan de Fuca estuaries