Department of Planning & Development

Environmentally Critical Areas Code Update: **Best Available Science Review for Fish and Wildlife Habitat Conservation Areas**

August 2005, updated December 2013

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3.1. SUMMARY

This review of recent literature provides the City of Seattle (City) with pertinent information developed in recent years that identifies the effects of urban development on the aquatic habitat and those actions appropriate to protect and restore natural functions to this habitat. The review deals with literature pertinent to the urban environment of Seattle, but also incorporates relevant information obtained from investigations in rural and forested environments. The report is organized by basic habitat type proceeding from the small fresh-water streams to the estuarine and Puget Sound shoreline habitats.

The City has reviewed the BAS regarding the aquatic environment that includes lakes, estuaries, rivers, streams, and the nearshore environment, and we have included an evaluation of the functions of these aquatic environments including in-water habitat and riparian buffers. Additionally, WAC 365-195-925 states that measures to conserve and protect anadromous fisheries should protect habitat for all life stages of anadromous fish. This review of BAS includes identifying information describing the habitat requirements of anadromous fishes in these aquatic environments and the way the fish use the habitats in order to devise appropriate conservation and protection measures. Our evaluation of conservation and protection measures attempts to address each of the distinct life stages of Pacific salmon that are likely to occur in the various waters within the City.

3.2. INTRODUCTION

The aquatic areas affected by Seattle's ECA regulations include streams, lakes, estuaries and shallow marine areas and the associated riparian areas. Riparian areas are the transition zones between aquatic and terrestrial ecosystems. These areas commonly have substantial gradients in biological and physical conditions, as well as in ecological processes. Riparian areas have been demonstrated by numerous investigations to play a major role in the maintenance and dynamics of aquatic habitat natural functions.

Essentially all of Seattle's shorelines have been highly modified by urban development within the city. Forests were removed and replaced with human development over nearly all the city's landscape in the late 19th and early 20th century. Narrow riparian areas with natural vegetation and slope characteristics remain along some of the City's streams. However, nearly all the shorelines of the lakes, estuaries, and many streams have been highly modified by residential, commercial or industrial development. Major historic changes have taken place in the Lake Washington watershed. Early in the 1900s the Lake Washington Ship Canal (Ship Canal) was constructed and the elevation of Lake Washington lowered by nine feet. At the same time the Cedar River was channelized and re-routed from the Green River basin into Lake Washington with discharge through the Ship Canal and Salmon Bay. The combined alterations produced irrevocable changes to the landscape that are major influences in the current functions of the shoreline conditions. Therefore, this BAS includes scientific information that applies to such highly modified environments. However, information from naturally forested and unaltered areas is incorporated in this review because this information identifies the habitat functions and characteristics desired for the urban aquatic areas.

This document provides a review of reports and information currently available that represent BAS pertinent to management and regulation of the City of Seattle's aquatic habitats. We have also evaluated the use and habitat requirements of anadromous fish in these aquatic environments in order to devise appropriate conservation and protection measures. Washington State's administrative code (WAC 365-195-925) states that measures to conserve and protect anadromous fisheries should protect habitat for all life stages of anadromous fish. This evaluation of conservation and protection measures attempts to address the BAS identifying the habitat characteristics supporting each distinct life stage of Pacific salmon including:

- upstream migration,
- spawning,
- egg incubation,
- fry emergence,
- freshwater juvenile rearing,
- juvenile migration,
- estuarine juvenile rearing, and
- marine rearing.

The marine nearshore, estuarine, lake, and stream habitats within the City, provide important habitat for three federally listed fish species: Chinook salmon (*Oncorhynchus tshawytscha)*, steelhead (*O. mykiss)*, and bull trout (*Salvelinus confluentus*) (see NOAA Fisheries 2013a and USFWS 2013). The Puget Sound Chinook Evolutionarily Significant Unit (ESU), which was listed as threatened under the Endangered Species Act (ESA) in March 1999. Multiple populations of the Puget Sound Chinook ESU are supported by the aquatic habitats within the City. Similarly, aquatic habitats in the City also support multiple runs of the Puget Sound steelhead ESU which was listed as threatened under the ESA in May 2007. NOAA Fisheries has proposed critical habitat for Puget Sound steelhead which includes only the Duwamish River and the marine shorelines of the City (NOAA Fisheries 2013b), although steelhead also utilize the Lake Washington and Cedar River system.. The proposed critical habitat excludes all parts of Lake Washington, including all Lake Washington system freshwater aquatic habitats in the City, due to the economic impact of such a listing. Other anadromous salmonids, such as chum (*O. keta)*, coho (*O.* kisutch*)*, sockeye (*O. nerka)*, and cutthroat trout (*O. clarki clarki)* are also found in the water bodies within Seattle.

This report is organized by basic habitat type, proceeding from the small freshwater streams to the estuarine and Puget Sound shoreline habitats. A brief glossary is appended at the end of this report to provide definitions of some of the more technical terms commonly used in literature dealing with the subjects covered by the BAS report.

3.3. AQUATIC HABITAT TYPES WITHIN CITY

The City of Seattle contains a complex array of aquatic habitats and shorelines within the city boundaries. These include lotic, lentic, estuarine and marine nearshore habitats. Lotic waters are flowing streams such as rivers and creeks (Goldman and Horne 1983). The city has approximately 45 small streams as well as the lower portion of the Green/Duwamish River. Lentic waters are standing water such as lakes and ponds. The western shorelines of Lake Washington, Lake Union, the Ship Canal, and three smaller lakes (Green, Bitter, and Haller Lakes) are within Seattle. Estuaries are transition areas of variable salinity where freshwater streams and rivers mix with salt water. The Duwamish estuary and Salmon Bay estuary are the substantial estuarine waters within the city. Smaller estuaries occur at the mouths of the several streams, such as Pipers and Fauntleroy that discharge directly to Puget Sound. Marine shorelines occur along the city's Puget Sound shorelines (including Elliott Bay and Shilshole Bay). Each of the water bodies and their adjacent shorelines are important for healthy aquatic ecosystems including salmon. Gende et al. (2002) recently reviewed the literature discussing the role of aquatic and terrestrial ecosystems in supporting anadromous salmonids.

The following are brief descriptions of the aquatic environments that occur within the City of Seattle with maps showing their general extent.

Lotic Systems (running water/rivers and streams)

Seattle has approximately 45 streams or creeks. Some of the creeks have been sufficiently modified by development of their small drainage basins that they are confined in pipes or ditches and difficult to recognize as streams. Some streams such as Thornton and Taylor Creeks have at least part of their drainage basin outside the city limits. Thornton, Taylor and several other streams discharge to Lake Washington, contributing a small amount of flow to the discharge through the Ship Canal and Hiram M. Chittenden Locks to Salmon Bay. Other creeks such as Pipers and Fauntleroy discharge directly to Puget Sound, while Hamm, Puget, and Longfellow Creeks discharge to the estuarine portion of the Duwamish River. Thornton, Piper's, Taylor, Longfellow and Fauntleroy creeks are the five current salmon-bearing stream systems in Seattle.

A key concept in the protection and restoration of streams is the "river continuum concept" described by Vannote et al. (1980). The river continuum concept describes aquatic systems with physical variables present in a continuous gradient from headwaters to mouth. Recent literature has well established the naturally dynamic characters of streams that are a product of their entire landscape, including hydrologic, geomorphic, and vegetation characteristics, as well as climate, geology, and topography (Kondolf 2000, Booth et al. 2002, Buffington et al. 2003, Collins et al. 2003, Montgomery and Bolton 2003, Wissmar et al. 2003). Prior to human modification the rivers that typically incised Holocene valleys through Pleistocene glacial sediments had an anastomosing pattern with multiple channels, floodplain sloughs, and frequent channel-switching avulsions due largely to wood jams (Collins et al. 2003). Smaller streams had many of the same characteristics. Biota and ecological processes also have variable gradients within this continuum that correspond to the physical gradients.

Thus, streams are naturally dynamic, continually changing over time and area. It is important to recognize this natural aspect of the lotic systems in formulating regulations to deal with subsequent changes to these aquatic systems and restoration of this habitat. Most of the recent literature follows this landscape approach (Garcia et al. 2003) for assessing and suggesting restoration strategies for aquatic systems. Although the river continuum concept deals primarily with the geomorphologic processes and dynamic physical conditions of river channels, it is consistent with the current emphasis on the connection of aquatic, riparian, and terrestrial ecosystems within a river basin that interact with and influence the channels physical conditions.

Lentic Systems (lakes and ponds)

Lakes are the basin portions of the landscape that retain water throughout the year (Goldman and Horne 1983). In the city this includes both lakes that are directly connected to Puget Sound (Lake Washington-Lake Union-Ship Canal) providing migratory corridors for anadromous fishes, and lakes that are functionally isolated from Puget Sound (Green Lake, Haller Lake, Bitter Lake). As described by Schindler and Scheuerell (2002), lakes are functionally part of a larger ecosystem with habitat coupling in the system playing an important role in complex nutrient cycling, predator-prey interactions, and food-web structure and stability.

Lake Washington is the largest and most obvious of Seattle's lentic systems. It is important to the region because of the resident biota it supports and the functions it serves for anadromous and other migratory species. Lake Washington provides rearing habitat and migratory corridors for anadromous salmonids (Chinook, coho, chum, and sockeye salmon, steelhead, bull trout, cutthroat trout) as well as numerous resident species. These species are a major component of the aquatic biota important to the local region. Lake Washington also provides resting and feeding habitat for a variety of birds. Bald eagles, osprey and peregrine falcons forage along the shorelines. Numerous species of waterfowl (e.g. ducks, geese) rest and feed in both the open water and protected portions of Lake Washington during their autumn and winter migrations through the area. Some of these waterfowl winter in the Lake Washington habitat.

Within the city smaller isolated lakes such as Bitter, Haller, and Green Lakes provide lentic habitat. Pipes and culverts downstream from these small lakes functionally isolate them from Puget Sound. These small lakes connect through man-made drainage systems to Puget Sound.

Estuaries

Estuaries are the aquatic transition zones between streams and marine waters. They commonly have variable salinity that ranges from fresh water to high salinity approaching that of marine waters. These salinity gradients extend from fresh water at the upstream end to high salinities at the estuary mouths. Vertical salinity gradients also commonly occur with lower salinity at the surface and higher salinity at the bottom. Estuaries are tidally influenced with extreme ranges of about 18 feet at the mouth to less than one foot at the upstream end. The tidal force and variability in stream flow produce changes in salinity at any location within the estuary over short periods of hours, requiring many species either to adapt to a substantial salinity range or move vertically or horizontally with the variable salinity.

Seattle has a rather typical, although highly modified, estuary within the Duwamish River. This estuary extends from the river mouth at the north end of Harbor Island to about river mile (RM) 11 which is approximately 6.5 miles upstream (south) of the City Limit (i.e., the lower 4.6 miles of estuary are in the City). Within the city, the Duwamish River estuary is a dredged navigation channel commonly referred to as the Duwamish Waterway. Although substantial intertidal habitat restoration efforts have been conducted in recent years (Cordell et al. 2001, Port of Seattle 2009), the shoreline and riparian habitats, remain highly modified for commercial, residential, and flood control purposes. The estuary is restrained within a dredged channel having hardened shorelines and numerous piers over much of the steepened shorelines. Little riparian vegetation remains other than at the habitat restoration sites. The natural tide flat and saltmarsh habitat that historically supported rearing and migration of juvenile salmon produced in the Green/Duwamish River system have been reduced to small remnants. Side channels and marsh sloughs that were a part of the natural estuary are no longer present to provide quiet water rearing areas for juvenile Chinook and other salmon. Recent work by Ruggerone et al. (2006) identified the estuarine transition zone as supporting relatively high abundances of juvenile Chinook salmon and therefore the authors hypothesized that this is a particularly important area to focus salmon restoration. Ruggerone et al. (2006) approximated the estuarine transition zone as occurring between RM 4.6 and 6.5, i.e., just upstream of the City limits, although this is intended as an approximation and some additional habitat upstream and downstream of this stretch can be assumed to provide similar benefits.

A second highly modified estuary also exists at Salmon Bay in the area between the Hiram M. Chittenden Locks (the Locks) and Shilshole Bay. Historically, this area drained only a small stream. However, the water courses were altered to connect the estuary to Lake Washington via the Ship Canal and the estuary now estuary drains the entire Lake Washington watershed, including the Cedar River and Lake Sammamish. The Locks form the upper extent of the estuary as freshwater occurs upstream of the Locks and saltwater is present downstream. Historically, a small stream discharged to the estuary that existed upstream from the present day Locks. This existing estuary is highly saline with a reduced salinity surface layer provided by the freshwater discharge from Lake Washington through the Locks. The Locks are located within the tidal zone eliminating the shallow low salinity portion of a natural estuary, other than along the intertidal shorelines of Salmon Bay. In this way, the estuarine transition is abrupt, rather than what would be expected in a more natural setting.

Other very small estuaries occur at the mouths of small streams that discharge directly to Puget Sound. Streams such as Pipers Creek and Fauntleroy Creek have very small estuarine areas constrained by human alterations to the surrounding landscape. Longfellow Creek technically has an estuarine area that occurs within the large culvert that discharges to the Duwamish estuary, rather than natural habitat. Puget Creek has a restored estuary that discharges to the middle portion of the Duwamish estuary.

Nearshore Environment

Seattle has about 33 miles of Puget Sound shorelines along the western side of the city that is a portion of the Puget Sound ecosystem. The nearshore environment of Seattle includes intertidal and shallow subtidal areas and terrestrial habitats. These shorelines provide a complex physical and biological habitat that is important to both anadromous and marine fish species. The shallow water habitat of these marine shorelines is highly productive with abundant marine algae, eelgrass, and diatoms providing primary production. A wide variety of invertebrates (e.g., worms, clams, sea stars, crabs, etc.) live within and on these shoreline substrates. Many species of marine and anadromous fish spend a portion of their life cycle in the shallow waters of the nearshore environment.

The natural nearshore environment is dependent on shore processes that erode and transport terrestrial soils to maintain substrate conditions commonly present in shallow water. Wave and current energy continually transports and modifies the shoreline sediments in a manner that produces apparently stable (short term), but clearly dynamic (long-term) conditions that are a major factor in maintaining the natural environment. Basic habitat modifications such as bulkheads, seawalls, shoreline armoring, etc. interfere with the natural erosion and transport processes along most of the city's nearshore environment. These man-made structures isolate the source of shoreline materials and interrupt the transport of sediment already present in the intertidal portion of the nearshore environment (Downing 1983). Given the natural redistribution of sediments along the nearshore, the disconnection of sediment sources caused by human alterations typically affects much longer stretches of shoreline than just the area where the sediment supply is disconnected (Johannessen and MacLennan 2007). In fact, the effects can extend across several miles of shoreline.

3.4. CHARACTERISTICS OF HABITAT TYPES

This section describes the general characteristics of the habitat types that occur within the City of Seattle and recent literature describing the characteristics of these habitats. Although the shorelines of these various habitat types in the city are often highly modified, natural characteristics are discussed to identify those characteristics that historically provided the biological functions appropriate to maintain naturally functioning ecosystems. Aquatic habitats and shorelines are the result of dynamic landscape processes influenced by supply, storage, and transport of water, sediment, and wood (Benda et al. 1998). The natural disturbance process continually alters these habitats, but not in the same manner as urban development. Management of the urban areas relies heavily on information obtained from investigations conducted in forested landscapes, which provides information on the natural landscape processes. However, aquatic areas and shorelines that are highly modified by urban development require different management than harvested forest landscapes (Naiman et el. 2000, Seattle 2003, Appendix A). Knutson and Naef (1997) provide a review of riparian management recommendations from literature compiled to that date and discussed below.

3.4.1. Streams (Lotic Systems)

Streams (creeks) form a substantial portion of the shoreline habitat present within the City of Seattle (Seattle 2003, Appendix A). During the last 20 years, there has been a substantial amount of research dealing with streams, the processes that form and change them and their relationship to other aspects of the landscape within a watershed. This research has continued to expand our understanding of the dynamics, functions and relationships involved in natural landscapes as well as those landscapes highly altered by urban development such as the City of Seattle. The following sections identify both the natural conditions desired for streams and the highly altered conditions of Seattle's approximate 45 streams.

While the basic characteristic of streams are incompletely understood (Pess et al. 2003), they are clearly dynamic systems (Bilby et al. 2003, Collins et al. 2003) continually changing over time and distance. Streams naturally change from their headwater origin to their estuarine or freshwater terminus. Streams naturally change over time as physical and biological forces modify their structure. The following describes the general conditions of natural streams. Limiting factors, data gaps and priority actions for the specific conditions of Seattle's streams and the factors limiting production within the aquatic habitats within the City of Seattle are provided by Seattle (2003) (Appendix A).

3.4.1.1 Physical Structure Of Streams

The dominant feature of streams (lotic environment) is the swift unidirectional flowing water. The discharge rate (volume per time) and current (distance per time) interact with the bottom, shorelines, and floodplain of the stream or river and determines the substrate composition of the streambed (cobble, gravel, mud, detritus etc.) (Ziemer and Lisle 1998). The current, depth, and discharge rate also tends to maintain the oxygenated water throughout the stream. A series of physical structures, that have regular vertical and horizontal periodicity, make up streams and rivers (Leopold 1994). These structures are defined as meanders, pools, riffles and glides. Water seeking the path of least resistance or requiring the least energy produces the horizontal meanders, which occur in the flatter portions of the watercourses. Meanders tend to produce areas of deeper, swifter flows with erosion at the outer edge of the meander and shallow, gradual slopes on the inner side of curves (Leopold 1994). Riffles, pools and glides are a part of the physical structure of the streams and rivers that are formed by a combination of boulders, large woody debris, water depth, and the current of the water. Deeper pools of relatively slow moving water are separated by riffles, which are areas of shallow turbulent water passing through or over stones or gravel of a fairly uniform size. Intermediate areas of moderate current often found in larger streams are termed runs or glides. It is important to recognize that stream structure is dynamic (Bilby et al. 2003).

The physical processes that incorporate and transport sediment, wood, nutrients, etc. vary with location along streams as a result of geology, landform, riparian vegetation, disturbance regimes, etc.(Fox 2001, Gomi et al. 2001, Montgomery and Bolton 2003). These dynamic physical structures of the streams provide an abundance of specialized and dynamic biological niches. For example, certain benthic invertebrates will be associated with areas of fast current on the upstream face of a rock whereas different invertebrate species will be found behind the same rock in the eddy where little downstream flow occurs (Johnson et al. 2003). The different habitat beneath the rock provides refuge for small animals from their predators, while the upper surface provides a well-lighted site for attached algal growth (Johnson et al. 2003, Roni 2003). Riffles tend to contain more of a stream's benthic invertebrates than pools.

An often overlooked aspect of stream ecosystems is the hyporheic zone. The hyporheic zone is the volume of saturated sediment under and along the sides of the stream where groundwater and surface water intermix (Edwards 1998). Hyporheic zones occur in portions of streams with depositional floodplains that provide porous sediment. Processing of nutrients within the hyporheic zone can equal the amount that occurs in the open channel.

3.4.1.2 Biological Structure of Streams

The biological structure of streams is dependent on the physical structure of the stream as well as the spatial patterns of drift (living benthic invertebrates and algae which have released or lost their attachment to the substrate) and detritus (dead organic fragments coated with bacteria and fungi) (Goldman and Horne 1983, Hershey and Lamberti 1998, Milner et al. 2000, Johnson et al. 2003). The primary nutrient source for streams is allochthonous organic matter produced by photosynthesis within the riparian areas (Suberkropp 1998). Fungi and bacteria in flowing water break down particulate and dissolved organic matter from decomposition of leaves and wood. Invertebrates process nutrients from bacteria, fungi and leaf litter into the aquatic food web. Particulate organic material and insects drift downstream to be consumed by other invertebrates and fish (Siler et al. 2001, Goldman and Horne 1983). Benthic algae and macrophytes within the streams provide additional primary production (Murphy 1998).

The relationship of detritus and invertebrate drift in streams is discussed by Siler et al. (2001) who observed that excluding leaf litter from a treatment stream resulted in a significantly lower invertebrate abundance, but did not alter the biomass present. These biological components provide further structure to the stream ecosystem because of their distribution in relation to current speed, substrate, and food supply (Goldman and Horne 1983, Hershey and Lamberti 1998). Larger organisms that are part of a stream's biological structure include fish and wildlife. The types of fish using Seattle's major watercourses vary by watercourse and receiving water body (e.g., Puget Sound, Lake Washington, or the Duwamish River). Common fish species include salmon, cutthroat trout, stickleback, sculpin, lamprey, and non-native species such as sunfish (Seattle 2007). Tabor (2006) found that juvenile Chinook salmon originating in the Cedar River are often present at Lake Washington tributary mouths. Similarly, Beamer et al. (2013) report extensive juvenile salmon use of tributary mouths and lower reaches of streams entering Puget Sound. Small numbers of salmon, notably coho and chum, spawn in the streams of the City. A vast majority of the salmon in the City originate in rivers beyond the city limits but in the same broader watersheds (e.g., Cedar River upstream of Lake Washington and Green River upstream of the Duwamish estuary). Stream wildlife includes waterfowl, amphibians, and small mammals.

3.4.1.3 Riparian Corridor Functions

Riparian corridor, riparian ecosystem, riparian buffer, riparian zone, riparian area, stream corridor, and stream buffer are the various terms used by the authors of the scientific literature reviewed for this document. Essentially, these terms have the same meaning and refer to the upland area adjacent to a water body, although some authors also include the water body in their definition.

According to Naiman et al. 1998, riparian refers to the biotic communities and the environment on the shores of the streams, rivers, ponds, lakes and some wetlands. The stream corridor, riparian corridor or riparian ecosystem is defined as the area of transition between the aquatic zone and the upland zone (Budd 1987, Johnson and Ryba 1992, Desbonnet 1994, Furfey et al. 1999, Naiman et al. 2000, National Academy of Science 2002, May 2003). These stream corridors contain elements of both aquatic and terrestrial ecosystems.

Riparian corridors are the most biologically diverse components of Pacific Northwest ecosystems (Pollock 1998). The degree to which the riparian ecosystem is fully vegetated with no breaks in the vegetation affects the natural character and water quality of streams (Haberstock et al. 2000).

Pollock (1998) and Budd et al. (1987) found wildlife to be most abundant along stream corridors because of the proximity of the riparian zone to water. Approximately 29% of the wildlife species occurring in Northwest riparian forests are species that depend upon riparian and aquatic resources (Relsey and West 1998). Factors affecting biodiversity include disturbances such as flooding, debris flows, channel migration, beaver modifications and vegetation removal (Pollock 1998). For these reasons, it is important to consider the impacts of changes in riparian corridor conditions, on fisheries and wildlife habitat.

Bottom et al. (1983) concluded that riparian vegetation affects the physical composition of stream habitat as well as the biological communities of which salmonids are a part. Anthropogenic alterations to riparian corridors have negatively impacted the streams in the Pacific Northwest and Seattle (Budd et al. 1987, Knutson and Naef 1997, Naiman et al. 2000). Small streams have been affected most by pollution such as excessive nutrients because the dilution factor is lowest (Budd et al. 1987). The major fish habitat elements influenced by riparian corridor conditions and correlated with riparian corridor widths are:

- water temperature,
- food supply and allochthonous input,
- stream structure/LWD,
- hydrology/stormwater management
- sedimentation control, storage and transport; and
- nutrient input.

Additionally the riparian corridors provide wildlife habitat for terrestrial species.

Water Temperature

A number of factors affect water temperature in a stream. Water temperature is largely influenced by the initial temperature of the stream's source (surface flow, spring, and reservoir), the rate of stream discharge or flow, the elevation of the stream, and the vegetation in the riparian corridor (Budd et al. 1987, Ebersole et al. 2001, May 2003, WDOE 2007). Other stream channel characteristics that affect water temperature are groundwater discharge, undercut embankments, organic debris, surface area, depth, and stream velocity. Water temperature is of concern both because of its potential lethal effects for cold water fishes such as salmonids, but also because of its potential effect on general growth and fish health. Water temperatures both too warm and too cool can reduce survival and growth. Alcorn et al. (2002) recently reported juvenile sockeye reared at temperatures of 12^{o}C had a greater immune response to disease organisms than juveniles raised at 8^{o}C. Complex temperature conditions in streams resulting from cool subsurface discharge can increase trout production and Chinook abundance (Ebersole et al. 2001). They concluded that the effectiveness of cold-water patches as thermal refuges is determined by physiognomy, distribution, and connectivity that were associated with channel bed form and riparian features. In Cascade coastal streams, geomorphic controls on hyporheic (subsurface) exchange can be different for various streams and will influence stream temperature (Kasahara 2000, Kasahara and Wondzell 2003, WDOE 2007). In an analysis of western Washington streams, WDOE (2007) reported that riparian vegetation has the greatest control on stream temperature at lower flow rates which in Seattle corresponds to late summer when solar radiation potential is maximized.

Riparian corridors act as reservoirs restraining the flow of precipitation by temporarily storing runoff in vegetation, soil spaces and wetlands. This characteristic minimizes fluctuations in stream flow and maintains lower water temperatures during summer periods as cool stored water is discharged to the stream. However, In the Pacific Northwest, the fundamental hydrologic effect of urban development is the loss of water storage in the soil column. This may occur because the soil is compacted or stripped during the course of development, or because impervious surfaces convert what was once subsurface runoff to Horton overland flow (Booth et al. 2002). Recent literature has demonstrated that riparian vegetation of sufficient width can produce a microclimate (Chen 1991, Johnson and Ryba 1992, Chen et al. 1995, Blann et al. 2003) that helps maintain a more constant temperature minimizing the extreme high and low temperatures. The vegetation canopy adjacent to streams shields the water from direct sunlight, which moderates extreme temperature fluctuations during summer. This canopy can be grasses and shrubs for smaller streams, as well as trees and shrubs for larger streams.

The impacts of forest management practices on stream temperature have been documented by many recent studies (Brown and Krygier 1970, Spence et al. 1996, Kauffman et al. 2001, Blann et al. 2003, May 2003). Harvested watersheds with buffer strips exhibit no increase in temperature attributable to tree harvest demonstrating that riparian buffers effectively regulate temperature in small streams (Brazier and Brown 1973). However, clear-cut watersheds have shown monthly mean maximum increases of 2-8^{o}C in some cases. According to Montgomery (1976) the peak daily maximum rise in these clear-cut streams may reach 25.5^{o}C during low flows experienced in late summer, but buffer strips have been effective in controlling temperature changes resulting from removal of timber. However, Mellina et al. (2002) observed only modest changes (0.05-1.1^{o}C) in summer daily maximum and minimum temperatures, diurnal fluctuations, and stream cooling in clear-cut logging areas on Vancouver Island. Their survey of multiple streams originating from small lakes or swamps indicated water from these sources tended to cool as the water moved downstream, while water from headwater streams warmed with and without logging. Urban areas such as the City of Seattle tend to have conditions similar to harvested forest areas indicating that riparian buffers will influence stream temperature.

The effect of riparian buffers on stream temperatures is dependent on the size of the stream because the area, volume, and flow of water is greater in larger streams (Budd et al. 1987). For example, large trees would have little effect on the temperature of rivers the size of Duwamish because even large trees cannot provide shade in the middle portion of the river. However, most of Seattle's streams are small with narrow channel widths (1-2 m) where even tall grasses can provide substantial shading. Smaller streams can recover sooner because early successional vegetation can provide as much shade as wooded buffers for channels of bankfull widths < 2.5 m (Blann et al. 2002 as cited in WDOE 2007) Water temperature control requires shading of about 60% to 80% of a stream's surface. Shading of 60-80% of the stream area can be achieved with 11-24.3 m (35-80ft) of buffer width (Brasier and Brown 1973) and 23-38 m (75-125 ft) (Steinblums et al. 1984, Budd et al. 1987). Brazier and Brown (1973) concluded the maximum shading capability of the average strip was reached within a riparian buffer width of 25 m (80 feet) and 90% of the maximum occurred with a 17 m (55 feet) wide buffer. Brazier and Brown (1973) concluded the effectiveness of the buffer strips in controlling temperature changes is independent of timber volume.

Blann et al. (2003) used the U.S. Fish and Wildlife Service's Stream Network Temperature Model to evaluate the role of riparian buffer type in mediating summer stream temperatures. The simulations indicated that grasses and forbs (successional buffers) provide as much shade as wooded buffers in small streams less than 2.5 m wide. With constant discharge and low width-depth ratio, grasses and forbs mediated mean temperatures as well as wooded buffers.

Grazed and successional buffers had a significantly lower percentage of shade than wooded buffers.

The shading requirement for the maintenance of fisheries habitat is dependent on stream size whereby the vegetation in the riparian corridors influences stream temperature greater in small streams than in large streams and rivers. Daily temperature variations in undisturbed streams were approximately 2.2°C (4°F) or more while temperature variation increased to 5.6°C (10°F) or more when all shade along the stream was removed (Montgomery 1976). This effect is mitigated by stream size with larger streams having less temperature variation than small streams due to their larger volume relative to the surface area exposed to sunlight. Orientation of the stream and buffer also is a factor with vegetation on southern banks providing more shade than vegetation on northern banks (Bren 1995).

Water temperature also has a direct effect on oxygen level, with cooler water holding higher levels of dissolved oxygen than warm water (Lamb 1985). One of the most influential water quality parameters on stream biota, including salmonid fish, is dissolved oxygen (Lamb 1985). Although salmon are able to survive dissolved oxygen levels of less than 3 parts per million (ppm), levels below 5 or 6 ppm may result in behavioral changes and increased stress in adults or rearing juveniles (Pauley et al. 1986). Water turbulence and biochemical demand also affect amounts of available oxygen. Biochemical demand can stem from the decomposition of organic materials including pollution (animal waste, sewage etc.), and algal respiration (Lamb 1985).

Beschta et al. (1987) suggests that direct fish mortality is probably not a major concern when shading over a stream has been removed, but that temperature changes can influence rates of fish egg development, rearing success, and species competition resulting in biological changes. However, several investigations have reported a detrimental effect on coho embryo and juvenile survival following removal of riparian forest cover (Martin et al. 1986, Cederholm and Reid 1987, Hartman et al. 1987). No recent literature was found that addresses these issues.

Allochthonous Input/Nutrient Cycling/Terrestrial Insect Input/Food Supply

It has been well estimated that 99% of the energy and hydrocarbon in aquatic food webs originates in the adjacent riparian and terrestrial components of the ecosystem (Bormann et al. 1968, Bormann et al. 1969, Likens et al.1970). Allochthonous organic matter from riparian areas is the primary nutrient source for streams (Suberkropp 1998). Dissolved and particulate organic matter from decomposition of leaf litter and wood is broken down in streams by fungi (hypomycetes) and bacteria. Invertebrates consume the bacteria, fungi and leaf litter to incorporate the nutrient sources into the aquatic food web. Particulate organic material and insects drift downstream to be consumed by other invertebrates and fish (Goldman and Horne 1983, Bisson and Bilby 1998).

Light within forested streams is commonly limited to as little as 5% of full sunlight, limiting photosynthesis. Benthic algae and macrophytes within these streams provide additional primary production (Murphy 1998). The results of this is that small streams commonly provide only a small portion of primary production, while large rivers produce about 80% of instream primary production for a major watershed (Murphy 1998).

Peterson et al. (2001) determined that the most rapid uptake and transformation of inorganic nitrogen occurs in the smallest streams and that ammonium entering these streams was removed from the water within 30 meters to hundreds of meters. During seasons of high biological activity less than half of the dissolved inorganic nitrogen input from watersheds to headwater streams is exported to downstream areas.

Habitat Structure/LWD Recruitment

Large woody debris (LWD) is an important structural component of Seattle and Washington's coastal streams that provides salmonid habitat (Bisson et al. 1987). The critical functions of LWD in forested lowland streams include dissipation of flow energy, protection of stream banks, stream channel and pool formation, storage of sediment and it provides instream cover and habitat diversity (Gurnell et al. 2002, Booth et al. 1997, Gregory et al. 1991, Masser et al. 1988, Bisson et al. 1987). The influence of LWD may change over time both functionally and spatially, but its overall importance to salmonid habitat is significant and persistent (Collins et al. 2002, Guyette et al. 2002, May 1998).

The source and role of LWD in stream habitats has been the subject of numerous investigations in recent years (Bisson et al. 1987, Murphy and Koski 1989, Van Sickle and Gregory 1990, McDade et al. 1990, McKinley 1997, Beechie et al. 2001, Fox 2001, Wallace et al. 2001, Collins et al. 2002, Jackson and Sturm 2002, and many others). Instream LWD affects channel structure (Collins et al. 2002, Gurnell et al. 2002, Jackson and Sturm 2002, WDFW 2012); it produces pools and habitat diversity, provides cover, adds roughness (to slow water), and traps sediment (Bisson et al. 1987). Fundamental changes in the morphology, dynamics, and habitat abundance and characteristics of lowland rivers have occurred related to changes in wood abundance (Collins et al. 2002) such as have occurred with urban development. However, while the quantity and quality of LWD are negatively affected by urbanization even many of the natural undeveloped streams lacked LWD. Several studies (Gregory et al. 1991, May 1998, Masser et al. 1988) have found that intact and mature riparian areas are necessary to maintain instream LWD. The lack of functional quantities of LWD in Puget Sound lowland streams is significantly influenced by the major reduction in riparian habitat along urbanized streams.

Both large and small woody debris interact with water and sediment to produce localized sediment scouring and deposition. This action results in more complex and often more stable habitat than would occur in the absence of woody debris (Jackson and Sturm 2002, Ulrike and Peter 2002, Montgomery and Buffington 1998, Beechie and Sibley 1997, Ralph et al. 1994, Sedell and Beschta 1991 White 1991, Heede 1985). Generally LWD provides the key pieces in log jams that are major dynamic forces in stream structure formation and alteration (Collins et al. 2002). In streams, wood pools and riffles generated by debris provide habitat for migration, spawning, rearing, and refuge from periodic disturbances (such as major storms or landslides).

Wood jams are now rare in many coastal streams because of the lack of very large wood that functions as key pieces, together with low rates of wood recruitment (Collins et al. 2002). The contribution of woody debris to stream structure is believed to be derived from within 31 m (100 feet) of the banks of a stream (Bottom et al. 1983). Removal of large wood from streams and riparian areas greatly reduces the supply of new wood to streams (Gonor et al. 1988, Collins et al. 2003). Additionally, hydraulic considerations motivated widespread removal of not only riparian vegetation but also in-stream obstructions. On large rivers any logs or snags reduced navigability; on small streams mobile debris can be seen to lodge under bridges and clog culverts, encouraging local sediment deposition and flooding. Thus, wood jams are rare in Seattle's streams because of the lack of very large wood in riparian areas providing wood recruitment and key jam-forming pieces.

The duration of wood within streams has been an issue in evaluation of stream processes forming aquatic habitat. Both short life species such as red alder (*Alnus rubra*) and long-life species such as Douglas fir (*Pseudotsuga menziesii*) provide key LWD pieces producing channel forming actions (Beechie et al. 2000). Immersion in water leads to deterioration of the wood. Bilby et al. (1999) found that the diameter loss of wood ranged from 10.6 mm in five years for western hemlock to 21.8 mm for big leaf maple. Standards for properly functioning amounts of LWD in western Washington streams are 80 pieces per mile or greater (NMFS 1996). However, Jackson and Sturm (2001) found that the role of woody debris in habitat formation that has been documented for larger streams does not apply to headwater streams. They concluded that the major step-forming agent in the small streams is small wood (10-40 cm diameter), inorganic material, and organic debris (<10 cm diameter), while LWD (>40 cm diameter) produced less than 10% of the steps. Wood quantity, volume, and mean piece size increased with channel size due to the increased proclivity for fluvial transport and spatial accretion, along with greater lateral area for wood to accumulate (Fox 2001). Thus, relatively small wood pieces play a substantial role in most of Seattle's streams because of their relatively small channel width as headwater streams (first and second order streams, see glossary for definition).

Wood size as related to the size of the stream rather than absolute sizes is important in determining the role of LWD (Gurnell et al. 2002). Wood pieces that are large in comparison to small streams tend to remain near the point of delivery and provide important structures that control, rather than respond to hydrological and sediment transfer characteristics of smaller streams. In "medium" streams the combination of wood length and form becomes critical to the stability of wood within the channel. Key pieces of larger wood produce accumulations of smaller pieces. Flow regime and buoyancy of the wood govern wood transport, with even large pieces requiring partial burial to give them stability. In "large" rivers wood dynamics vary with channel geometry (slope, channel pattern), which controls delivery, mobility, and breakage of wood, as well as with riparian zone characteristics. Wood retention depends on the channel pattern and distribution of flow velocities. Wood tends to be stored at the channel margins in larger rivers and greater contact between the active channel and the riparian areas in these larger rivers produces greater quantity of stored wood.

There are a variety of models available to evaluate the dynamics of large wood in streams (Gregory et al. 2003). Meleason et al. (2003) provides a model for the dynamics of stream wood including tree entry, breakage, movement and decomposition. STREAMWOOD is an individual-based stochastic model operating at a reach scale on an annual time step.

Each of the salmonid species occurring in the Pacific Northwest is commonly found in debris-rich environments characteristic of unmanaged coniferous forest streams, at least in coastal streams. They have developed adaptations that allow them to maximize production in hydraulically complex channels where debris is abundant (Bisson et al. 1987). Roni and Quinn (2001) found that the densities of juvenile coho salmon were 1.8 and 3.2 times greater in LWD treated reaches in summer and winter respectively than in reference reaches of Washington streams. Response of coho populations was correlated with the number of pieces of LWD forming pools during the summer and the total pool area during the winter. Cutthroat trout and steelhead trout densities for age 1+ fish did not differ between treatment and reference reaches during the summer and were negatively correlated with increased pool area. Roni and Quinn (2001) also observed the density of trout fry was negatively correlated with pool area during the winter. Harvey et al. (1999) observed that retention of cutthroat trout appeared to be greater in pools with LWD; however its presence in pools did not influence immigration or growth of cutthroat trout.

Large woody debris plays a role in providing prey for rearing juvenile salmonids. Johnson et al. (2003) concluded that LWD provides habitat and flow refugia for stream invertebrates, and biofilm production that provides food for grazing invertebrates. These invertebrates rapidly colonize logs added to streams resulting in changes in community composition and processes. Wipfli (1997) found that rearing salmonids preyed equally on terrestrially derived and aquatically derived insects in both old growth and alder-dominated young forested areas.

Jeanes and Hilgert (2001) found that young Chinook salmon in the Green River used areas of the thalweg associated with scour pools downstream from boulders and large wood mats. Mean water column velocities were less than 2 feet/second in these areas. Yearling coho salmon and cutthroat trout tend to occur in off channel habitats that contain complex woody debris structure. Attached root systems and accumulated mats of small wood were used by young salmonids, apparently providing visual isolation from fish and bird predators. Rainbow trout were found more often in mainstem than off channel habitats. Ulrike and Peter (2002) found that whole trees placed in a stream increased brown trout and rainbow trout abundance and biomass. The trees also affected physical habitat features, and provided additional trout habitat.

Large woody debris may also play a role in habitat formation for non-salmonid fishes and amphibians. Roni and Quinn (2001) examined the effect of LWD placement in streams on juvenile lampreys (*Entosphenus tridentatus*, *Lampetra* spp.), reticulate sculpins (*Cottus perplexus*), torrent sculpins (*C. rhotheus*), and giant salamanders (*Dicamptodon* spp.) in 29 small streams. Densities and mean lengths of giant salamanders, reticulate sculpins, torrent sculpins, and lampreys did not differ significantly between treatment and reference reaches. Lamprey densities and length of age-1 and older reticulate sculpins positively correlated with LWD in the wetted stream channel. Lamprey length also positively correlated with the percentage of pool area. These results indicate that artificial placement of LWD in northwest streams may benefit lampreys and age-1 and older reticulate sculpins (species that prefer pools), but have little effect on other non-salmonid species.

Stormwater Management (Quantity and Quality)

Riparian areas play a role in maintaining stream water quality by removing pollutants (i.e., nutrients, contaminants, toxic substances, and pesticides) and sediment from stormwater. Biofiltration or the removal of nutrients and sediment from stormwater during its flow through riparian buffers is an effective means of treating overland flow of stormwater in urban areas (Horner and Mar 1982, Vought et al. 1984, Dillaha et al. 1989, Osborne and Kovacic 1993, Horner 1996, Kauffman et al. 2001, McDowell and Sharpley 2003). Both forested and grass riparian vegetation can remove 40-90% of nitrate-nitrogen and total phosphorus concentrations from water (Osborne and Kovacic 1993). Excessive phosphorus is typically a problem in urban watersheds because it leads to nuisance plant growth in urban streams. Plant decay in turn, consumes oxygen and reduces the quality of available aquatic habitat (Arnold and Gibbons 1996). Nutrient removal efficiency is dependent on vegetation type, buffer width, and water flow rate.

Sediment control can be achieved by stable stream banks that minimize instream erosion and riparian buffers to control overland erosion and remove sediment from stormwater (Simon and Collison 2002, Naiman et al. 2000). Erman et al. (1977) found 30-m buffer widths protected aquatic insect communities from increased sedimentation. Some forest surface soils have been found to have a percolation rate exceeding 250 inches per hour (Broderson 1973). This high filtration rate along with other factors such as rough terrain, exposed rocks, logs, brush and micro-variations in surface relief tends to impede and detain overland flows, preventing storm water from directly entering streams (Brown 1972 in Broderson 1973 and Pierce 1965). Broderson (1973) found that sediment reached channel bottoms through a 2.5 m (8 feet) undisturbed buffer strip, but not through a strip more than 10 m (33 feet) wide. This study was done on forest lands, thus it cannot be assumed that denser, more compacted urban soils will absorb water at the same rate. Urban environments, such as Seattle have highly compacted urban soils and considerable impervious surface area near streams that greatly increases the rate of stormwater runoff as well as degrades its quality (May 1998a and 1998b). Riparian areas can have buffers that effectively provide long-term removal of sediment (Lowrance et al. 1988). Prevention of high levels of nutrients and sediment from entering salmon bearing streams in short periods of time maintains oxygen levels and sediment characteristics thereby maintaining salmon spawning and rearing habitat and aquatic health.

Maintaining clean gravel is necessary for salmon reproduction. The fine sediment particles commonly carried by stormwater have the potential to clog spawning gravel resulting in smothering of developing embryos. Tagart (1976) showed that survival of alevin to emergence from redds was positively correlated with gravel sizes > 3.35 mm and < 26.9 mm. In such gravel beds, water is able to percolate through the redd. Healey (1991) suggests that 87% of Chinook fry emerged successfully from large gravel with adequate sub-gravel flows. Upland disturbances, which cause erosional sedimentation flows into small streams, can potentially clog gravel beds leading to a decrease in spawning success. Sandercock (1991) notes that if gravel is heavily compacted or loaded with fine sediment and sand, fry will not be able to emerge from the redds. Shaw and Maga (1943), Wickett (1954), Shelton and Pollock 1966 (as cited in Sandercock 1991) have shown that percolation is affected by siltation and that siltation in spawning beds can cause high mortality in eggs and alevins.

Pollutants enter a stream from point and non-point sources. Point sources are discernable, confined and discrete conveyance, such as a pipe or channel. Non-point source pollution in urban landscapes typically originates from discrete urban and residential land use activities (Feist et al. 2011). Common urban pollutants include: phosphorus and nitrogen from fertilizers, pesticides, bacteria and several other groups including PCBs and heavy metals including copper and zinc, which are harmful to aquatic species including salmonids. Sources of phosphorus and nitrogen in urban runoff include fertilizers, animal wastes, leaking septic tanks, sanitary sewer cross-connections, detergents, organic matter such as lawn clippings and leaves, eroded soil, road de-icing salts, and automobile emissions (Seattle 2007). Motor vehicles deposit an assortment of chemicals onto roads such as heavy metals including copper, zinc, and chromium from brake pads and tires; and PAHs from emissions, leaking fluids and tire wear (Feist et al. 2011).

Impervious surfaces collect and concentrate pollutants, delivering them to streams via runoff during heavy storm events (Feist et al. 2011, May et al. 1997a). May (1998) found that conductivity was strongly related to the level of basin development under base flow conditions. These findings indicate that the water quality of urban streams is generally not significantly degraded in areas with low amounts of impervious surface, but may be substantially degraded in streams draining highly urbanized watersheds with high levels of impervious surface area. Feist et al. (2011) have advanced the study on pre-spawn mortality and report that more mortality has been observed in streams with more roads, more impervious surfaces, and more commercial property. Both the concentrated pollutants and short, intense peaks in storm flows degrade salmon habitat in areas with high levels of impervious surface area.

Wildlife Habitat

Riparian areas are important to wildlife, fish, invertebrates and amphibians. Riparian corridors are diverse parts of the ecosystems that support more amphibian, bird, and mammal species than adjacent terrestrial areas (Kauffman et al. 2001). Carothers et al. (1974) found that alteration of wetland and riparian zone habitat has significant effects on fish and wildlife populations. A majority of North American wildlife is dependent upon riparian habitats for their survival (Hubbard 1977). Riparian habitat provides access to water, food, and shelter (Knutson and Naef 1997), particularly in urban areas where resources supporting wildlife are commonly very limited. Riparian habitat also provides migratory corridors used by many wildlife populations (Palone and Todd 1998). Knutson and Naef (1997) concluded that 85% of Washington's terrestrial wildlife use the riparian habitat during at least some portion of their life. Tabor (1976) found as many as 1,500 birds per 100 acres of riparian forests along the

Columbia River, which was greater than that found in adjacent non riparian habitat areas. Carothers (1976)) found that the number of breeding birds in riparian corridors that had been thinned to 25 trees per hectare (ha) was 54 % of the number found in a nearby undisturbed riparian corridor that had 116 trees per ha.

Stream Riparian Corridor Widths

Effective riparian areas are only those portions of the vegetated landscape that are within a short distance of a stream. The riparian area must be of sufficient width and density to effectively support the ecological functions described above. Given the nature of the various functions, there is variability in the width of vegetated riparian corridors necessary to provide the functions (see May 2003). The appropriate width of riparian areas to be ecologically effective has not been clearly defined, however, a number of investigations have addressed this issue. Generally recommended riparian area widths are in the range of 50-200 feet to maintain most stream functions with wider riparian areas needed for wildlife corridors (see Knutson and Naef (1997), May (2003)). Table 1 lists information on riparian functions and required widths to protect these functions as identified in existing literature.

Table 1. Riparian Corridor Widths and Functions

Function	Width (feet)	Reference	Finding
Over All	50	Budd et al. 1987	Found that many reaches of the Bear-Evans Creek had a 50' riparian corridor. Authors suggest evaluating streams on a case by case basis using a technique based on field surveys and ecological analysis.
Sediment Removal	53	Jacobs and Gilliam 1985	Most sediment removal
	26 – 600	May 2000	80% sediment removal
	100-125	Knutson and Naef 1997	Erosion control
	100	Castelle and Johnson 2000	Approaches 100% particulate organic matter production
	100	Lynch et al. 1985	75-80% removal
	100	Wong and McCuen 1982	90% removal
	26-300	Karr and Schlosser 1977	75% removal
	100 - 125	Knutson and Naef 1997	Sediment filtration
	200	Wong and McCuen 1982	95% removal
	200	Horner and Mar 1982	80% removal in grassy swale
	200	Broderson 1973	Controls overland flows of sediment on forest lands under almost all conditions
	290	Gilliam and Skaggs 1986	50% deposition
	295 – 400	Wilson 1967	Clay

Function	**Width (feet)**	**Reference**	**Finding**
Pollutant Removal	10	US EPA 2005	50% nitrogen removal based on correlation analysis of results from 66 studies
	13	Doyle et al. 1979	Grass Buffers
	13 - 600	Knutson and Naef 1997	Pollutant removal
	13 – 860	May 2000	80% nutrient removal
	15	Madison et al. 1992	90% removal of ammonia, nitrate and phosphorous
	33	Peterson et al. 1992	Minimum for nutrient reduction
	49	Neary 1993	Minimum width for effective removal of pesticides
	49-328	USACE 1991	Effective removal of pesticides
	50	Castelle et al. 1992	80% pollutant removal
	92	US EPA 2005	75% nitrogen removal based on correlation analysis of results from 66 studies
	100	Terrell and Perfetti 1989	Nutrient pollution in forested riparian areas
	100	Lynch et al. 1985	75-80% pollutant removal
	100	Grismaer 1981	Reduced fecal coli form bacteria by 60%
	100 – 140	Jones et al. 1988	Nutrient reduction
	120	Young et al. 1980	Minimum for nutrient reduction
	200	Terrell and Perfetti 1989	Removes pesticides and animal waste
	300	Vanderholm and Dickey 1978	80% removal on a 0.5% slope
	367	US EPA 2005	90% nitrogen removal based on correlation analysis of results from 66 studies
	860	Vanderholm and Dickey 1978	80% removal on a 4% slope

Function	Width (feet)	Reference	Finding
Large Woody Debris Recruitment	16 – 33	Castelle and Johnson 2000	40-60% LWD input
	33	McDade et al. 1990	<50% of naturally occurring LWD
	33-328	May 2000	1 site potential tree height (SPTH) based on long-term natural levels
	50	McDade et al. 1990	60-90% of all LWD
	55	Thomas et al. 1993	Minimum for 80% LWD input
	65 – 100	Castelle and Johnson 2000	80-100% LWD input
	65	Murphy and Koski 1989	95% of LWD
	100	McDade et al. 1990	85% of natural occurring LWD
	100	May et al. 1997	Recommended minimum
	100	Bottom et al. 1983	Minimum to supply LWD
	150	Harmon et al. 1986	Supply most LWD
	150	Robison and Beschta 1990	Supply most LWD
	165	Van Sickle and Gregory 1990	Minimum for LWD input
	330	May et al. 1997	Sensitive streams

Function	Width (feet)	Reference	Finding
Stream Temperature Maintenance	35 – 80	Brazier and Brown 1977	60-80% shade
	36-141	May 2000	Based on adequate shade
	40	Corbett and Lynch 1985	Control stream temperature fluctuations
	50 low canopy 200 high canopy	Broderson 1973	Buffer widths should be set on a case by case basis – using a canopy densiometer
	55	Steinblums et al. 1984	Maximum angular canopy density
	55	Moring 1975	Maintain stream temperature if in forested conditions
	75 – 90	Steinblums et al. 1984	60-80% shade
	> 124	Steinblums et al. 1984	100% natural shading in Western Cascades
	100	Beschta et al. 1987	Minimum shade to level of old growth forest
	100	Lynch et al. 1985	Maintain stream temperatures that are within 1ºC of areas that are fully forested

	100 – 150	Jones et al. 1988	Maintain temperature similar to fully forested areas

Function	Width (feet)	Reference	Finding
Maintenance of Benthic Communities	33	Culp and Davies 1983	Minimum for healthy communities
	100	Roby et al. 1977	Maintain benthic communities similar to streams in fully forested areas
	100	Newbold et al.1980	Maintain healthy benthic communities
	100	Castelle and Johnson 2000	Minimum for healthy benthic communities
	100	Erman et al. 1977	Maintain macroinvertebrate diversity
	> 100	May et al. 1997	B-IBI high in streams with > 70% upstream buffer intact
	100	Gregory et al. 1987	Macroinvertebrate diversity
	>100	May et al. 1997	Macroinvertebrate populations
Salmon Habitat	65-200	Knutson and Naef 1997	Salmonid production
	100-200	Castelle et al. 1992	Salmon production
Wildlife Habitat	33	Petersen et al. 1992	Minimum for wildlife species
	36-141	May 2000	
	25-984	Knutson and Naef 1997	
	75	Mudd 1975	Pheasant, quail and deer use
	100 – 165	Dickson 1989	Range of amphibian, reptile requirement
	100 – 300	Castelle et al. 1992	Range for most wildlife species
	100 – 310	Rudolph and Dickson 1990	Reptiles and amphibians
	100 – 330	Allen 1983	Beaver
	105	Groffman et al. 1990	Forested buffer for minimizing noise impacts to wildlife
	220 – 305	Jones et al. 1988	Small mammals
	246 - 656	Jones et al. 1988	Birds

Buffer widths of less than 33 feet (10 m) are generally considered functionally ineffective (Castelle et al. 1994). Fragmented and asymmetrical buffers need to be wider than continuous buffers to perform the natural functions (May 1998). Riparian vegetation in floodplains and along stream banks tends to mitigate the impacts of urbanization in adjacent areas (Finkenbine et al. 2000).

To summarize the riparian buffer effectiveness presented from the studies listed in Table 1, recommended buffer widths from three literature review and synthesis documents (Knutson and Naef 1997 and May 2003) are provided in Table 2. Recommended minimum buffer widths presented by May (2003) are presented also.

Table 2. Summary of Effective Riparian Buffer Widths

Author	Effective Width of Buffer (in feet)				
	Sediment Control	Pollutant Removal	Water Temperature	LWD Recruitment	Wildlife Habitat
Knutson and Naef (1997)	100 - 125	13 - 600	35 - 151	100 - 200	25 - 984
Wenger (1999)	82 - 328	30 - 197	33 - 98	49 - 427	220 - 574
May (2003)					
Range	26 - 600	13 - 860	36 - 141	33 - 328	36 - 984
Minimum recommended width	98	98	98	164	328

3.4.1.4. Impacts of Urban Development on Streams

Many studies have shown that development can have serious impacts on stream and riparian environments (Budd et al. 1987, Booth 1991, Booth and Jackson 1997, May 1998, Groffman et al. 2003). In 2003, the City reviewed impacts of the urban environment to aquatic habitats within the City in the Limiting Factors Data Gaps and Priority Actions for Aquatic Habitat document prepared by Seattle Public Utilities (Seattle 2003). Limiting factors identified are: altered hydrology, degraded water quality, loss of floodplains, loss of connectivity, limited coarse gravel, increased sedimentation, lost channel-shoreline complexity, and lack of riparian vegetation. The existing conditions of each of the City's streams and receiving water bodies are discussed in the City's limiting factors analysis (Seattle 2003). Changes in land use produce problems of reduced water quality and open space, along with a reduction in the quality of riparian zones through vegetation loss, soil erosion, increased stormwater runoff and reduced species diversity (May 1998, Booth and Jackson 1997, Booth 1991, Budd et al. 1987). Sediment, toxic wastes, erosion, fecal pollution, decreased dissolved oxygen, higher water temperatures, increased flows, and algae blooms all reduce water quality and seriously impact anadromous fish and other aquatic species (Budd et al. 1987). Because Seattle's streams, other than the Duwamish-Green River, are entirely within the highly developed urban area of Seattle and adjacent municipalities, they are affected by these changes throughout their length.

General Impacts

Urban land use appears to be an influential variable in predicting biological community metrics (species present, diversity, abundance, life stage functions, etc.) (Booth 1991, Booth and Jackson 1997, Mensing, et al. 1998, and May 1998). Mensing et al. (1998) showed that of the 13 highly correlated models, urban land use was used in the majority of the models to predict aquatic health.

Small streams in urban environments are highly altered by development upon most of the land within each watershed (Schueler and Holland 2003). Altered development in urban areas includes channelization, bank hardening, removal of riparian vegetation, placing streams in culverts and increasing the amount of impervious surface in the creek's watershed, which leads to altered hydrology. In Seattle, the majority of each stream's watershed has urban development.

Thornton Creek is one of Seattle's larger streams that provides a classic example of urban alteration of natural habitat. It is a third order stream primarily within Seattle's city limits that flows into Lake Washington. Thornton creek is 18 miles long and drains an area of 11 square miles. Lucchetti and Fuerstenburg (1993) analyzed the drainage network of Thornton Creek between 1893 and 1977. They concluded that urban development has caused the loss of all major wetlands and 60% of the open channel network, including all first-order tributaries in the Thornton Creek watershed. The remaining stream system was constrained by loss of riparian vegetation, stream bank armoring, and an extensive series of culverts and underground pipes. In recent years the City has supported several projects to restore Thornton creek including a Water Quality Channel in the Northgate neighborhood (SPU 2013a)), and the creation of Meadowbrook Pond to manage flooding and improve water quality by holding sediment (SPU 2013b).

Typical urban effects include increased overland flow and stormwater runoff volume, increased peak flows, decreased groundwater flow resulting in low summer flows, increased suspended particulates and sedimentation of fine particles, increased channel erosion and increased inputs of nutrients and toxic substances (Hession et al. 2000). In highly disturbed watersheds, additional improvements including stormwater and/or water quality management may be required before stream ecosystems can be successfully restored (Hession et al. 2000).

Modifications of the land surface during urbanization produce changes in the type and the magnitude of runoff processes (Booth and Jackson 1997). These changes result from vegetation clearing, soil compaction, ditching and draining and finally covering the land surface with impervious roofs and roads (Booth and Jackson 1997). The infiltration capacity of these covered areas is lowered to zero and much of the remaining soil-covered area is trampled to a near impervious state (Booth and Jackson 1997).

Besides changing the hydrologic flow regime, urbanization affects other elements of the drainage system (Booth and Jackson 1997). Gutters, drains and storm sewers are laid in the urbanized area to convey runoff rapidly to stream channels by-passing any infiltration that could occur in the riparian corridor (Booth and Jackson 1997). Natural channels are often straightened, deepened, or lined with concrete to make them hydraulically smoother increasing the flow of the water (Booth and Jackson 1997). Each of these changes increases the efficiency of the channel, transmitting the flood wave downstream faster (Booth and Jackson 1997).

Even if flow durations are matched precisely in pre- and post- developed cases, the change from a subsurface to a surface flow regime renders the entire design analysis irrelevant and can lead to severe, entirely unanticipated, channel incision (Booth 1990 as cited in Booth and Jackson 1997).

According to (Booth and Jackson 1997) many of the changes to the landscape imposed by urbanization are probably beyond our best efforts to fully correct them, and so some downstream loss of aquatic system function is most likely inevitable at the present level of understanding (as of 1997) . The need to develop a more precise, process based understanding of how altered landscapes produce degraded stream channels is needed so that genuine protection of streams can be achieved (Booth and Jackson 1997). Limiting the extent of development has been shown to be the only effective way to protect streams thus far (Booth and Jackson 1997).

The portions of natural ecosystems most directly affected by urbanization are small streams and associated wetlands (May 1998). These ecosystems are critical spawning and rearing habitat for several species of native salmonids (both resident and anadromous), including cutthroat trout, steelhead trout, and coho, chum, Chinook, pink and sockeye salmon (May 1998). Beginning in the late 1990s, spawner surveys in streams within the greater Seattle metropolitan area discovered that adult coho salmon returning to spawn in small urban catchments were behaving abnormally (Spromberg and Scholz 2011). Death occurred in a matter of hours, prior to spawning, in some instances up to 90% of the returning fish (McCarthy et al. 2008). This phenomenon has been called prespawn mortality, and has been linked to pollutant runoff from urbanized areas (Feist et al. 2011).

Over the past century, salmon have disappeared from about 40% of their historical range, and many of the remaining populations (especially in urbanizing areas) are severely depressed (Nehlsen et al. 1991 as cited in May 1998). There is no one reason for this decline. The cumulative effects of land-use practices, including timber harvesting, agriculture, and urbanization have all contributed significantly to this widely publicized "salmon crisis." (May 1998 and NRC 1996).

The cumulative effects of watershed urbanization including extensive changes in the hydrologic regime of the basin, changes in channel morphology, and changes in physiochemical water quality has produced an instream habitat that is significantly different from that in which salmonids and associated fauna have evolved (May 1998). Additionally, development has had negative impacts on riparian buffers and wetlands, which are essential to natural stream functions (May 1998). May (1998) studied third order and smaller streams, ranging in basin area from 3 to 90 km squared, with headwater elevations less than 150 m. In May’s (1998) study, stream gradients were less than 3.5% and most were less than 2%. One of May’s (1998) conclusion is that urbanization effects watershed drainage density.

Salmonid Habitat Impacts

Salmon spawn, rear, and migrate in streams within the City of Seattle. Each of these functions relies on different habitat characteristics (Waldichuk 1993). Spawning and egg incubation tends to require clean, well oxygenated, cool water within areas of clean gravel. Juvenile rearing requires variable conditions depending on the age/size of the juvenile. Juveniles tend to rear in shallow water where benthic insect production provides their food supply and riparian vegetation provides cover from predators. Movements by rearing and outmigrating juvenile salmonids or returning adult salmon require access and connectivity. This is affected by stream crossings and culverts, particularly those providing extended lengths of piping to pass through and/or altered conditions affecting the availability of suitable water velocities and depths for passage.

Spawning gravel is critical habitat for salmonid egg incubation and embryo development (May 1998, Waldichuk 1993) and can be greatly modified by urban development. Stream gravel also provides habitat for benthic macroinvertebrates (May 1998) that provide the prey for rearing juvenile salmon. Deposition of fine sediment and streambed instability due to increased stormwater flows affects the quality of the streambed and degrades the habitat condition by filling the interstitial spaces between the gravel and disturbing the gravel (May 1998). Although the redistribution of streambed substrate is a natural process, extreme stormflows often cause excessive scour and aggradations (May 1998) degrading salmon habitat. High stream flows can cause scour in spawning areas resulting in loss of salmon embryos (Nawa and Frissell 1993, DeVries 1997). However, salmon commonly bury their embryos sufficiently deep to avoid scour except under extreme flow conditions. Urbanization leads to drainage basin changes that result in an increase in number and magnitude of extreme flows that can increase redd scour. Erosion is related to stream power, which is proportional to discharge and slope (May 1998). Therefore, because flows tend to increase with urbanization, stream power is likely to increase as urbanization increases resulting in increased erosion. Cooper (1996) and May (1998) found this to be true for the Puget Sound lowland steams. Additionally, sheer stress is dependent on slope, flow velocity and streambed roughness and it is the critical basal stress that determines the onset of streambed particle motion and the magnitude of scour and/ or aggradation (May 1998).

May (1998) determined urban streams in the Puget Sound Lowlands with gradients greater than 2% and lacking LWD are more susceptible to scour than natural streams. The amount and distribution of LWD is another aspect of stream habitat that is altered by urban development. May (1998) found with increasing basin urbanization both the prevalence and quantity of LWD declined. Concurrently, measures of salmonid rearing habitat including percentage of pool area, pool size, and pool frequency were strongly linked to the quantity and quality of LWD in Puget Sound lowland streams (May 1998).

Streambank stability and erosion are factors influenced by the condition of the riparian vegetation (May 1998). High levels of erosion produce high levels of fine sediment in the substrate that clog spawning gravel and adversely affect production of invertebrates that provide salmon prey. Streambank stability rating is strongly related to the width of the riparian area and inversely related to the number of breaks in the riparian corridor (May 1998). Increased amounts of fine sediment are a characteristic of urban development that degrades streambed habitat (May 1998). In urban areas the levels of fine sediment (percent fines) can be related to upstream urban development, but the variability, even in undeveloped reaches, can be quite high (Wydzga 1997). May (1998) found fines did not exceed 15% until total impervious area (TIA) exceeded 20%. In the highly urbanized basins with TIA > 45% the fine sediment was consistently >20% except in higher gradient reaches, where the sediment was <20% and presumably flushed down stream by high storm flows.

While not completely responsible for the level of streambank erosion, basin urbanization and loss of riparian vegetation contribute to the instability of stream banks (May 1998). Stream bank stability is also affected by other stream corridor characteristics, such as soil type and hill slope gradient.

Urban development has eliminated the source of most LWD that forms the key pieces in wood jams. Thus, wood jams are now rare in Seattle's streams because of the lack of very large wood in riparian areas providing wood recruitment and key jam-forming pieces. Wood jams are now rare in many coastal streams because low recruitment rates and the lack of large wood that functions as key pieces in log jams (Collins et al. 2002).

Pool habitat that supports salmon is also commonly reduced by urbanization. Pool habitat provides holding areas during the spawning season. In all but the most pristine Puget Sound lowland streams (TIA<5%) significantly less than 50% of the stream habitat area is pool habitat (May 1998). Even in reference streams pool habitat is generally below the target level of 50% recommended (Peterson et al. 1992). This reduction in pool habitat appears to be due to the effects of past land-use practices that have removed timber and the lack of instream LWD (May 1998). The riparian cover over pools has also decreased in proportion to sub-basin development. As a result, instream habitat complexity in urban streams is substantially below that necessary to support a diverse and abundant salmonid community (May 1998). Riffle habitat is important for providing adequate spawning substrates and invertebrate production. Increase in sediment supply through stormwater runoff leads to a decrease in the quality of habitat in riffles because the sediment fills the interstitial spaces and fills in the pool habitat resulting in a decrease in quantity and quality of in stream habitat.

Prespawn mortality is emerging as a significant factor among salmon populations spawning in urban streams. As described above, pre-spawn mortality has been documented in the City's streams since the late 1990s . Numerous studies have been performed to determine the cause and future impacts of prespawn mortality including Feist et al. 2011, McCarthy 2008, and Spromberg and Scholz 2011. Toxic runoff has been identified as the leading cause. While most pollutants are present in urban surface waters at concentrations below those that will typically cause fish kills, coho spawners undergo important physiological changes as they transition from saltwater to freshwater. These changes may render them more vulnerable to toxic chemicals, alone or in combination with other environmental stressors (McCarthy 2008). Though the particular chemical, or cocktail of chemicals has yet to be identified, Feist et al. (2011) honed in specifically on toxics originating from motor vehicles as responsible. Although further research is ongoing, currently the outlook is grim: Spromberg and Scholz (2011) has modeled urbanization scenarios on coho populations that demonstrate the potential for local extinction in a few decades.

3.4.1.5. Strategies to Protect the Lotic Environment

Protection and restoration of natural functions for streams is closely tied to maintenance or restoration of riparian areas and natural channel forming processes. These processes require near natural flow regimes, natural channel structure that can erode and accrete, natural amounts of large woody debris, and sometimes reconstruction of natural features. As described above, maintaining riparian buffer widths of 50-100 feet or wider along most or all of a stream corridor is desirable to provide natural functions for fish and wildlife. Most of the scientific efforts to prescribe appropriate buffer conditions have focused on forested portions of watersheds (Castelle et al. 1994, Naiman et al. 2000, Roni et al. 2002, Collins et al. 2003) rather than urban areas. Formation of stream channels with natural habitat characteristics is provided by the interaction of hydrology, sediment, and vegetation (Montgomery and Buffington 1998). The recent literature emphasizes that aquatic habitat restoration strategies should be based on a landscape perspective. Ward and Tockner (2001) outline the broad concept of restoring biodiversity that encompasses spatial and temporal heterogeneity, functional processes and species diversity as themes for ecological restoration. They advocate re-establishing functional diversity across the active corridor to support aquatic and riparian biota. In an urban setting such as Seattle, it is recommended that habitat protection strategies (including habitat management and habitat enhancement) focus on a stream by stream perspective. At this scale, habitat conditions can be assessed and actions taken to provide functional processes and connectivity. Where opportunities are available, localized areas of higher function can provide “stepping stones” of suitable habitat to support species movement and material transfer through more constrained areas. Key elements of focus include riparian buffers, habitat connectivity (passage), and instream habitat structure to increase habitat diversity.

Strategies that restore or protect riparian corridors, even if the width is limited, along substantial reaches of Seattle’s urban streams will provide some of the desirable habitat forming functions. Booth et al. (2002) provides information on restoration of flow regime, habitat structure, water quality, energy sources, and biotic integrity for urban streams. They suggest restoration strategies begin by first analyzing causes of degradation and develop rehabilitation of selected elements where complete recovery is not feasible. They also suggest education and outreach is crucial for restoration strategies in highly developed watersheds such as the City of Seattle.

Control of stormwater discharge to prevent extreme flows that disrupt stream habitat can be accomplished to some degree within the urban environment. Booth et al. (2002) describes the impacts of urban effects resulting from stormwater discharges as well as the means to avoid extreme flows that disrupt stream habitat. However, most of these recommendations are for developing areas rather than previously developed areas such as the City of Seattle.

Recent publications on strategies for improving aquatic and riparian habitats of the streams within the City have been developed. Following is a list of resources, some as hyperlinks, others references to documents:

- City of Seattle.
  - *Restore Our Waters.* Website. http://www.seattle.gov/util/EnvironmentConservation/OurWatersheds/RestoreOurWaters/index.htm
  - *Seattle Watershed Projects.* An Interactive Map. http://www.seattle.gov/util/groups/public/@spu/@conservation/documents/webcontent/01_015334.pdf
  - *Shoreline Characterization Report.* (2010)
  - *State of The Waters*. Report (2007).
  - *Scientific Framework for Ecological Health*. Report. (2007)
- WRIA 8. *Chinook Salmon Conservation Plan*. Report. http://www.govlink.org/watersheds/8/planning/chinook-conservation-plan.aspx
- WRIA 9. *Salmon Habitat Plan. Report*. Chapter 7. http://www.govlink.org/watersheds/9/plan-implementation/HabitatPlan.aspx

These strategies will restore riparian habitat and stream processes gradually where opportunities are available. Hydrology, fish access, habitat connections, and floodplain reconnection are common priorities in these strategies.

There is a need to make strategy and restoration decisions that incorporate information gathering tools (e.g., monitoring over time) to deal with our incomplete understanding of ecosystem processes (Pess et al. 2003). Restoration strategies should recognize the major sources of uncertainty, inadequate knowledge, and natural variability. Strategies should deal with these substantial levels of uncertainty by using adaptive management (Anderson et al. 2003). That is, habitat management efforts can and should be adapted in the future based on new information on the performance of previous efforts, whether it is a specific restoration technique or more general management requirement.

In addition to the above measures to protect and restore urban streams, the City of Seattle has developed incentive programs for citizens, and industrial and commercial customers. Incentives include installing rain gardens, free trees, and rebates on water-efficient fixtures. Full details are online at: http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/GreenStormwaterInfrastructure/IncentivesOpportunities/index.htm. The RainWise incentive program, which is for customers in targeted combined sere overflow basins, has created a map of all of the recorded water-saving projects: https://rainwise.seattle.gov/city/seattle/map.

3.4.2. Lakes (Lentic Systems)

Lake Washington and Lake Union provide habitat supporting anadromous salmonids and numerous resident species. Although the shorelines of these and other lakes within the city are highly modified by shoreline development, it is important to consider the characteristics of such lakes in their natural condition to understand the nature of the habitat in which the native populations developed. Little recent literature has dealt with the history of these lentic habitats, although substantial research has been conducted in recent years to provide information on Chinook rearing and migration in the Lake Washington watershed. Seattle Public Utilities and USACE published a synthesis of this work in 2008 (SPU and USACE 2008).

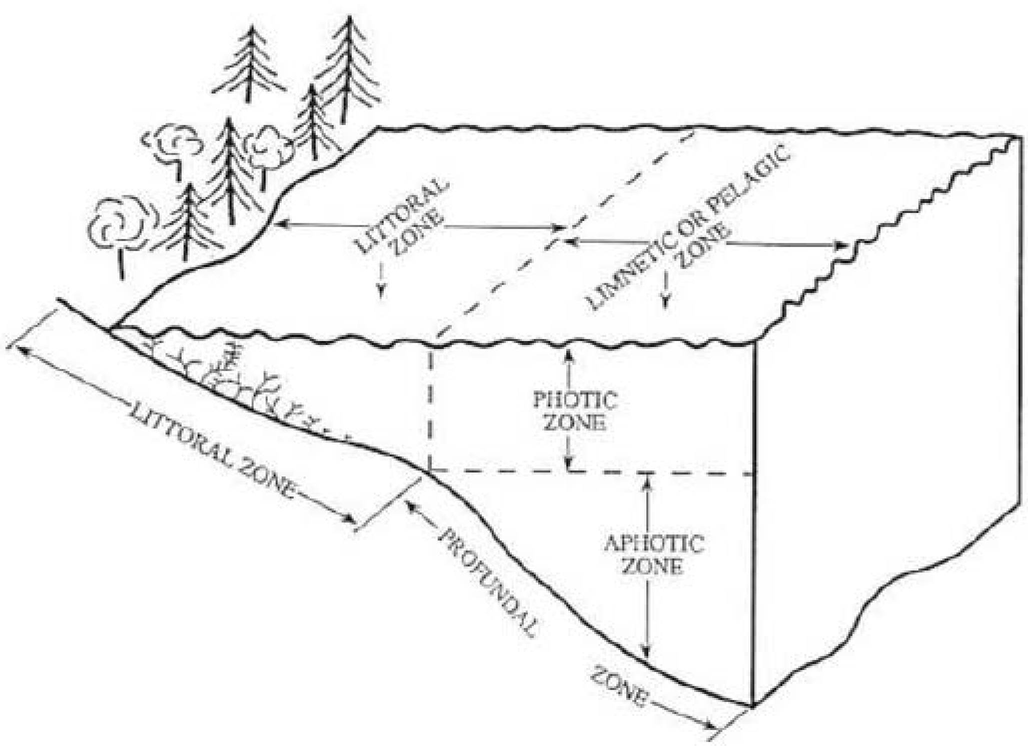
3.4.2.1 Physical Structure of Lakes

Because lakes have hydraulic conditions that tend to retain whatever enters the body of water, hydraulic retention time is an important physical characteristic and influences the quality of both the water and habitat. Hydraulic retention time is the term used to describe the amount of time that it takes for all water in the lake to pass through the outflow (Goldman and Horne 1983). This is an important parameter in determining the impacts of pollution and nutrient dynamics.

Lakes are divided into zones, which consist of the littoral, limnetic/pelagic, photic, and aphotic, zones (Seattle DPD 2010b, Figure 1). The littoral zone extends from the shore to a depth where the light is barely sufficient for rooted aquatic plants to grow. The pelagic zone continues offshore from the outer reaches of the littoral zone. The pelagic zone of a lake is open water, without contact with the lake bottom or shore (Horne and Goldman 1994 as cited in Seattle DPD 2010b). The organisms inhabiting this area are adapted to swimming, suspension, or floating. Large and small woody debris along the littoral area increases the amount, diversity and quality of cover for resting, foraging, and predator avoidance.

The photic zone extends as far down as light can penetrate; the aphotic zone extends to the bottom of the lake where light levels are too low for photosynthesis. Respiration, however, proceeds at all depths, so that the aphotic zone is a region of oxygen consumption and can become anaerobic because of this. The profundal zone refers to the lake bottom underlying the pelagic zone. Many shallow lakes with relatively transparent water have no profundal zones..

Figure 1 – Lake Structure Zones. Source: Seattle DPD 2010.



Biological Structures of Lakes

The aquatic species that inhabit the different zones of the lake are specifically adapted to the zones in which they live. Some species such as pelagic (free swimming) fish are able to move between the different zones. Different types of plant species are adapted to grow in different water depths; therefore, the species of plants that are found at the water's edge would not be found at the water depths of 0.6 m and 0.9 m (2 feet and 3 feet).

Juvenile Chinook rearing in Lake Washington tend to remain in very shallow water (<3 feet deep) gradually moving into deeper water as they grow (Tabor and Piaskowski 2002, Tabor et al. 2004, Seattle Public Utilities and USACE 2008). The Chinook fry and fingerlings tend to rear in sandy gravel beach areas with gentle slopes and no bulkhead below ordinary high water. Tributary creek mouths were also more utilized than index sites in Lake Washington pointing to the potential importance of these areas (Tabor et al. 2004). Chinook fry and fingerlings appear to rest near the bottom at night and move within a small area during the daylight hours. The young salmon move into small woody debris (tree branches, brush) when threatened by piscivorous bird or fish predators. The young salmon tend to avoid overwater structures and the shade cast by the structures. They appear to treat Eurasian milfoil beds as a substrate moving along the edge or above this vegetation. Juvenile Chinook also use tributary creek mouths as rearing areas.

Lake Washington shorelines also support beach spawning by sockeye salmon (Seattle Public Utilities and USACE 2008). Many sockeye also spawn in the mainstem Cedar River as well as its side channels (Hall and Wissmar). Juvenile sockeye rear for a year or more in the open waters of Lake Washington before migrating to the ocean through the Hiram M. Chittenden Locks (Burgner 1991, Ballantyne et al. 2003).

Young Chinook migrate from Lake Washington to Puget Sound through the Ship Canal and Lake Union. Research by the U.S Fish and Wildlife Service (Tabor and Piaskowski 2002, Tabor et al. 2004) has shown that juvenile Chinook migrate and rear along the Lake Washington shoreline in very shallow water, and utilize deeper habitats in Lake Union and the Ship Canal (Celedonia et al. 2008, Celedonia et al. 2011) as they pass through these areas.

Celedonia et al. (2011) describes Chinook utilization of these areas as following: "Chinook salmon smolt habitat use is markedly different between Lake Washington and the LWSC (Ship Canal). In Lake Washington fish stay close to shore during the day (1-5 m water column depth), and move into deeper water at night (> 10 m water column depth; up to 230 m and more from shore). In the Ship Canal (Portage Bay and north Lake Union) smolts fan out across broad areas, mix across the channel during all times of day and night, and primarily use water greater than 8-10 m deep. Water clarity generally appears greater in Lake Washington than in the LWSC during June, and this may be the primary driver behind the differences observed."

Some young Chinook may enter the Ship Canal and Lake Union early in the spring to rear along the shorelines as they do in Lake Washington. Sampling of salmon predators in Lake Union found juvenile Chinook salmon were eaten as prey in the southern portion of Lake Union (Tabor et al. 2004). Data is still very limited, but migrating juveniles appear to follow the shoreline as they apparently do in Lake Washington. They may also move across open water rather than migrating along a narrow path through the Ship Canal.

The timing of smolt migration through the Chittenden locks has been evaluated since 1997 (see Seattle Public Utilities and USACE 2008). In 1997, Chinook smolts were present throughout the sampling period, from mid-May to early June, but peak migration occurred during late May (Goetz et al. 1998). In 1998, peak migration occurred in early June, but sampling terminated during the highest Chinook catch of the season (Johnson et al. 1999). Although peak emigration appears to be in June, juvenile Chinook are present in the system through at least July (Kurt Fresh, WDFW, personal communication). Timing of Chinook migration is later than that of sockeye salmon, the most abundant salmonid migrating through the locks. Comparison of migration timing at the locks and in Cedar River suggests some of the juvenile Chinook may spend as much as 4-6 months rearing in Lake Washington, leaving the system with the later migrants from the Cedar River (Tabor et al. 2004).

3.4.2.2. Riparian Area Functions

The riparian area surrounding lakes provides similar functions to those provided for streams, although a much smaller portion of the water body is affected in lakes, particularly large lakes such as Lake Washington. Vegetation provides some shading and stormwater benefits and LWD at the shoreline serves to dampen erosive wave energy, caused by wind and fetch, along lake shorelines (Maser et al. 1988). Additionally, the allochthonous input from the vegetation contributes organic matter, including invertebrates, into the lake system.

The riparian buffer along lake shorelines can be particularly important to species that reside primarily in very shallow water such as Chinook and coho salmon fry. These very small fish (30-50 mm) seek water less than 1 m deep often with some natural brush or tree cover extending into the water (Tabor and Piaskowski 2002, Tabor et al. 2004). Trees, shrubs and grasses of shorelines provide potential cover for young salmonids rearing along lake shorelines (Tabor and Piaskowski 2002, Tabor et al. 2004). Trees falling into the shoreline water provide refuge habitat for the rearing salmonids. And terrestrial vegetation provides a food source in the form of terrestrial insects that drop into the water (Johnson and Ryba 1992, Constanz 1998, Kahler 2001, Koehler 2002). Juvenile fish are most often observed over sand-gravel substrates (Tabor et al. 2004).

3.4.2.3. Impacts of Urban Development on Lake Washington/Lake Union

Seattle's Lake Washington and Lake Union shorelines are currently highly altered habitat (Weitkamp and Ruggerone 2000). In 1916 a major alteration of the shorelines occurred with the lowering of the lake level by 9 feet resulting from construction of the Ship Canal and Locks (Chrzastowski 1981). Historically Lake Washington drained to the south through the Black River to the Duwamish River and to Puget Sound. Construction of the Ship Canal moved the lake’s outlet to Shilshole Bay. Seasonal shoreline flooding in Lake Washington was eliminated, along with approximately 1,300 acres of shoreline wetlands. In 1912, the Cedar River was diverted into the lake and currently comprises over half the inflow to the lake. These changes moved the migratory corridor for Cedar River Chinook from the Duwamish River to Lake Washington. The Cedar River is now the major tributary contributing flow to Lake Washington. Under existing conditions, the Lake flushes at a rate of approximately 0.43 times per year (Weitkamp and Ruggerone 2000).

The recent survey of the City's shorelines (Parametrix and NRC 1999) demonstrates a high degree of development that has eliminated or altered most shallow water shoreline habitat. The shoreline development has substantially altered rearing habitat for juvenile Chinook and other salmon. The Lake Washington shoreline is primarily bordered by private residences having landscaped yards, and several over-water condominiums. Whereas Lake Union and the Ship Canal shorelines are primarily developed with industrial, commercial, and floating home uses. The City's parks provide the only substantial exception to this highly modified shoreline condition. Park shorelines are relatively natural, although light riprap is typically present. City parks bordering Lake Washington and Lake Union include Seward Park together with Lake Washington Boulevard, as well as Leschi, Madison, Magnuson, Matthews Beach, Gas Works and South Lake Union Parks. City park ownership accounts for approximately 35% of shoreline use. Sand Point, Seward Park, Union Bay and the Arboretum provide substantial expanses of shallow water habitat in relatively natural condition.

Generally shoreline development results in less large woody debris (coarse woody debris) and macrophyte densities along a lake’s shoreline in the littoral fringe zone (Brown 1998). This decrease in woody debris apparently results in decreased forage fish densities as has been found in Lake Joseph, Ontario.

Shoreline development has eliminated most of the natural riparian vegetation that previously occurred along Lake Washington and Lake Union shorelines. Human development of lake shorelines commonly leads to loss of LWD (Christensen et al. 1996). This LWD provides littoral habitat for many aquatic organisms, including young salmon. The mature trees that historically occurred are now present at only a few locations such as Seward Park. Even most of the City's parks have managed vegetation that includes little natural vegetation near the shorelines. Most residences have little vegetation that provides any of the functions of natural riparian vegetation.

Bulkheads and other forms of shoreline armoring or retention are present along most of the Lake Washington shoreline within the city limits (Parametrix and NRC 1999). In many cases, installation of bulkheads has produced vertical or steep-sloped faces next to relatively deep water (4-6 feet). (Parametrix and NRC 1999). Thus, the natural sand-gravel beaches that provide refuge for young salmon from larger fish are lacking along these shorelines.

There are numerous docks associated with single-family residences and several small marinas along Lake Washington. The littoral area adjacent to the city has more than approximately 750 residential docks that extend out 30-100 feet from the shoreline. Docks within the city limits cover an estimated 4% of the lake surface area within 100 feet of the shoreline (Parametrix and NRC 1999). Boats moored at these docks shade additional water surface area.

The numerous docks, piers and bulkheads have significantly altered the lake's shoreline and littoral habitat. The primary concern regarding these shoreline structures is their potential to increase preferred habitat for predators while reducing shallow water refuge, thus potentially resulting in increased predation on Chinook and other salmon that occupy littoral habitat. Available data indicate that largemouth and smallmouth bass may be attracted to large structures, such as pilings and riprap, for reproductive purposes during spring (Stein 1970, Pflug 1981, Pflug and Pauley 1984, Ruggerone and Harvey 1995). They are known to consume salmon migrating along the shoreline of Lake Washington, although greatest predation rates have been observed in the Ship Canal (Fayram 1996, Warner and Footen 1999, Fayram and Sibley 2000). Northern pikeminnows appear to be attracted to cover provided by docks in Lake Sammamish (D. Pflug, City of Seattle, personal communication), but a study in Lake Washington did not find pikeminnows to be more abundant near docks (White 1975). However, data on juvenile Chinook use of the shorelines and the relationship among shoreline structures, Chinook use and predators' populations is very limited. Concern remains high because predation is considered a significant factor affecting Chinook populations (as described later in this chapter). Additional studies are needed and are planned to address this issue.

Docks and piers inhibit light penetration into the water column and may decrease algae (phytoplankton and periphyton) growth and secondary production of zooplankton and insects in relatively small, localized areas. However, food production in Lake Washington currently appears to be adequate, given the apparently significantly growth rate of juvenile Chinook and other salmon in the lake. White(1975) did not detect reduced production of chironomids, a key prey of juvenile Chinook, under docks in Lake Washington compared to adjacent areas.

Additionally, docks and piers may affect juvenile salmonid migration behavior. Some juvenile salmonids were observed moving out into deeper water before passing under a pier or avoiding the pier by following the edge of the pier around into deeper water and then returning to the littoral area (Tabor pers. comm.).

Other concerns regarding docks and piers include their potential effect on water circulation in the nearshore and whether they promote sedimentation of gravel. Sedimentation of gravel areas, which is also influenced by exotic plant production, is a primary concern for sockeye salmon, which spawn along some shoreline areas outside the city. Sedimentation may influence habitat structure (cobble reduced to sand) and prey composition and production. Finally, concerns have been raised regarding the potential toxic effects of creosote pilings (see Poston 2001). Use of creosote and other treated wood pile has been restricted in freshwater environments for a number of years, so concerns about potential effects will be decreasing over time as use of concrete piles or other options are required for new and replacement docks. However, more recent studies have indicated low levels of PAHs can impact salmonid egg survival.

Predation of resident fishes on juvenile Chinook rearing and migrating through Lake Washington has been a concern addressed by recent research. Moss (2001) used a bioenergetics model to estimate 5-26% of the Chinook juveniles and 11-59% of sockeye juveniles in Lake Washington may be eaten by prickly sculpins. Weitkamp and Ruggerone (2000) identified predation as a substantial factor in juvenile salmon survival in Lake Washington based on a review of available literature. Tabor et al. (2007) found that bass consumption of juvenile Chinook salmon was low in the south end of Lake Washington, but that a substantial portion of bass diets in the Ship Canal were comprised of juvenile salmonids. There tended to be more predation by bass in the eastern portion of the Ship Canal than the western portion of Lake Union and the Fremont Cut. Nevertheless, due to consumption rates the predation was considered to have only a minor impact to the overall Chinook population in the system.

Devries et al. (2004) found that some sub-yearling sockeye salmon were eaten by bass in the Ship Canal. Tabor et al. (2007) also documented bass consumption of yearling sockeye and coho salmon, although in lower numbers than Devries et al. (2004) reported for sub-yearling sockeye. Tabor (2004) reported that northern pikeminnow (*Ptychocheilus oregonensis*) are another major predator of salmon with 45% of their diets comprised of juvenile salmon.

The anthropogenic disturbances that are prevalent in Seattle such as eutrophication, habitat modification, and introduction of exotic species can severely alter habitat connections and the fundamental flows of nutrients and energy in lake ecosystems (Schindler and Scheuerell 2002). Thus, the altered state of the basic ecosystem must be considered in both evaluation and restoration of lake systems such as Lake Washington.

Young salmon migrating out of Lake Washington must pass through the Hiram M. Chittenden Locks. These juveniles either pass over the spillway, through smolt passage flumes, or through the Locks (Johnson et al. 2003). Fish passing through the Locks have been observed to suffer substantial mortalities. Johnson et al. (2003) found the fish passage flumes are effective in bypassing juvenile salmon to avoid injury and mortality in Locks passage. Recent tracking of migrants with ultrasonic telemetry showed fish spent 5 to 22 hours in the immediate vicinity of the Locks prior to downstream passage (Johnson 2004).

The Army Corps of Engineers has recently developed a computational model addressing the movements of water and adult salmon at the Locks (Goetz 2004). Adults have been found to hold for up to 47 days immediately upstream from the Locks. Model results show fish holding at an interface of cool seawater and warm freshwater near the Locks' saltwater drain.

3.4.2.4. Strategies to Protect the Lentic Environment (including the Ship Canal)

Protection and restoration of natural functions and habitats for lakes is tied to maintenance or restoration of riparian areas, increasing the amount of natural shoreline and decreasing the amount of predation that occurs on salmonid populations. As described above, the riparian area of lakes provides similar functions as in the stream systems; therefore, buffers protect the water quality, decrease the amount of sediment input to the lake and increase the amount of terrestrial insects and other detritus into the lake to feed the food web.

Strategies that restore or protect riparian areas along the lakes and ship canal, even if the width is limited, along substantial reaches of Seattle's urban lake systems will provide some of the desirable habitat forming functions. Similar to the strategies listed in the stream section, first analyzing causes of degradation and then developing rehabilitation of selected elements where complete recovery is not feasible is recommended. Education and outreach is crucial for restoration strategies in highly developed watersheds such as the City of Seattle.

The City of Seattle has developed and published strategies for improving aquatic and riparian habitats of the shorelines within the City (Seattle 2003, Appendix A). These strategies include restoring riparian habitat and increasing the complexity of the shoreline environment through removal of bulkheads and restoring sandy shallow water habitat, where opportunities are available. In 2010, the City of Seattle also published a document focusing on bulkhead alternatives for Lake Washington (Seattle DPD 2010a). Reduction of shoreline armoring is essential for the long-term maintenance of the lakeshore environment and for increasing rearing and refuge areas for juvenile salmonids. With the majority of the shoreline currently altered by hardening, a reduction of shallow water habitat and loss of riparian areas have been the long-term effects. Tributary creek mouths should also be reconnected to restore juvenile salmonid rearing areas.

Limiting the amount of new over-water structures is desirable to prevent further degradation of the lakeshore environment. During redevelopment, existing overwater and in-water structures that currently shade the littoral areas of the lake and potentially attract predators should be replaced with structures designed to minimize impacts on juvenile salmon migration, rearing and survival.

Additionally, the amount of pollution and contaminants caused from chemical lawn care and stormwater runoff from industrial, commercial and street use should be reduced.

3.4.3. Estuaries

3.4.3.1. Physical Structures of Estuaries

Estuaries are aquatic areas where rivers and streams meet the marine environment. Estuaries are defined as semi-enclosed bodies of seawater measurably diluted with fresh water (Hobbie 2000). Estuaries form the transition from the freshwater bodies to the marine habitats. Estuaries can extend over several miles and provide a variety of habitats along a salinity gradient from freshwater to salt water. In natural settings, the estuaries associated with larger freshwater inputs (i.e., rivers) tend to be larger than the estuaries associated with smaller freshwater inputs (i.e., streams). The dominant features of estuaries are that they have variable salinity and a salt wedge or interface between salt and fresh water where the heavier salt water is deeper than the lighter freshwater. Natural or undisturbed estuaries also have large areas of shallow, turbid water overlying mud flats or salt marshes.

Annually, 6.5 million tons of sediment is carried from freshwater systems into estuaries and Puget Sound. This sediment is derived from the weathering and erosion of bedrock and soil in basins from rain and snow. The discharge and slope of the river define the quantity and size of sediment transported into the Sound. For example, mountainous rivers can transport large, coarse particles while slower moving waters tend to hold finer sediments. These fine particles travel into Puget Lowland and into Puget Sound where they redistribute due to tidal and wind current interactions throughout the bay and inlets (Czuba et al. 2011).

In marine nearshore and estuarine environments, woody debris diffuses the energy of tides and waves, thereby modifying on-shore sediment transport and helps to produce habitats ranging from muddy bays to gravel or bedrock beaches. The trapping of sediment from the woody debris can promote vegetation growth (Maser et al. 1988). Additionally, where water energy is very low, woody debris increases the amount, diversity and quality of cover for resting, foraging, and predator avoidance.

3.4.3.2. Biological Structures of Estuaries

Estuaries are biologically complex habitats because of both their variable salinity and high productivity conditions. Estuaries are more complex and numerous than any other type of marine environment (Jay et al. 2000). The complex array of estuarine biota ranges from species adapted to fresh water with slight tolerance of high salinity to species adapted to high salinities and little tolerance for fresh water. The diversity of biota found in estuaries is such that there is an abundance of fewer species; therefore, the diversity of species is less than either marine or freshwater systems.

Despite being physically challenging environments requiring special adaptations by the species occupying the habitats, estuaries tend to be highly productive areas. Estuaries are important nursery areas for many fish species. Estuaries are important to anadromous fish because they provide a highly productive rearing habitat where young salmon grow rapidly prior to entering marine waters and undergo their physiological transition from fresh water to saltwater. The growth young salmon undergo during their estuarine residence is important to their survival as the young fish enter the marine environment where increased size helps them avoid predation (Reimers 1973, Levings et al. 1986). Cordell et al. (2001) found juvenile Chinook and chum salmon consumed a large variety of prey among sites across time, as have previous investigations in many estuaries. At different sites and times in the Duwamish they found prey were dominated by planktonic crustaceans, harpacticoid copepods and amphipods, benthic insect larvae and worms, or terrestrially derived insects. They determined intertidal habitat restoration within the Duwamish River estuary to be ecologically important. Estuaries are also important for marine fish because they provide a highly productive rearing habitat where the young fish grow rapidly.

Marsh vegetation is an important component of the estuarine environment that enhances primary production, accumulation of organic material, and enhances sediment deposition (Reed 2000) Vegetative areas promote healthier water quality, shade and control microclimates, provide fish and wildlife habitat, contribute detritus and nutrients, and create an input source for LWD. Through their root networks, marsh vegetation can affect the impact of sediment in a riparian area by limiting fine sediment movement as well as changing hydrology and slope stability. Brennan et al. 2009). Sediment is a physical-chemical aspect of the estuarine environment that has a substantial effect on the biological structure of the estuaries. The ecological role of sediment contaminants has been extensively discussed in recent literature (Arkoosh et al. 1998). Contaminants and nutrients that adsorb to fine sediments can affect water quality, nearshore and offshore habitats, and aquatic-ecosystem health. These contaminated sediment particles often reach Puget Sound and bioaccumulate in fish and shellfish tissue. Species effected by the bioaccumulation of contaminated material can be toxic for human consumption as well as predators such as marine mammals, birds and other fish species (Czuba 2011).

3.4.3.3. Biological Structure of the Riparian Area

The function of riparian areas in the estuarine environment is that the overhanging vegetation in the riparian area provides cover and shade for aquatic species as well as a source of food in the form of terrestrial insects. However, estuaries are commonly very broad areas with most of the habitat a considerable distance from the riparian zone. Another function of riparian areas is that they provide stormwater management by filtering overland runoff that would enter the estuary directly. Water quality is not generally a concern in estuaries due to flow through the riparian areas since most of the water, nutrient input, and contaminant sources come from other sources, both upstream and downstream (due to tidal action).

Estuaries are coastal areas where juvenile fish including anadromous fish, rear. The functions of the riparian zone in the estuarine environment have not been well studied however several conclusions can be drawn based on this limited work. Juvenile salmonids are known to eat terrestrial insects in estuaries; therefore, the riparian zone contributes food to the estuarine environment (Brennan et al. 2004). Additionally, the shallow water near the shoreline of estuaries functions as refuge habitat from predators. The overhanging vegetation provided by riparian vegetation can increase cover or refuge for aquatic species, thus protecting these species from avian predators. LWD that falls into the riparian areas also provides refuge and contributes to habitat forming processes within the estuarine environment as mentioned above.

3.4.3.4. Impacts of Urban Development on Estuaries

Estuaries have tended to be the location where large port cities develop. This development affects the biota of the estuaries through dredging activities and industrial or domestic pollution. The Duwamish River estuary is no different. The Duwamish River estuary is the principal estuary within the City of Seattle and is a highly altered estuary resulting from dredging, filling and channelization over the last 125 years. The Duwamish River is the lower 11-mile long estuarine portion of the Green-Duwamish River System from Tukwila to Puget Sound. The dredged navigation channel commonly referred to as the Duwamish Waterway extends from Elliott Bay to river mile (RM) 6. It is tidally influenced, including saltwater intrusion upstream from the navigation channel. Surface salinities may be reduced to 5% or less by the freshwater discharge of the river while bottom salinities tend to be substantially higher (20-30%), but vary depending on tide stage and river discharge (Dawson and Tilley 1972).

Habitat conditions along most of the lower Duwamish River are highly influenced by the previous dredging and filling from Turning Basin 3 at RM 6 to Harbor Island. The navigation channel is U shaped with a bottom depth at 56 feet mean lower low water (MLLW) at the mouth and a depth of 10 feet (MLLW) near Turning Basin 3 (Weston 1993). Remnants of natural intertidal habitat occur on the northern portion of Kellogg Island and in occasional patches throughout the Duwamish Waterway. Currently there is a straightened river channel with the majority of shoreline composed of riprap, pier aprons, and/or sheet piling (Tanner 1991). The shoreline armoring is usually present at the top of the intertidal zone, but areas of sloping mud and sandflats can exist below, producing narrow intertidal mud flats at about -2 to +4 feet MLLW and extending to steep middle and upper intertidal shorelines (Battelle et al. 2001). The channel profile characteristics, straight shorelines, absence of off channel habitat, and steep hardened upper intertidal areas provide little refugia for young salmonids and limited habitat for estuarine fishes.

The estuary from the Lake Washington watershed is also significantly modified and degraded. As noted previously, the plumbing of the entire system was reworked at the start of the 20th century to make the system flow out through the Lake Washington Ship Canal and Locks. The Locks are positioned at the outlet of the freshwater system and provide a particularly abrupt transition from fresh to saltwater. The estuary from the Locks out to Salmon Bay is almost entirely lined by bulkheads and shoreline armoring with several overwater structures. The area provides limited shallow water habitat. There are pockets of shoreline with adjacent riparian vegetation and restored shoreline habitat.

Additionally, the above mentioned shoreline modifications have limited native vegetation to small pockets scattered along the shoreline and has resulted in isolating the intertidal flats from inputs of sediment, nutrients, and organic matter (i.e., woody debris) from upland riparian vegetation zones. This isolation degrades the habitat quality of these flats (Battelle et al. 2001). The overwater structures shade shallow and intertidal habitats, alter microclimates, and inhibit growth of plant communities, further degrading nearshore habitats for native fauna (Battelle et al. 2001).

The loss of estuarine habitat from draining and filling has resulted in the loss of rearing area for juvenile aquatic species; this in turn, substantially alters the food base of the estuarine communities. The loss of tidal swamps, tidal marshes, and tidal flats reduces production of emergent vegetation and benthic algal production. Additionally, the placement of anthropogenic structures (rock jetties and pile dikes) together with draining and filling of the estuaries to improve navigation reduces the tidal prism (salt wedge), simplifies the complex network of tidal channels, and focuses the flow into these navigation channels. These changes along with alterations in sediment and water transport characteristics resulting from upstream impoundments and water uses, have had a profound effect on benthic invertebrates that contribute substantially to the biological productivity of estuaries.

The effects of losing estuarine habitat can ripple across many habitat features. Water quality of stormwater can diminish due to less infiltration and corresponding reduction of runoff, as well as less ability to intercept nutrients, fine sediments and pollutants. Reduction of habitat limits the ability to bind dissolved pollutants with soil particles and convert contaminants into less harmful forms (Brennan et al. 2009) Vegetative communities within riparian areas provide this erosion control, which has been linked to the presence and density of trees and shrubs as well as herbaceous species with deep roots. These vegetative areas protect from the main causes of sediment erosion: high flow scour, wind and intercepting runoff (Anchor QEA 2013).

In recent years, several habitat restoration projects have constructed new salt marsh habitat within the Duwamish estuary (Armbrust et al. 2008, Port of Seattle 2009). These areas together with the substantial middle intertidal flats along the dredged river channel provide foraging habitat for young Chinook and other salmonids. Three Pacific salmon species inhabit the Duwamish-Green River basin in substantial numbers: Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and chum (*O. keta*) salmon.

3.4.3.5. Strategies to Protect the Estuarine Environment

The potential for habitat restoration in the Duwamish River estuary was reviewed by Tanner (1991). This review identified potential sites and techniques that could be employed in a strategy for habitat restoration in Seattle's major estuary. In 2009, the Port of Seattle prepared a restoration plan for restoration and protection in the Duwamish River estuary. The plan focused on properties owned by the Port of Seattle, but identifies several potential restoration sites.

Simenstad (2000) identifies guiding concepts for restoration of estuarine habitat to support juvenile salmon. The concepts rely on restoration of the landscape structure of the land margin used by juvenile salmon to restore habitat patches along a corridor connecting freshwater and marine environments. Restoration strategies should develop means to satisfy the refugia, feeding and physiological requirements of young salmon. The strategies should take advantage of existing geomorphic structure of the landscape, build on fundamental estuarine processes, and provide opportunities to support diverse life history patterns.

In heavily urbanized environments, limited opportunities for restoration often result in less than optimum restoration of habitat functions (Simenstad et al. 2004). These limitations tend to be directly related to the size, location, and design options possible at urban sites available for restoration. Nevertheless, strategic restoration in urban estuaries can provide: 1) proportionally high function for their size, 2) remove passage barriers for fish and wildlife, 3) provide public exposure and appreciation for the value of restoration and protection, and 4) enhance the quality of the urban landscape (Simenstad et al. 2004).

Given the highly urbanized condition of the Duwamish estuary and Salmon Bay, there are limited opportunities for major restoration. Instead, as noted by Simenstad et al. (2004), at smaller sites that provide the potential to provide proportionally high function for their size may be most realistic. In addition, re-establishment of riparian buffers, improvement of shallow water habitats, and the minimization of shoreline modifications should be pursued in these areas.

3.4.4. Nearshore Environment

The following information relies heavily on Seattle's Urban Blueprint for Habitat Protection and Restoration (December 2003, City of Seattle).

The city of Seattle's marine nearshore area extends from North 145th Street south to Brace Point in West Seattle and includes approximately 30 miles of Puget Sound shoreline. The nearshore environment in the city of Seattle includes areas within both WRIA 8 and WRIA 9. The nearshore environment in Puget Sound possesses an extremely productive and dynamic ecosystem. Tides, currents, wave action, and intermixing of salt with freshwater create a complex physical environment situated at the juncture between land and water. The marine nearshore environment encompasses the area from upland bluffs, banks, and beaches, the lower limit of the photic (light penetration) zone, which varies with season and climatic conditions. Some define the lower limit of the photic zone at approximately 30 m or 100 feet below the Mean Lower Low Water (MLLW) line. The nearshore area includes a wide variety of upland, marine, and estuary habitats including marine riparian areas, backshore areas, beaches, tidal marshes, tidal flats, eelgrass meadows, kelp forests, and exposed habitats. Terrestrial habitats along the shoreline such as bluffs, sand spits, and coastal wetlands are also included within the nearshore environment as well as the tidally influenced region found within the lower sections of mainstem rivers and coastal streams.

3.4.4.1. Physical Structure Nearshore

The habitat forming processes that produce the natural characteristics of intertidal and shallow subtidal nearshore areas of Seattle are important because of the dynamic nature of this habitat. The physical structure changes gradually over time due to wave and current forces, and rapidly at times due to the effects of storm events.

The nearshore environment of Seattle has two basic components, the semi-protected shorelines of Elliott Bay and the exposed open shorelines north and south of Elliott Bay. These two habitat types differ primarily in their exposure to wind/wave energy and the amount of shoreline modification resulting from human actions. Most of Elliott Bay has been modified by filling and construction of shoreline structures (seawall, bulkheads, piers, breakwaters, etc.). From the Duwamish Head on the southern side, to West Point on the north, only a small amount of shoreline retains natural characteristics (substrate, slope, exposure). Most of the gently sloping, sand-gravel beaches with riparian vegetation have been converted to steep hardened shorelines with no riparian vegetation. The existing condition of the nearshore ecosystem in Seattle and the remainder of King County was assessed by Starkes (2001). Anchor (2004) inventoried shoreline modifications along the marine nearshore shoreline of Seattle. Battelle (2001) concluded Puget Sound's nearshore ecosystem provides critical support to a wide variety of biological resources. Battelle determined the effect of human-caused changes and natural variability on nearshore physical processes and resources has not been adequately studied. In the nearshore environment, they concluded the essential habitat-forming and fundamental processes have been severely damaged throughout the Seattle area by shoreline modifications.

Seattle's open exposed shorelines along Puget Sound tend to retain relatively natural characteristics at middle and lower intertidal elevations. Along much of these shorelines the upper intertidal and riparian areas have been highly modified by development. South of Elliott Bay bulkheads, single-family residences, and commercial developments border the shoreline. Riparian vegetation, where present, is limited to landscape plantings, or a few small natural areas such as Lincoln Park. North of Elliott Bay the shoreline is in a relatively natural condition around West Point and the sewage treatment plant/Discovery Park location. North of the entrance of the Ship Canal commercial development, single family residences, and Shilshole Marina modify more than a mile of shoreline. Following the relatively natural shoreline of Golden Gardens Park the shoreline is again modified by the railroad track that has filled the upper intertidal zone extending far north of the City limit.

The morphology of Puget Sound's shoreline is dependent upon exposure to wave energy and windstorms as well as the sediment composition of beaches and bluffs. A large portion of Puget Sound's beach morphology is created through high-energy events such as large storms which increase water interactions with beach, backshore and bluff sediments. Large storms can lead to substantial erosion along the shoreline, further increasing the available beach sediment and moving cobble-sized material. Natural erosion of coastal bluffs allows for the establishment and replenishment of beaches and spits which is critical for shoreline habitat formation. Erosion creates substrate for riparian vegetation which in turn provides LWD and organic material to the shoreline. Beaches support vegetation such as eelgrass beds that provide habitat for migratory species, forage fish and shellfish. Beaches and bluffs also provide feeding, roosting and nesting areas for shorebirds (Johannessen and MacLennan 2007).

The morphology of Puget Sound beaches differ from other beaches in the country by a lack of apparent seasonal change in the beach profile. Although some regions may experience "winter beaches", a phenomenon where the elevation is lowered from high-energy storms, Puget Sound beaches are characterized by consistent, periodic large windstorms throughout the year. These events overshadow the "winter beach effect" and allow for less regular beach profile adjustment (Johannessen and MacLennan 2007).

3.4.4.2. Biological Community (Aquatic and Riparian)

The biological resources of the nearshore environment include contributions from upland terrestrial areas, such as recruitment of woody debris. Input of LWD can provide important functions for the marine riparian area such as: bank stability and erosion control, accumulation of organic matter, habitat structure, substrate for growth of plant species, moderation of benthic temperature and moderation of moisture on beaches (Brennan and Culverwell 2004, Brennan et al. 2004, Brennan et al. 2009) Contributions to the nearshore environment also include those from the marine environment within the upper, middle and lower intertidal zones (Kozloff 1983). Algae, invertebrates and fish species use the nearshore environment. The shallow water (<10 m) provides sufficient light to allow dense algal and eelgrass beds on the silty sand substrate that occurs throughout most of the area. Many species of marine fish also reside in or use the shallow water habitat of the nearshore environment for some portion of their life. Flatfishes, surf perch, rockfishes, and sculpins are some of the more common groups. Juvenile salmonids, particularly Chinook, chum and pink salmon commonly rear for brief periods in the nearshore environment during their migration from estuaries to the ocean. Their habitat requirement and food resources are very similar to those they used in the estuaries. According to Brennan et al. (2004), resources such as eelgrass, kelps and other macroalgae are associated with benthic and epibenthic organisms that juvenile Chinook prey upon. Additionally, eelgrass and algae provide a food source for avifauna such as black brant (*Branta bernicla*). Herring, an important prey species of Chinook salmon, are dependent on eelgrass for spawning.

In the harsh environment of the upper intertidal zone, a few hardy algal species and invertebrates reside. The coarse sand substrate of the upper intertidal zone provides spawning habitat for sand lance and surf smelt. Surf smelt spawn in sand and small gravel substrates (1 to 7 mm in diameter) along the shoreline, using the uppermost one-third of the tidal range. Pacific sand lance spawn in upper intertidal beach areas consisting of sand (0.2 to 0.4 mm in diameter) scattered around the Puget Sound basin, using sand that is finer-grained than that of surf smelt. These fish often inhabit beaches at distal ends of drift-cells where accretionary shoreforms occur (Penttila 2000, 2001, 2007). These forage fish are a key component of the food web that supports salmon and anadromous bull trout, as well as many marine fishes.

3.4.4.3. Riparian Area Functions

Riparian areas are the transition zones between aquatic habitats and upland areas such as banks and bluffs. Although much is known about the importance of riparian areas in freshwater systems, relatively little research has been conducted on the functions and values of riparian vegetation in marine systems. Desbonnet et al. (1995) and Brennan and Culverwell (2004) hypothesize that marine riparian areas provide functions similar to freshwater riparian areas and may provide additional roles unique to marine systems. Riparian areas provide food sources in the form of insects dropping into the water. Brennan et al. (2004) found prey of Chinook originated from three general habitat types, one being the riparian area. The prey from the riparian areas habitat dominated the Chinook diet, especially for those Chinook that were 110 – 149 mm in length. Most of the insects found in the diet analysis were fully developed which suggests that the source of the prey was directly from overhanging vegetation or were blown in by wind action, rather than via a river flow. Brodeur (1989) also found terrestrial insects as part of juvenile coho and Chinook diets off the Washington and Oregon coasts and Locke and Corey (1986) found all winged adults in their neuston sampling suggesting that these insects entered the water through wind-transport.

Sobocinski (2003) studied insect fallout from Puget Sound shorelines and found that nearshore areas altered by shoreline armoring and other development resulted in consistently lower taxa richness than sites where the shoreline was in a more natural state.

Natural riparian habitat also provides some large wood to Puget Sound shorelines, which traps sediment thereby providing shallow water habitat (Maser et al. 1988). Insects that live in the drift at the upper intertidal level and in the riparian vegetation also provide a food source for juvenile fish rearing along the shorelines (Brennan et al. 2004).

Marine riparian areas are likely to play a central role in the health of aquatic and terrestrial ecosystems. These roles are similar to those played in freshwater systems, yet marine riparian areas also provide functions that are unique to nearshore environments. This is due to differences in biogeochemical processes, ocean influences and the differences in biota between freshwater and marine environments. The discussed functions include water quality, sediment control, shade/microclimate, LWD, nutrients, habitat and hydrology/slope stability. Water quality is improved through these riparian areas by infiltration and reduction of surface runoff. By intercepting nutrients, sediment and pollutants marine riparian areas can prevent introduction as well as convert excessive pollutants into less harmful forms by riparian vegetation and regulating water temperature. Sediment control is provided largely by vegetation which can bind and restrain soil particles, slow runoff, and moderate soil moisture levels through transpiration leading to less surface water runoff. Shade and microclimate is controlled by the marine riparian area's vegetation which intercepts solar inputs and effects soil and ambient air temperature, soil moisture, wind speeds and humidity. LWD is provided by the forested riparian areas from both freshwater and marine riparian sources by natural processes such as landslides, waves, fires and windstorms. The input of this LWD allows for structural complexity, sediment trapping, support for vegetation, moderation of microclimate and accumulation of detritus as a food source. Marine riparian vegetation provides an input of organic matter serving as habitat and food for fishes and aquatic invertebrates as well as slope stability. Other functions provided by marine riparian areas include: recreation, cultural and aesthetic resources, carbon sequestration and protection from threats of coastal hazards (Brennan 2009).

Large trees in the riparian area also provide shade to upper intertidal beaches. Penttila (2001) determined sand lance and surf smelt embryos have a higher rate of survival when shading prevents summer sunny periods from raising the temperature too high and causing egg desiccation. Through research on the effects of shoreline modification on surf smelt embryos, Rice (2006) demonstrated that temperature is among the most important factors in the survival of intertidal embryos. Those embryos exposed to higher temperatures may have been exposed to higher developmental rates, which can cause smelt embryos to mature early therefor compromising their ability to await hatching opportunities or survive after hatching, The high temperature environment can also lead to higher mortality due to thermal stress and desiccation (Rice 2006).

3.4.4.4. Impacts of Urban Development on Nearshore Environment and their Riparian Areas

Human alteration to the nearshore environment has been occurring in Seattle since at least the late 1800's. These activities included extensive filling within Elliott Bay and other areas to increase the city's land base, bank hardening along a significant portion of the shoreline areas for a railroad right-of-way and for property protection, and construction of commercial piers and marinas. The combination of these historic habitat losses and the cumulative impacts of urban development have resulted in major changes to the shoreline environment and the marine nearshore ecosystem. Relatively little is known about the direct effects of urban development and other human impacts on the migration, growth, survival, and habitat of Chinook salmon in the marine nearshore areas of Seattle. However, we do know that bulkheads, bank armoring, and other human activities within shoreline areas have affected many physical processes including sediment production and transport, and that these processes are important for forming and maintaining habitat for juvenile Chinook salmon in the marine nearshore and estuary areas.

The marine nearshore environment within the city of Seattle can be divided into four areas: Elliott Bay, Shilshole Bay, Duwamish Estuary, and other nearshore areas. These areas are discussed below except for the Duwamish Estuary, which is discussed in a separate section of this report.

Elliott Bay

Historically, Elliott Bay consisted of extensive intertidal mud and sand flats and vegetated wetlands bordered by steep banks (Blomberg 1988). The development of the existing downtown business and industrial districts has resulted in extensive filling, dredging, and grading along the shoreline (Weitkamp et al. 2000). Currently, the shoreline along Elliott Bay is characterized by seawalls, bulkheads, and overwater structures. In Elliott Bay, overwater structures are the predominant shoreline modification, occupying over 65 percent of the bay shore. Shoreline areas having natural characteristics are very limited within Elliott Bay, and are found from the mouth of the Duwamish River to Duwamish Head. Most of the shoreline areas of Elliot Bay have been altered, with water depths dropping rapidly to 80 feet and deeper (Weitkamp et al. 2000). In addition, several combined sewer outfalls (CSO) operated by the city of Seattle and King County discharge to Elliott Bay. The mouth of the Duwamish/Green River is located at the southern extent of Elliott Bay.

Armoring of the shorelines of Elliott Bay has reduced shoreline and bluff erosion, reducing sediment inputs that are important to the formation and maintenance of nearshore habitats. Bank armoring along Elliott Bay has reduced the habitat areas provided by beaches and sand spits to an area from Duwamish Head to Alki Point. The shallow subtidal sandflats and other remnant sandy subtidal areas between Alki Point and Duwamish Head support productive eelgrass patches that are important to a variety of marine organisms, including juvenile Chinook salmon (KCDNR 2001). Less armoring has occurred north of the city center and feeder bluffs along the city's Magnolia neighborhood remain active and continue to support the beaches to the north and broad sandflats near West Point.

Salmon and Shilshole Bay

Salmon and Shilshole Bays are located at the westernmost portion of the Lake Washington Ship Canal system and connect the Lake Washington drainage (WRIA 8) to Puget Sound. Salmon Bay includes the Fremont Cut and Hiram Chittenden Locks, and extends east to west from Lake Union to about the railroad bridge west of the Locks. At its western end, it connects to Shilshole Bay, a stretch of the Puget Sound nearshore shoreline running north to south from Golden Gardens Park to the tip of Magnolia at West Point. Historically, Salmon Bay was the estuary of a small creek draining the Lake Union watershed. It featured brackish water and a saltwater marsh at its eastern end. After the rerouting of the Cedar River and construction of the Ship Canal and Locks, the western end of Salmon Bay, together with Shilshole Bay, became the estuary for a much larger freshwater system, however, because of the operation of the Locks the estuary does not function as a natural estuary.

Residential development is the primary land use downstream of the Hiram M. Chittenden Locks in both bays. This area has experienced substantial bank armoring, which has reduced the quantity and quality of shallow intertidal habitat. The construction of the Shilshole Bay marina on the north of Shilshole Bay involved the construction of a large breakwater jetty, dredging, and shoreline filling that has resulted in the loss of both subtidal and intertidal habitats. Connection with bluffs and terrestrial upland development is largely limited by the construction of roads, parking area for the marina and waterfront parks, bulkheads, and the railroad that extends north from Salmon Bay to the City of Everett. The most natural shoreline areas within Shilshole Bay are found adjacent to the cliffs and bluffs in Discovery Park, and within the sand beach areas of Golden Gardens Park.

Other Shoreline Areas

The shoreline areas south of Elliott Bay are affected primarily by residential land use, except for a few water-dependent municipal, commercial, and industrial facilities, and city parks. Bank armoring is a major factor affecting the formation and maintenance of nearshore habitat within this region of the city. Approximately 87 percent of shoreline in WRIA 8 and 75 percent of shoreline in WRIA 9 have been armored (KCDNR 2001). The majority of this armoring has occurred from the construction of bulkheads to protect residential properties, roads, and railroad right-of-ways. Bank armoring is nearly continuous along the nearshore areas north of Golden Gardens Park, as a result of a railroad right-of-way which has been constructed directly adjacent to the shoreline. The railroad bed is protected from wave action by a large riprap embankment upon which the railroad tracks have been placed. The extensive bank armoring along these nearshore areas has substantially reduced the distribution and availability of upper intertidal habitats. Unlike the situation in Elliott Bay and Shilshole Bay, the lower intertidal region of the nearshore environment has not been directly affected by extensive filling or dredging (Weitkamp et al. 2000). The lower intertidal and subtidal habitats within this region are affected by bank armoring and resulting reductions in sediment inputs, transport, and deposition, altered substrate composition, and loss of riparian vegetation.

As discussed above, land use patterns and habitat modifications within the nearshore environment in the city of Seattle have the potential to affect survival, growth, and condition of juvenile, subadult, and adult Puget Sound Chinook. Factors that have impacted the functions of the marine nearshore environment include the loss of habitat within the migratory corridor, degradation of water and sediment quality, alteration of physical processes including bank erosion and alongshore sediment transport, and loss of riparian functions. These human activities have resulted in disrupting the natural processes that create habitat within the nearshore environment. Bank armoring, dredging, filling, and the construction of overwater structures have resulted in direct modification to the nearshore habitat within the city of Seattle shoreline area.

One of the most important physical impact caused by urban development has been to sediment inputs, transport, and deposition along marine nearshore and estuary areas. Few quantitative studies of the effects of shoreline development on sediment transport have been done for habitats in Seattle, and there is limited quantitative information on the more general effects of interrupted sediment transport on biological communities. The transport of sediments from landslides is thought to be critical to the maintenance of beaches, spits, flats, eelgrass beds, and other nearshore habitats. Most of these source areas have been isolated from the nearshore environment by widespread shoreline armoring. Bank armoring, including the construction of riprap (boulder) banks and bulkheads, prevents damage to shoreline properties but also prevents erosion processes such as bank sloughing from occurring. This results in the nearshore area being “starved” of a source of small substrates (i.e., silt, sand and gravel), resulting in a shift in substrate composition from smaller substrate to larger substrate, which in turn, changes the composition of the biota in this area. Sediment inputs from streams and rivers into estuary and marine nearshore areas have generally increased as a result of land-development. However, the increased inputs of sediment from streams and rivers probably cannot compensate for the reduced sediment inputs caused by widespread bank armoring along shoreline areas. Widespread diking of the lower Green River, and channelization and dredging in the Duwamish, further reduces the availability of sediments to marine nearshore and estuary areas.

Waves and alongshore currents (drift cells) carry sediment from slides and streams to areas of deposition such as beaches, headlands, and sandspits. Bank armoring and inwater structures such as rock jetties and gabions can reduce the mobilization and transport of sediments along the shoreline. The lack of sediment recruitment, and reduced alongshore mobilization and deposition, can result in substantial changes to substrate composition in many marine nearshore and estuary areas. These substrate changes can in turn result in the reduction or elimination of intertidal and subtidal vegetation including eelgrass beds and kelp forests. Loss of vegetation may substantially reduce the availability of critical refuge, forage, and acclimation habitat areas for juvenile Chinook salmon, as well as baitfish spawning areas. Alterations in marine riparian vegetation can lead to a loss of habitat complexity, predator refuge availability, and nutrient sources and may affect the carrying capacity of the nearshore ecosystem (Brennan and Culverwell 2004). The loss of riparian vegetation along the shoreline may also decrease the productivity of deeper water habitats by decreasing detrital inputs. Almost all native coniferous forests along the Seattle shoreline have been removed. Shoreline riparian areas are generally limited to landscaping in parks and residential areas and remnant deciduous forests growing on bluffs and steep slopes along the few remaining natural shoreline areas.

All the bluffs that are the sources of the sand and gravel that is transported along the shorelines are currently isolated from the erosive forces. Therefore the transport of sand and gravel along the beaches is gradually moving materials away for the upper end of drift sectors and concentrating the material in deeper water.

3.4.4.5. Strategies to Protect the Nearshore Environment

Considerable effort has been expended in recent years to address strategies for restoration of Puget Sounds' highly modified nearshore habitats (Broadhurst 1998, MacDonald 2000). Strategies discussed involve restoration of natural shoreline processes that would restore the naturally dynamic conditions. Starkes (2001) and WRIA 8 (2005) identify data gaps that should be addressed or recognized in strategies developed to restore nearshore habitat in Seattle. Projects such as the Prioritization of Marine Shorelines of WRIA 9 for Juvenile Salmonid Habitat Protection and Restoration by Anchor Environmental, LLC (2006), Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) and the Shoreline Master Program (SMP) Restoration Plan continue to provide scientific data supporting strategies to protect the nearshore environment.

Habitat protection to maintain existing intertidal and shallow subtidal resources is a key component of any strategy to protect the nearshore environment. Substrate types, slopes, algal and eelgrass resources would be maintained in their current condition through development regulations that prevent substantial alteration of the intertidal and shallow subtidal areas, or require appropriate mitigation at other locations.

Reduction of shoreline armoring is essential for the long-term maintenance of the nearshore environment. With the majority of the shoreline currently altered by hardening of the upper intertidal and riparian areas, the shore processes that maintain natural conditions are not properly functioning. The long-term effect is to alter the slope and substrate to steeper and harder beaches. Management strategies to restore sediment supply through beach nourishment may need to be developed to mitigate the impacts of shoreline armoring.

Prevention of over-water structures in new areas is desirable to prevent further degradation of the nearshore environment.

3.5. ANADROMOUS FISHES

Anadromous fish are species of fish that reproduce in fresh water, migrate to marine waters as juveniles to grow and mature, and finally return to spawn in their natal stream. Salmon are members of the Salmonidae family of fishes that includes salmon, trout, char, whitefish and grayling (collectively called salmonids). Many salmonids are entirely anadromous or have anadromous portions of their populations. Table 3 lists the salmonids and other anadromous fishes that occur within the City of Seattle and are dependent on Seattle's aquatic habitats and shorelines.

Table 3. Anadromous Fish Species Present or Potentially Present in Seattle Aquatic Environment

Common Name	Scientific Name	Group
Chinook salmon	*Oncorhynchus tshawytscha*	Pacific salmon
coho salmon	*O. kisutch*	Pacific salmon
chum salmon	*O. keta*	Pacific salmon
pink salmon	*O. gorbuscha*	Pacific salmon
sockeye salmon (anadromous form) kokanee (resident form)	*O. nerka*	Pacific salmon
sea-run cutthroat trout (anadromous form) coastal cutthroat trout (resident form)	*O. clarki clarki*	native trout
steelhead (anadromous form) rainbow trout (resident form)	*O. mykiss*	native trout
bull trout	*Salvelinus confluentus*	native char
Dolly Varden	*Salvelinus malma*	native char
Pacific lamprey	*Entosphenus tridentatus*	lamprey
river lamprey	*Lampetra ayresi*	lamprey
long-fin smelt	*Spirinchus thaleichthys*	smelt
three-spined stickleback	*Gasterosteus aculeatus*	stickleback

Sources: Wydoski and Whitney (1979) and WDFW (1998)

The term “fisheries” commonly refers to stocks of fish that are managed for commercial, recreational, cultural or ceremonial use. Several fish are currently regulated for these purposes in the state of Washington: Pacific salmon, bull trout/Dolly Varden, coastal resident/sea-run cutthroat trout, steelhead/rainbow trout, and longfin smelt..

There are seven species of Pacific salmon of the genus *Oncorhynchus* that inhabit the North Pacific Ocean. Pacific salmon spawn in fresh waters of western North America (California to Alaska), Russia, and Japan. Four Pacific salmon species occur within the City of Seattle. Populations of chum, coho, Chinook and sockeye migrate through or reproduce in Seattle’s streams. The majority of individuals migrate through the Duwamish River or Ship Canal/Lake Washington to spawn in waters upstream from the City. Anadromous bull trout and steelhead also migrate through these pathways.

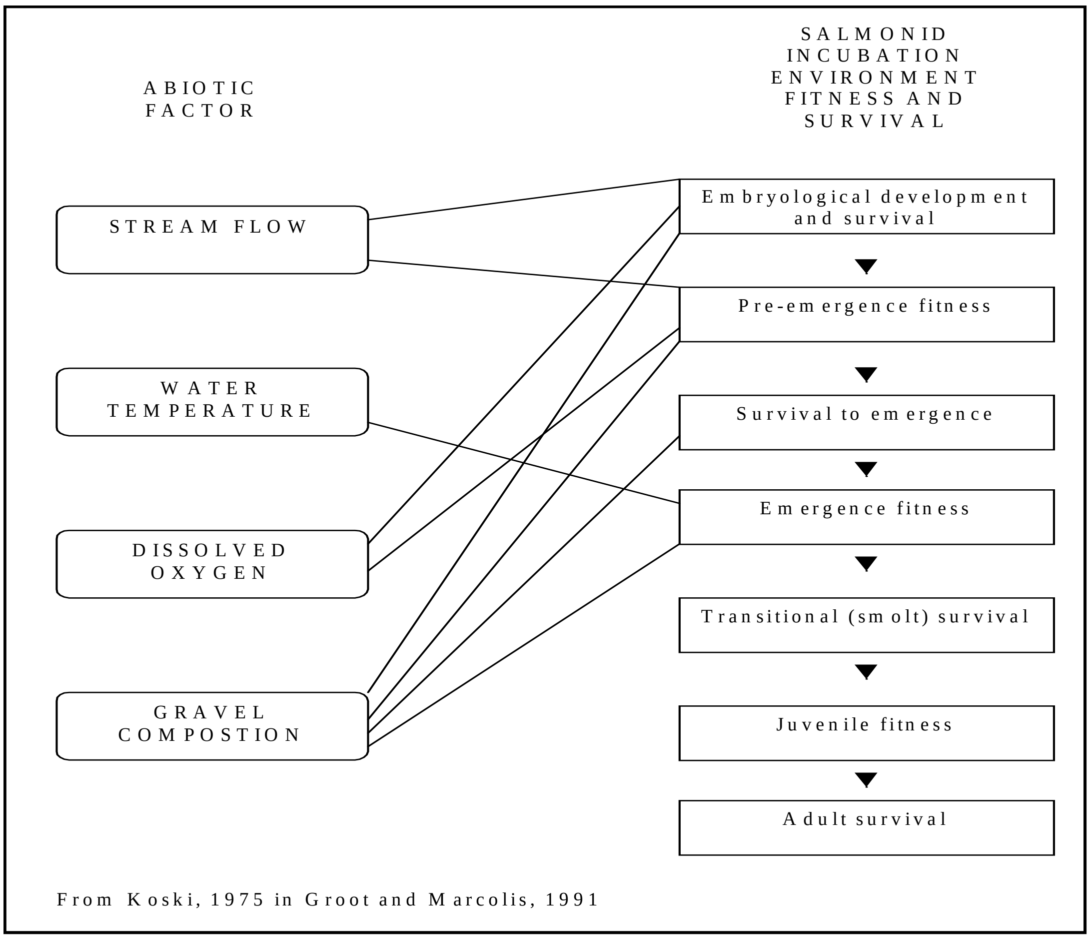
Seattle’s creeks provide spawning and rearing habitat for substantial numbers of chum and coho salmon as well as steelhead/rainbow trout/ and cutthroat trout. Chinook and sockeye salmon reproduce in small numbers in several of the larger streams within the City and sockeye reproduce on the shores of Lake Washington.

Pacific salmon reproduction and survival are affected by the following abiotic and biotic factors (Salo 1991):

- stream flow
- water temperature
- dissolved oxygen
- gravel composition
- spawning time
- spawner density
- genetic characteristics

Stream flow, water temperature, dissolved oxygen levels and gravel composition are factors determined by the local quality of the spawning area and stream. Figure 2 shows how each of these four abiotic stream factors relates to egg-to-fry fitness and survival.

Figure 2. Abiotic Stream Factors that Influence Egg-to-Fry Fitness and Survival.



Spawning time, spawner density, and genetic characteristics are biotic variables determined by genetics, predation, harvest, and general conditions outside the local area. The distinction is made between the local and general factors because local habitat qualities are produced by forces within the area surrounding the stream and can be regulated by the City. However, spawner density is a product of many different factors including harvesting, predation and ocean conditions that are not influenced by the City.

General habitat requirements of the different life history stages of salmonids are listed in Table 4.

Table 4. Salmonid Freshwater Life Histories and Habitat Requirements

Life History	**Habitat Requirements/ Considerations**
Upstream migration	passage (e.g. culverts, dams, low flows, fluctuation in lake levels)/ water quality (temperature, pollution)/ high flows/ low flows/ water diversions/ channel modification/ simplification/ frequency/ depth of holding pools/ available cover/ cold water refugia/ Predation resulting from habitat modification
Spawning	Availability of suitable spawning gravel Siltation of suitable spawning gravel High flows - scouring Redds Low flows – dewatering Redds Disturbance – Humans/wildlife trampling Redds Temperature/ water quality
Egg incubation	Temperature/ water quality/ Dissolved Oxygen
Fry emergence	Temperature/ water quality
Juvenile Rearing	Frequency, area and depth of pools Channel complexity and cover Temperature/ water quality Access to habitat (upstream and down) Off-channel areas and riparian wetlands Fluctuating stream flows (high and low) Predation due to habitat simplification or loss of cover Nutrient and prey availability and competition for prey
Smolt out migration	Water quality Fluctuating stream flows (high and low, timing, quality) Down steam passage Predation due to habitat simplification or modification
Marine rearing	Food source

3.4.5. Chinook Salmon

Nearly all Chinook salmon using the waters within the City of Seattle originate in the Green/Duwamish or Cedar/Sammamish watersheds. They migrate through the City of Seattle as juvenile fish on their way to the ocean and as adults returning to spawn. Both these watersheds terminate within the City of Seattle's boundaries in the marine waters of Puget Sound. The spawning and rearing habitat that supports these runs is present in the watersheds upstream from the City of Seattle. Small numbers of Chinook do spawn, at least occasionally in the larger of Seattle's creeks, but they are a small fraction of the Chinook population.

The existing populations of Chinook have been produced within the substantially modified two watersheds during the past 150 years (Weitkamp and Ruggerone 2000). These modifications have had an important effect on how Chinook use the Seattle's waters. Permanent diversion of the White River and its Chinook salmon production to the Puyallup River system together with the combined lowering of Lake Washington and diversion of the Cedar River from the Duwamish to Lake Washington has greatly altered the Chinook population of the

Green/Duwamish River. Hatchery production in both the Green/Duwamish River and Cedar-Sammamish systems currently produces many of the juvenile Chinook migrating through the City of Seattle and many of the returning adults.

Chinook salmon exhibit two basic life history patterns, ocean type and stream type. Chinook migrating and rearing along Seattle's shorelines are primarily ocean type. Ocean type Chinook spend weeks to several months rearing in freshwater before migrating to the marine environment. Stream type Chinook rear in freshwater for one year in freshwater prior to migrating to the ocean. Stream type Chinook also tend to stay closer to the shore once in the ocean than the ocean type Chinook. Ocean type Chinook are more dependent on the estuarine habitat where they acquire substantial growth that helps them avoid predation as they migrate to the ocean.

In estuaries such as the Duwamish, Chinook appear to prefer shallow water. They are commonly found in areas that provide refuge from wave and current energy apparently due to their preference at this life stage for shallow water beach areas and feeding at the beach substrate when in these shallow shoreline areas. The young Chinook fry appear to preferentially feed at the substrate surface when in shallow shoreline areas commonly no more than 1-2 m deep (Kaczynski et al. 1973, Feller and Kaczynski 1974, Weitkamp et al. 1981, MacDonald et al. 1987) where wave energy is likely to make feeding difficult. In this restricted environment, it is likely they are more adversely affected by wave energy than fish in slightly deeper water or fish that tend to be near the surface over deeper water.

In estuaries, young Chinook commonly prey on epibenthic invertebrates such as harpacticoid copepods and chironomid (dipteran insects) larvae and pupae, and many other small invertebrates (Meyer et al. 1980, Parametrix, Inc. 1985, Shreffler et al. 1992, , Cordell et al. 2001, Bottom and Jones 1990, Tanner and Williams 1991). It is not clear if young Chinook are selecting chironomid larvae from the bottom or from drift, or both. Other insect larvae including other dipterans, hymenopterans, coleopterans, ephemeropterans, and tricopterans have been identified as juvenile Chinook prey. Epibenthic prey also include several species of the amphipod *Corophium* consumed by young Chinook collected in a number of investigations. Pelagic prey include some of the varieties of insects listed above, which may be present in drift entering the estuary or as emerging pupae as well as cladocerans that are fresh water organisms. Other pelagic organisms commonly consumed by Chinook are invertebrates found only in more saline waters. These include calanoid copepods, gammarid amphipods, cumaceans, euphausids, mysids, decapod larvae, and fish larvae (herring, sand lance). Table 5 provides a list of the wide variety of more common juvenile Chinook prey identified in a number of investigations from many different estuaries.

Table 5. Prey report for juvenile Chinook stomach contents.

Pelagic	Epibenthic/Benthic
Cladocerans	Amphipods
Bosmina	Corophium
Daphnia	Corophium salmonis
Daphnia longispina	Corophium spinicorne
	Gammarids
Copepods	Anisogammarus
Cyclopoids	Eogammarus confervicolus
Calanoids	
Epischura	Copepods
Neocalanus	Harpacticoids
Eurytemora dirundaides	

Pelagic	**Epibenthic/Benthic**
Amphipods Euphausids Mysids Neomysis Cumacea Cumella Barnacle larvae Crangonid shrimp Crab larvae, Decapod Larvae Insects chironomid larvae & pupae coleoptera larvae drift insects Dipnerans (flies) Hymenoptera (bugs) Coleoptera (beetles) Tricoptera (caddis flies) Ephemeroptera (mayflies) Fish Larvae (herring, sand lance)	Insects chironomid larvae

3.4.6. *Chum Salmon*

Chum salmon commonly reproduce in relatively small streams and often within a short distance of marine water. This characteristic enables them to populate many of Seattle's creeks that do not meet the habitat requirements of Chinook. Chum salmon are exclusively an ocean type species whose juveniles migrate to marine waters within a few months following emergence from spawning gravels in the spring. This characteristic allows them to avoid the limiting low water conditions that commonly occur in small streams in late summer and early autumn.

Like Chinook, chum salmon are highly dependent on estuarine habitat for rearing and rapid growth, prior to migrating into Puget Sound. They are commonly found in the same habitat as young Chinook, often in mixed schools. The amount of time chum spend feeding in freshwater systems varies from weeks to months (Salo 1991).

Young chum eat both benthic and pelagic prey (Beamish et al. 1998, D'Amours 1987, Cardwell et al. 1980, Levy 1978, Okada and Tanaguchi 1971, Foskett 1951). Harpacticoid copepods and chironomids are among the most common benthic prey consumed by young chum in estuarine habitats. Many studies have also found that juvenile chum have consumed pelagic prey in estuarine areas. When they first enter estuaries, prey includes pelagic freshwater cladocerans (*Cyclops*, *Bosmina*, *Daphnia*) apparently carried into the estuary by river flow.

Pelagic prey found in higher salinity areas include calanoid and cyclopoid copepods, gammarid amphipods, barnacle larvae, cumaceans, euphausids, mysids, and larvaceans. Chum fry have also occasionally been found to consume fish larvae.

3.4.7. Coho Salmon

Coho salmon are a substantially abundant species in the Pacific Northwest and Seattle's waters. They are commonly produced in many hatcheries. In most areas of the North Pacific, coho occur in small numbers compared to other species of Pacific salmon (Sandercock 1991). Although coho do exhibit an ocean type life style, more commonly they are stream type fish that spend at least one year rearing in fresh water. Generally the embryos/alevins spend 4 - 6 months incubating in spawning gravel and up to 15 months rearing in fresh water followed by 16 months rearing in the marine environment (Sandercock 1991). Adult coho, like other salmon, tend to migrate upstream during daylight hours (Fraser et al.1983).

Juvenile coho prefer structurally complex streams that contain stones, logs and bushes in the water, which tends to support larger numbers of fry (Scrivener and Andersen 1984). Chapman (1965) demonstrated that in Oregon streams, there was a positive correlation between the amount of terrestrial insect material found in coho stomachs and the extent to which the stream was overgrown with vegetation. Coho juveniles are highly dependent on visual cues for locating and capturing food (Hoar 1958) tending to pick food out of suspension or off the water's surface.

Coho spawn in shallow streams with moderate flow rates. In the Green River coho tend to select areas where flow is between 5.0-6.8 m^3/min and stream width does not exceed 1 m (Sandercock 1991). In urbanized areas, coho must overcome significant in-stream obstacles in order to reach suitable spawning areas. Individual fish have been known to leap more than 2 m into the air in order to clear obstructions which would otherwise block fish passage (Sandercock 1991), while during autumn storms coho can be seen swimming up streets in several inches of water.

Coho's life strategy of a prolonged upstream journey to small streamlets before spawning allows the coho to inhabit streams that generally tend to provide cool, clear, well-oxygenated water, which are ideal conditions for incubation and rearing (Sandercock 1991). Historically, in these headwater streams, high and low water temperatures are moderated by groundwater seepage (Sandercock 1991) and vegetation cover, leading to a relatively stable environment. For a year following their emergence from the gravel, coho rear in slow backwaters, side channels, and small creeks especially in shady areas with overhanging branches (Cederholm et al. 1997, Shirvell 1994, Nickelson et al. 1992). Coho remain in freshwater for a year and thus, are more susceptible to in stream conditions than chum, pink, and ocean-type Chinook salmon (Sandercock 1991).

Coho fry rear in relatively slow water, feeding on drifting organic material and terrestrial insects (Mundie 1969, Mason 1974, Cordell et al. 1998). Juvenile coho are also piscivorous feeding on other small salmonids (Armstrong 1970, Beall 1972), although they continue to prey on insects and other pelagic prey during freshwater and estuarine rearing. The most productive areas for coho are small streams rather than large rivers (Sandercock 1991). Woody debris is an important feature of this habitat, but is not essential (Spalding et al. 1995).

Coho tend to be fairly adaptable. This is evidenced in the species ability to use small coastal streams as well as the headwater creeks and tributaries of larger rivers to spawn (Sandercock

1991). Of the seven Pacific salmon species, coho have also been the most successfully transplanted.

Since 1998, Seattle urban streams have been experiencing up to 88% of coho returning to the stream to spawn dying before they reach the spawning grounds. This trend in pre-spawning mortality has occurred in coastal streams located between Bellingham and Portland. Currently SPU and NOAA Fisheries are conducting studies to determine the cause of this.

3.6. DISCUSSION

In general the information provided by the scientific literature published in recent years has not radically changed any aspect of our understanding of the functions, attributes, and characteristics of shorelines along streams, lakes, estuaries, and marine areas. Most of the literature has expanded and enhanced our understanding of previously identified principles and characteristics. Table 6 provides a summary of information describing the habitat needs of salmon living in, or migrating through, Seattle's aquatic habitats.

Table 6. Juvenile Salmon Freshwater Life History - Summary and Conclusion.

Factor	Finding	Species	Source
Water/Depth/ Stream Velocity	The range in water depths and stream velocity acceptable for spawning is broad (5cm – 700cm) and (10cm/s – 150.0cm/s)	Chinook	Healey 1991
	Flow control appears to result in a significant increase in average egg survival	Chinook	Healey 1991
Water Temperature	Temperatures required for incubation vary among stocks. In Washington State a water temperature drop below 2.5ºC inhibits nest construction and spawning	chum	Schroder 1973
	Upper and lower temperatures for 50% pre-hatch mortality are 16ºC and 2.5-3ºC	Chinook	Alderdice and Velsen 1978
Dissolved Oxygen	Several authors have shown that survival of eggs and alevins is directly related to the intra-gravel dissolved oxygen content	chum	Salo 1991
	Lethal level (minimum) dissolved oxygen is 1.67 mg/l	chum	Wickett 1954
	Survival rate decreases rapidly when concentration of oxygen drops below 2 mg/l	chum	Koski 1975
	As embryos develop, oxygen demand goes up. Critical oxygen levels range from 1 ppm in early embryonic stages to 7 ppm shortly before hatching.	chum	Alderdice et al. 1958
	Chum have lower oxygen requirements than either coho or Steelhead reflecting lower metabolic demand	chum	Fast and Strober 1984

Factor	Finding	Species	Source
Gravel Size	87% of fry emerged successfully from large gravel with adequate sub-gravel flows	Chinook	Healey 1991
	Survival to hatching is greater than 97% in gravel provided percolation rate is at least 0.001 feet/second	Chinook	Shelton 1955
	Survival to emergence is positively correlated with gravel sizes >3.35 mm and <26.9mm	coho	Tagart 1976
	If gravel is heavily compacted or loaded with fine sediment and sand, fry will not be able to get out	coho	Sandercock 1991
Stream Habitat	Smaller fry tend to inhabit back eddies produced by fallen trees, undercut tree roots or other areas of bank cover	Chinook, coho	Healey 1991
Stream Habitat	Chinook are rarely found in still water or where flow velocity is greater than 30 cm/s	Chinook	Murphy et al. 1989
	At night Chinook move into shore to quiet water over sandy substrates and settle to the bottom	Chinook	Edmundson et al. 1968
	There is little overlap in Chinook habitat and coho or sockeye habitat	Chinook, coho, sockeye	Healey 1991
	Coho fry congregate in slow backwaters, side channels and small creeks especially in shady areas with overhanging branches, commonly side channel areas	Coho	Gribanov 1948 (in Sandercock 1991) Swales and Levings 1989
	Most productive areas for coho are small streams rather than large rivers because of the higher proportions of marginal slack water to midstream area.	Coho	Sandercock 1991
Age at Maturity	Chum mature at 2-6 years of age with 95% of the species maturing in the three to five year age group. In Seattle, approximately 60% of the population matures in 3 years, 39.4% matures in 5 years.	chum	Pratt 1974 (in Salo 1991)
	Chinook mature and return at an average age of 4 years, males tend to mature younger while females tend to be older	Chinook	Healey 1991
	Majority of coho mature in their 3rd year, having spent 4 -6 months in incubation, up to 15 months rearing in fresh water and 16 months in sea water	coho	Sandercock 1991

Factor	Finding	Species	Source
Stream Re-entry	Chum enter streams stimulated by an increase in steam runoff of almost any magnitude.	chum	Salo 1991
	Chinook may return during almost any month of the year.	Chinook	Snyder 1931 Rich 1942 Hallock et al.1957
	Chinook return yearly in 1 to 3 peaks	Chinook	Healey 1991
	Coho arrive at their rivers of origin in later summer and autumn.	coho	Sandercock 1991
	Coho migrate when water temperature is between 7.2º - 15.6ºC, depth is at least 18cm and velocity does not exceed 2.44 m/s	coho	Reiser and Bjornn 1979
	Coho migrate farther upstream than pink and chum but not as far as Chinook or sockeye.	coho, pink, chum, Chinook, sockeye	Sandercock 1991
Spawning	In the Fraser River, Chinook populations spawn between June and November	Chinook	Healey 1991
	Coho spawn between November and January	coho	Sandercock 1991
Feeding	Chum fry in Ulkhan River begin feeding early and linger as late as June. Their basic diet consists of larvae and chrysalis of chironomids, mayfly larvae, *Trichoptera*, and other insects.	chum	Kostarev 1970
	In a series of studies conducted in Big Beef Creek, Washington coho yearlings selected smaller chum fry and predation rate decreased as the size of the fry increased.	coho / chum	Beall 1972
	Larval and adult insects make up the main portion of rearing Chinook's diet in freshwater.	Chinook	Healey 1991
	In British Columbia streams, coho tend to feed on drifting organic material and terrestrial insects	coho	Mundie 1969
Out Migration	Chum fry migrate downstream into estuaries from February to May in Washington State	chum	Salo 1991
	Some fish migrate downstream as fry while others remain in streams for a period of time	chum, Chinook	Salo 1991 Healey 1991
	Stream type Chinook delay out migration until the spring following their emergence from the gravel	Chinook	Healey 1983

Recently it has been determined that adult salmon contribute marine nutrients to freshwater and riparian habitats (Larkin and Slaney 1997). Research has shown that salmon-borne marine derived nutrients (MDN) are an additional nutrient input to estuarine, freshwater and riparian ecosystems. Migrating salmon move MDN from the ocean into the nutrient-poor freshwater and terrestrial ecosystems. After spawning and dying, their decaying carcasses provide nutrients in and near the stream and are spread by wildlife through feces creating a highly resilient and productive ecosystem. These nutrients directly affect terrestrial wildlife by introducing regular food sources for species such as coastal brown bear (*Ursus arctos*), wolves (*Canis lupus*) and bald eagles (*Haliaeetus leucocephalus*) and are redistributed to areas away from the stream system promoting productivity in other terrestrial areas (Naiman 2009).

An emphasis of the recent literature is the naturally dynamic characteristic of lentic systems. Streams naturally change both over time and as they progress downstream. Urban development limits that capacity of urban streams to change by confining their channels, greatly reducing their riparian support habitat, and dramatically altering their hydrology. Since biological functions of streams are maintained in part by the natural dynamic characteristic of the aquatic habitat and shorelines, it is important to provide regulatory provisions that encourage and enhance reestablishment of this dynamic characteristic. Although intense human development is commonly not compatible with complete restoration of streams dynamics, it is valuable to restore the physical characteristics this dynamic condition maintains wherever possible.

A continuing and pertinent aspect of BAS is the substantial level of uncertainty in the information available to guide management of the natural resources (Healy 1998). Despite substantial research efforts, the complexity and variability of the natural ecosystems results in a high level of uncertainty. The adaptive management approach to habitat protection and restoration has become a necessary adaptation to deal with this recognized uncertainty (Anderson et al. 2003).

Conservation and protection measures to protect and enhance species of anadromous salmon reproducing, rearing, and migrating in Seattle's aquatics habitats are currently being undertaken (Seattle 2003). These efforts focus primarily on the streams, Lake Washington shoreline, and the Duwamish River estuary shorelines within the City.

3.7. GLOSSARY

adaptive management: management strategies that deal with uncertainty and adapt to accommodate new knowledge acquired over time during implementation and operation of an action.

adfluvial: fish that migrate to and spend most of their life in lakes or reservoirs following incubation and initial rearing in tributaries.

alevin: the first post-hatch life stage of salmon. Alevins will have some portion of their yolk sac showing on their abdomen. A life stage commonly found only within spawning gravel or hatcheries.

allochthonous: organic material formed outside the stream, riparian plant material entering streams.

allopatry: fish populations that occur in isolation in different areas.

anadromous: fish that hatch in freshwater, migrate to seawater as juveniles and return to freshwater as adults to spawn.

anthropogenic: man made or man-caused.

aphotic zone: deeper portions of a water body below which light penetration is adequate to support photosynthesis.

backwater: a pool formed by an eddy along the stream channel margin downstream from an obstruction such as large boulders, large woody debris, etc. May be separated from the main channel by a bar or other topographical feature.

benthic: an environment or habitat related to the bottom of a stream or body of water; living in or on the bottom.

boulder: sediment particles larger than 15 cm.

cascade : a continuous series of small waterfalls, highly turbulent

chute : a steep narrow channel with moderate turbulence.

chironomids: dipterans (midges) that have aquatic larvae commonly providing a food source for young salmon and other fishes.

cobble: stones of about 6-15 cm in diameter.

cut bank: a steep stream bank, commonly undercut by the stream current that provides holding or refuge habitat for fish.

diurnal: having a daily cycle, generally day v night.

diversity: a measure of the biological complexity of an ecosystem, number of multiple species and/or life stages present in area or habitat type.

eddy: an area having a recirculating current, may be highly elongated, but with a portion of the flow in the reverse direction of the main current. Commonly formed by shoreline or bed features obstructing the general river flow.

epibenthic: living on or just above the bottom of a stream or body of water.

escapement: the number of adult fish that survive ocean conditions and fisheries to enter streams where they reproduce.

estuary: the transition zone from freshwater to seawater where the two mix, commonly having relatively thin layer of reduced salinity on the surface and a higher salinity layer below, and influenced by tidal exchange.

evolutionarily significant unit (ESU): a distinct population segment of a species that interbreeds when mature, generally genetically distinct from other groups, and representing a significant portion of the evolutionary lineage of the species.

exotic species: fish species that have been artificially introduced to a watershed where they did not naturally exist.

fingerling: an early freshwater life stage of salmon that are several months old and are about finger size, usually about 40-50 mm in length. Follows fry life stage and precedes smolt life stage.

fluvial: pertaining to large rivers or major tributaries.

freshet: a major increase in stream flow due to storms or snowmelt, commonly in the autumn and spring.

fry: an early life stage of salmon that have emerged from gravel but still within its first few months of life. Generally about 30-50 mm in length. Follows alevin life stage and precedes fingerling stage.

glide: a slow moving moderately shallow section of a stream with a generally smooth surface (little or no surface turbulence), water velocities 10-20 cm/sec.

habitat: the physical space or location where an organism or species lives, including its physical and biological characteristics.

hyporheic zone: a biologically active underground area of porous sediment adjacent to and under a stream where groundwater and surface water mixes

gravel substrate: gravel forming a stream bottom or shoreline area that provides a basic habitat type used by Chinook for spawning and rearing. Generally 2-6 cm in diameter (Wentworth).

incised channel: a stream channel cut down into a valley floor by erosion.

impervious surface: surface of the earth that has been converted from natural soil to some artificial form (such as building roofs, pavement, sidewalks, etc.) that is impervious to rainfall.

iteroparous: fish that survive their first spawning to undergo one or more subsequent spawnings (e.g., steelhead, cutthroat, bull trout). Contrast “semelparous”.

juvenile salmon: young salmon that have not reached sexual maturity. Generally referring to young salmon that have not yet migrated to the sea, or have just entered the marine waters.

larvae: immature life stage of fish and invertebrates that have fundamental characteristics different from the adult life stage of the species.

lentic: lake type or still waters that are not actively flowing.

limnetic: the open water area of a lake or similar body of water.

littoral zone: the nearshore zone of a water body that is sufficiently shallow to permit photosynthetic activity by macrophytes.

lotic: stream type waters that are actively flowing.

macrophytes: multicellular aquatic plants that attach to the bottom by roots or holdfasts, as opposed to planktonic plants.

natal stream: the stream in which the adult salmon were originally spawned, incubated and reared.

native stock: salmon that are genetically derived from wild fish native to the watershed.

naturally producing or spawning stock: salmon of both wild and hatchery origin that spawn together within a stream. Commonly producing some hybrid fish from the two genetic sources

neritic: residing in shallow water.

ocean type: salmon that commonly spend a brief period of weeks to several months rearing in freshwater before they migrate to seawater, as contrasted to “stream-type” salmon that spend at least one winter in freshwater.

order (stream): relative size of a stream based on the joining of tributaries. First order: no tributaries. Third order: tributaries join to produce tributaries that join other tributaries to form a third order stream.

pelagic: residing within the water column rather than near the bottom or shoreline in either fresh or seawater.

photic zone: shallow water where light penetration is sufficient to support photosynthesis by aquatic vegetation.

plunge pool: a pool located immediately downstream from a falls or other obstruction that causes the stream flow to plunge resulting in a scoured stream bed.

point bar: a bar of sand, gravel, cobble or other deposited material on the inside of a bend in the stream, generally producing some obstruction to flow.

pool: a section of the stream with relatively deep water and low velocities.

primary production: production by plants that use sun light (photosynthesis) as an energy source to sustain life.

profundal: deep water, usually well below the photic zone.

redd: the nest formed by a spawning female salmon as it digs in a small area of the stream bottom with its tail to form several depressions (egg pockets) in which eggs are deposited.

riffle: a shallow rapid section of a stream with turbulent water, but lacks standing waves.

riparian zone: that portion of the land adjacent to a stream or body of water, usually within several hundred feet of the water’s edge.

run: a shallow rapid section of a stream with no obvious waves and little turbulence, water surface generally parallel to the stream gradient.

sand: substrate particles of about 0.0625-2.0 mm in diameter (Wentworth).

scouring: e.g., displacement of spawning gravel along with incubating embryos and alevins in a stream due to high flows (freshets).

semelparous: species such as Pacific salmon that die after their first spawning (Chinook, coho, chum, pink, sockeye). Contrast "iteroparous."

silt: substrate particles of 0.0039-0.0625 mm in diameter (Wentworth)

side channel: a roughly parallel channel separate from the main stream channel that receives its flow primarily from the main channel, and with less flow than the main channel

smolt: a life stage of salmon that is undergoing or has completed the physiological transition that allows it to live in seawater. Commonly involves changes in body form to a slightly more streamlined form and silvery body coloration.

stream incision: cutting down of a stream through erosion of the stream bottom by strong currents.

stream type: salmon that rear for approximately a year or more in freshwater prior to migrating to seawater, as contrasted to "ocean-type" salmon.

sub-basin: a portion of a watershed collecting precipitation draining to a tributary of a larger stream.

thalweg: the center of the main path of a stream having the greatest depths of a channel cross section.

thermocline: a layer of sharp temperature change in a stratified body of water.

vertical temperature gradient: a vertical boundary layer of substantial temperature change within a lake or test aquarium that provides fish with a choice of temperatures.

watershed: the entire geographical area collecting precipitation discharged to a stream, also referred to as a catchment or river basin.

wild stock: a group of fish from a watershed that have continuously spawn naturally, and have not been intermixed with a hatchery population.

3.8. REFERENCES

Alcorn, S.W., A.L. Murray, and R.L. Pascho. 2002. Effects of temperature on the immune functions of sockeye salmon (*Oncorhynchus nerka*). Fish and Shellfish Immunology 12:303-334.

Alderdice D. F., and F. P. J. Velson. 1978. Relation between temperature and incubation time for eggs of Chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada 35:69-75.

Alderdice, D.F., W.P. Wickett, and J.R. Brett. 1958 Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15(2): 229-250.

Allen, A. W. 1983. Habitat suitability index models: beaver. U.S. Fish and Wildlife Service, Fort Collins, Colorado. 29 p.

Anchor Environmental, LLC. 2006. Prioritization Of Marine Shorelines of Water Resource Inventory Area 9 for Juvenile Salmonid Habitat Protection and Restoration. Final Report. Prepared for Water Resource Inventory Area 9 Technical Committee by Anchor Environmental, LLC, Seattle, WA.

Anchor QEA. 2013. Final Draft Semi-Arid Riparian Functions and Associated Regulatory Protections to Support Shoreline Master Program Updates. Report prepared for Grant County by Anchor QEA, LLC, Kennewick, WA.

Anderson, J. L., R. W. Hilborn, R. T. Lackey, and D. Ludwig. 2003. Watershed restoration-adaptive decisions making in the face of uncertainty. Pages 203-232 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Arkoosh, M. R., E. Casillas, E. Clemons, A. N. Kagley, R. Olson, P. Reno, J. E. Stein. 1998. Effect of pollution on fish diseases: potential impacts on salmonid population. Journal of Aquatic Animal Health.10:172-190.

Armbrust, E., J.R. Cordell, A. Cummins, and J. Toft. 2008. Inspection of Corps of Engineers Ecological Restoration Projects in the Puget Sound Region, 2008: Review of past monitoring and current status. Prepared for U.S. Army Corps of Engineers, Seattle District, WA.

Armstrong, R. H. 1970. Age, food, and migration of Dolly Varden smolts in Southeastern Alaska. Journal of the Fisheries Research Board of Canada 27:991-1004.

Arnold, C. L. and C. J. Gibbons. 1996. Impervious surface coverage: The emergence of a key environmental indicator. Journal of the American Planning Association 62(2):243-258.

Ballantyne, A. P., M. T. Brett, and D. E. Schindler. 2003. The importance of dietary phosphorus and highly unsaturated fatty acids for sockeye (*Oncorhynchus nerka*) growth in Lake Washington – a bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences 60:12-22.

Bams, R. A. 1982. Experimental incubation of chum salmon (*Oncorhynchus keta*) in a Japanese-style hatchery system. Canadian Technical Report of Fisheries and Aquatic Sciences 1101:65p.

Bams, R. A. 1983. Early growth and quality of chum salmon (Oncorhynchus keta) produced in kepper channels and gravel incubators. Canadian Journal of Fish and Aquatic Sciences 40:449-505.

Barton, D. R. and W. D. Taylor. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. North American Journal of Fisheries Management 5:364-378.

Battelle Marine Sciences Laboratory and others. 2001. Reconnaissance assessment of the state of the nearshore ecosystem: eastern shore of central Puget Sound, including Vashon and Maury Islands (WRIAs 8 and 9). Report prepared for King County Department of Natural Resources, Seattle, Washington. 290 p.

Beamer, E.M., W.T. Zackey, D. Marks, D. Teel, D. Kuligowski and R. Henderson. 2013. Juvenile Chinook Salmon Rearing in Small Non-Natal Streams Draining into the Whidbey Basin. Prepared by Skagit River System Cooperative, LaConner, WA.

Beamish, R. J., M. Folkes, R. Sweeting, and C. Manken. 1998. Intra-annual changes in the abundance of coho, Chinook, and chum salmon in Puget Sound in 1997. Pages 531-541 in Puget Sound Water Quality Action Team, Puget Sound Research ’98, Olympia, Washington.

Beechie, T. J. and T. H. Sibley. 1997. Relationship between channel characteristics, LWD, and fish habitat in NW Washington Streams. Transactions of the American Fisheries Society 126:217-229

Beechie, T. J., G. Pess, P. Kennard, R. E. Bilby, and S. Bolton. 2000. Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington Streams. North American Journal of Fisheries Management 20:436-452.

Benda, L. E., D. J. Miller, T. Dunne, G. H. Reeves, and J. K. Agee. 1998. Dynamic landscape systems. Pages 261-288 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Berge, H. B., and B. M. Mavros. 2001. King County bull trout program: 2000 bull trout surveys. King County Department of Natural Resources, Seattle, Washington. http://dnr.metrokc.gov/topics/salmon/SALtopic.htm

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

Beyerlein, D. 2000. Why standard stormwater mitigation doesn’t work. Aqua Terra Consultants, Everett, Washington.

Bilby, R. E. 1988. Interactions between aquatic and terrestrial systems. Pages 13-29 in. Raedeke, K. J., editor. Streamside management: riparian wildlife and forestry interactions. College of Forrest Resources Contribution No. 59. University of Washington, Seattle, Washington.

Bilby, R. E., G. H. Reeves, and C. A. Dolloff. 2003. Sources of variability in aquatic ecosystems: factors controlling biotic production and diversity. Pages 129-146 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems:

sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Bilby, R. E., J. T. Heffner, B. R. Fransen, and J. W. Ward. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. North American Journal of Fisheries Management 19:687-695.

Binford, M. W. and M. J. Becheneau. 1993. Riparian greenways and water resources. In: Smith, D. S. and P. Cawood, editors. Ecology of Greenways, University of Press. Minneapolis, Minnesota.

Bisson, P. A., and R. E. Bilby. 1998. Organic matter and trophic dynamics. Pages 373-398 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K V. Koski, and J. R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest, past, present, and future. Pages 143-190 in Salo, E. O. and T. W. Cundy editors. *Streamside Management: Forestry and Fishery Interactions*. College of Forestry, University of Washington: Seattle, Washington.

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

Blann, K., J. F. Nerbonne, and B. Vondracek. 2003. Relationship of riparian buffer type to water temperature in the Driftless Area ecoregion of Minnesota. North American Journal of Fisheries Management 22:441-451.

Bledsoe, B.P. and C.C. Watson. 2001. Effects of Urbanization on Channel Stability. Journal of the American Water Resources Association 37(2):255-270.

Blomberg, G., C. Simenstad, and P. Hickey. 1988. Changes in Duwamish River estuary habitat over the past 125 years. Pages 437-454 In: Proceedings of the First Annual Meeting on Puget Sound Research. Volume II. Puget Sound Water Quality Authority, Seattle, WA.

Boesch, D. F., J. Burger, C. F. D'Elia, D. J. Reed, and D. Sacavia. 2000. Scientific synthesis in estuarine management. Pages 507-526 in Hobbie, J. E., editor. Estuarine science: a synthetic approach to research and practice. Island Press, Washington D.C. 539 p.

Bolton, S., and J. Shelberg. 2001. Ecological issues in floodplains and riparian corridors. White paper prepared for Washington Department of Fisheries, Washington Department of Ecology and Washington Department of Transportation, Olympia, Washington. 88 p + appendix.

Booth, D. B. 1990c. Stream-channel incision following drainage-basin urbanization. Water Resources Bulletin 26:407-417.

Booth, D. B. 1991. Urbanization and the Natural Drainage System – Impacts, Solutions and Progress. Northwest Environmental Journal 7(1): 93-118.

Booth, D. B. and C. R. Jackson. 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association 33(5):1077-1090.

Booth, D. B., D. Hartley, and R. Jackson. 2002. Forest cover, impervious surface area, and the mitigation of stormwater impacts. Journal of the American Water Resources Association 38(3): 835-845.

Booth, D. B., J. R. Karr, S. Shauman, C. P. Konrad, S. A. Morley, M. G. Larson, P. C. Henshaw, E. J. Nelson, and S. J. Burges. 2001. Urban Stream Rehabilitation in the Pacific Northwest. Final report of EPA Grant R82-5284-010.

Booth, D.B., D. Hartley, and R. Jackson. 2002. Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts. Journal of the American Water Resources Association. Vol 38, No. 3.

Booth, D.B., D.R. Montgomery, J. Bethel. 1997. Large woody debris in urban streams of the Pacific Northwest: in Roesner, L.A., ed., Effects of watershed development and management on aquatic ecosystems: Engineering Foundation Conference, Proceedings, Snowbird, Utah, August 4–9, 1996, pp. 178-197.

Borgmann, U. 2003. Derivation of cause-effect based sediment quality guidelines. Canadian Journal of Fisheries and Aquatic Sciences 60:352-360.

Bormann, F. H., G. E. Likens, and J. S. Eaton. 1969. Biotic regulation of particulate and solution losses from a forest ecosystem. BioScience 19:600-610.

Bormann, F. H., G. E. Likens, D. W. Fisher, R. and S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. Science 159:882-884.

Bosch, D. D., R K. Hubbard, L. T. West, and R. R. Lowrance. 1994. Subsurface flow patterns in a riparian buffer system. Transactions of the American Society of Agricultural Engineers 37(6):1783-1790.

Bottom, D. L., and K. K. Jones. 1990. Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River Estuary. Progress in Oceanography 25:243-270.

Bottom, D. L., P. L. Howell and J. D. Rodger. 1983. Final Report: Fish research project Oregon, salmonid habitat restoration. Oregon Department of Fish and Wildlife, Portland, Oregon, 1983. 155p.

Brazier, J. R. and G. W. Brown. 1977. Effect of roots on the shear strength of a colluvial soil. Pages 77-78 in Proceedings, 5th Danube European Conference of Soil Mechanics and Foundation Engineering, CSSR, Bratislava.

Bren, L. J. 1995. Aspects of the geometry of riparian buffer strips and its significance to forestry operations. Forest Ecology and Management 75:1-10.

Brennan, J. S. and H. Culverwell. 2004 Marine Riparian: An Assessment of Riparian Functions in Marine Ecosystems. Published by Washington Sea Grant Program. Copyright 2005, UW Board of Regents. Seattle, WA. 34 p.

Brennan, J. S., K. F. Higgins, J. R. Cordell, and V. A. Stamatiou. 2004. Juvenile Salmon Composition, Timing, Distribution, and Diet in Marine Nearshore Waters of Central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, Wa. 164pp.

Brennan,J., H. Culverwell, R. Gregg, P. Granger. 2009. Protection of Marine Riparian Functions in Puget Sound, Washington. Prepared for Washington Department of Fish and Wildlife by Washington Sea Grant, Seattle.

Broadhurst, G. 1998. Puget Sound nearshore habitat regulatory perspective: a review of issues and obstacles. Puget Sound /Georgia Basin Environmental Report Series: Number 7, Puget Sound Water Quality Action Team, Olympia, Washington. 49 p.

Broderson, J. M. 1973. Sizing buffer strips to maintain water quality. Thesis. University of Washington, Seattle, Washington.

Brodeur, R.D. 1989. Neustonic feeding by juvenile salmonids in coastal waters of the Northeast Pacific. *Can. J. Zool*. 67:1995-2007.

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

Brown, A. M. 1998. Shoreline residential development and physical habitat influences on fish density at the lake edge of Lake Joseph, Ontario. Thesis, University of Toronto, Toronto, Ontario, Canada. 74 p.

Brown, E. R., editor. 1985. Riparian zones and freshwater wetlands. management of wildlife and fish habitats in forests of western Oregon and Washington, Part I - Chapter Narrative, Pages 57-80.

Brown, G. W. and J. T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resource Research 6:1131-1139.

Buchanan, D. V., and S. V. Gregory. 1997. Development of water temperature standards to protect and restore habitat for bull trout and other cold water species in Oregon. Pages 119-126 in Mackay, W. C., M. K. Brewin, and M. Monita, editors. Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

Budd, W. W., P. L. Cohen, P. R. Saunders, and F. R. Steiner. 1987. Stream corridor management in the Pacific Northwest: 1. determination of stream corridor widths. Environmental Management, 11(5):587-597.

Buffington, J. M., T. E. Lisle, R. D. Woodsmith , and S. Hilton. 2002. Controls on the size and occurrence of pools in coarse-grained forest rivers. River Research and Applications 18:507-531.

Bugert, R. M., and T. C. Bjornn. 1991. Habitat use by steelhead and coho salmon and their responses to predators and cover in laboratory streams. Transactions of the American Fisheries Society 120:486-493.

Burgner, R. L. 1991. Life history of sockeye salmon in C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, University of British Columbia, Vancouver, British Columbia.

Cardwell, R. D., S. J. Olson, M. I. Carr, and E.W. Sanborn. 1980. Biotic, water quality and hydrologic characteristics of Birch Bay Village Marina in 1978. Washington Department of Fisheries, Technical Report No. 54. 103 p.

Carothers, S. W., R. R. Johnson, and S. W. Aitchison. 1974. Population structure and social organization of southwestern riparian birds. American Zoologist 14:97-108.

Castelle, A. J. and A. W. Johnson. 2000. Riparian vegetation effectiveness. National Council for Air and Stream Improvement Technical Bulletin No. 799.

Castelle, A. J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements – a review. Journal of Environmental Quality 23:878-881.

Castelle, A. J., C. Conolly, M. Emers, E. D. Metz, S. Meyer, M. Witter, S. Mauermann, T. Erickson, and S. S. Cooke. 1992. Wetland buffers: use and effectiveness. Publication 92-10, Washington Department of Ecology, Olympia, Washington. 171 p.

Cederholm, C. J. 1994. A suggested landscape approach for salmon and wildlife habitat protection in western Washington riparian ecosystems. Pages 8-90 in A. B. Carey and C. Elliott. 1994. Washington forest landscape management project – progress report. Report No. 1, Washington Department Natural Resources, Olympia, Washington.

Cederholm, C. J. and L. M. Reid. 1987. Impact of forest management on coho salmon (Oncorhynchus kisutch) populations of the Clearwater River, Washington: a project summary. Pages 373-398 in Salo, E. O., and T. W. Cundy. Streamside management: forestry and fishery interactions. University of Washington, Seattle, Washington

Cederholm, C. J., R. E. Bilby, P. A. Bisson, T. W. Bumstead, B. R. Fransen, W. J. Scarlett, and J. W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. North American Journal of Fisheries Management 17:947-963.

Celedonia, M.T., R.A. Tabor, S. Sanders, D.W. Lantz, and I. Grettenberger. 2008. Movement and Habitat Use of Chinook Salmon Smolts and Two Predatory Fishes in Lake Washington and the Lake Washington Ship Canal: 2004-2005 Acoustic Tracking Studies. Prepared by the U.S. Fish and Wildlife Service. December 2008.

Celedonia, M.T., Z. Li, S.T. Sanders, R.A. Tabor, S. Damm, D.W. Lantz, and B.E. Price. 2011. Movement and Habitat Use of Chinook Salmon Smolts in the Lake Washington Ship Canal: 2007-2008 Acoustic Tracking Studies. Prepared by the U.S. Fish and Wildlife Service. May 2011.

Chapman, D. W. 1965. Net production of coho salmon in three Oregon streams. Transactions of the American Fisheries Society 94:40-52.

Charbonneau, R. and V. H. Resh. 1992. Strawberry Creek on the University of California, Berkeley Campus: A case history of urban stream restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 2:293-307.

Chen, J. 1991. Edge effects: microclimatic pattern and biological responses in old-growth Douglas-fir forests. Dissertation, University of Washington, Seattle, Washington. 160 p.

Chen, J., J. F. Franklin, and T. A. Spies. 1995. Microclimatic pattern and basic biological responses at the clearcut edges of old-growth Douglas-fir stands. Northwest Environmental Journal 6:424-425.

Christensen, D. L., B. R. Herwig, D. E. Schindler, and S. R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Chrzastowski, M. 1981. Historical changes to Lake Washington and route of the Lake Washington Ship Canal, King County Washington. Open-File Report 81-1182, U.S. Geological Survey, Tacoma, Washington. 9 p.

City of Seattle's Salmon Team. 2003. Seattle's urban blueprint for habitat protection and restoration. City of Seattle: Seattle, Washington.

Collins, B. D., and D. R. Montgomery. 2002. Forest development, wood jams, and restoration of floodplain rivers in the Puget Lowland, Washington. Restoration Ecology 10(2):237-247.

Collins, B. D., D. R. Montgomery, and A. D. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget lowland rivers. Canadian Journal of Fisheries and Aquatic Sciences 59:66-76.

Collins, B. D., D. R. Montgomery, and A. J. Sheikh. 2003. Reconstructing the historic river landscape of the Puget Lowland. Pages 79 in 128 in Montgomery, D. R., S. Bolton, and L. Wall, editors. Restoration of Puget Sound Rivers. University of Washington Press, Seattle, Washington. 505 p.

Comings, K. J. 1998. Stormwater pollutant removal by two wet-ponds in the Lake Sammamish Watershed. Thesis, University of Washington. Seattle, Washington.

Constanz, G. 1998. Ecology of natural riparian. River Voices, 9(1) 8-10.

Cooke, S. S. 1992. Wetland buffers: use and effectiveness. Unpublished report by Adolfson Associates, Inc. to Shorelands and Coastal Zone Management Program, Washington Department of Ecology, Olympia, Pub. No. 92-10.

Cooper, C. 1996. Hydrologic Effects of Urbanization on Puget Sound Lowland Streams. Thesis, University of Washington, Seattle, Washington.

Cordell, J. R., H. Higgins, C. Tanner, and J. K. Atkin. 1998 Biological status of fish and invertebrate assemblages in a breached-dike wetland site at Spencer Island, Washington. University of Washington, Fisheries Research Institute, FRI-UW-9805, Seattle, Washington. 19p.

Cordell, J. R., L. M. Tear, and K. Jensen. 2001. Biological monitoring at Duwamish River coastal America restoration and reference sites: a seven-year retrospective. School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. 75 p.

Crandell, C. J. 2001. Effect of grazing by Brandt Canadensis (Canada geese) on the fitness of Carex lyngbyei (Lyngby's sedge) at a restored wetland in the Duwamish River estuary. Thesis, University of Washington, Seattle, Washington.

Crobett, E. S. and J. A. Lynch. 1985. Management of Streamside Zones on Municipal Watersheds. Pages 187-190 in Johnson, R.R., C. D. Ziebell, D.R. Patton, P. F. Folliott, and R. H. Hamre, editors. Riparian ecosystems and their management: reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona.

Culp, J. M. and R. W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1208, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, British Columbia. 115p.

Currens, K. P. 2000. Independent Science Panel, Report 2000-2, December 2000, recommendations for monitoring salmonid recovery in Washington State, Office of the Governor http://www.governor.wa.gov/esa/science/ispsalmonid.pdf

Czuba, J.A., C.S. Magirl, C.R. Czuba, E.E. Grossman, C.A. Curran, A.S. Gendaszek, and R.S. Dinicola. 2011. Sediment Load from Major Rivers into Puget Sounds and its Adjacent Waters. USGS, Washington Water Science Center, Tacoma, WA.

D'Amours, D. 1987. Trophic phasing of juvenile chum salmon chum salmon (Oncorhynchus keta Walbaum) and harpacticoid copepods in the Fraser River estuary, British Columbia. Thesis, University of British Columbia, Vancouver, British Columbia. 142 p.

Dawson, W.A., and L.J. Tilley. 1972. Measurement of the salt-wedge excursion distance in the Duwamish River estuary, Seattle, Washington, by means of the dissolved-oxygen gradient. Geological Survey Water-Supply Paper 1873-D 27 p.

Desbonnet, A. 1994. Vegetated buffers in the coastal zone: A summary review and bibliography. Coastal Resources Center, University of Road Island, Providence, Road Island.

Desbonnet, A., V. Lee, P. Progue, D. Reis, J. Boyd, J. Willis and M. Imperial. 1995. Development of Coastal Vegetated Buffer Programs. Coastal Management 23: 91-109.

DeVries, P. 1997. Riverine salmonid egg burial depths: review of published data and implications for scour studies. Canadian Journal of Fisheries and Aquatic Sciences 54:1685 1698.

Dickson, J. G. 1989. Streamside Zones and Wildlife in Southern U.S. Forests. Pages 131-133 in R. G. Gresswell, B. A. Barton, and J.L. Kershner, editors. Practical Approaches to Riparian Resource Management: An Educational Workshop. U.S. Bureau of Land Management, Billings, Montana.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. Transactions of the American Society of Agricultural Engineers 32:513-518.

Donnelly, R. E. 2002. Design of habitat reserves and settlements for bird conservation in the Seattle metropolitan area. Thesis, University of Washington, Seattle, Washington. 80 p.

Downing, J. 1983. The coast of Puget Sound its processes and development. University of Washington Press, Seattle, Washington. 126 p.

Doyle, R. C., C. G. Stanton, and D. C. Wolf. 1977. Effectiveness of forest and grass buffer strips in improving the water quality of manure polluted runoff. American Society of Agricultural Engineers Paper No. 77-2501. St. Joseph, Missouri.

Duncan, S. 2000. Too Early to Tell, or Too Late to Rescue? Adaptive management under scrutiny, science findings. U.S. Department of Agriculture, Pacific Northwest Research Station, Portland, Oregon.

Ebersole, J.L., W.J. Liss, and C.A. Frissell. 2001. Relationships between stream temperature, thermal refugia, and rainbow trout (*Oncorhynchus mykiss*) abundance in arid-land streams in the northwestern United States. Ecology of Freshwater Fish 10:1-10.

Edmundson, E., E.F. Everest, and D.W. Chapman. 1968. Permanence of station in juvenile Chinook salmon and steelhead trout. Journal of the Fisheries Research Board of Canada 25:1453-1464.

Edwards, R. T. 1998. The hyporheic zone. Pages 299-429 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Erman, D. C., J. D. Newbold and K. B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. Technical Completion Report, Contribution 165, California Water Resources Center, University of California, Davis, California.

Fast, D. E., and Q. J. Stober. 1984. Intragravel behavior of salmonid alevins in response to environmental changes. Final Report FRI-UW-8414, to City of Seattle, by Fisheries Research Institute, University of Washington. 103 p.

Fayram, A.H. 1996. Impacts of largemouth bass (Micropterus salmoides) and smallmouth bass (Micropterus dolomieui) predation on populations of juvenile salmonids in Lake Washington. Thesis, University of Washington, Seattle, Washington.

Fayram, A.H., and T.H. Sibley. 2000. Impact of predation by smallmouth bass on sockeye salmon in Lake Washington, Washington. North American Journal of Fisheries Management 20: 81-89.

Feist, B.E., E.R. Buhle, P. Arnold, J.W. Davis, N.L. Scholz. 2011. Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams. PLoS ONE 6(8):e23424. doi:10.1371/journal.pone.0023424.

Feller, R. J., and V. W. Kaczynski. 1975. Size selective predation by juvenile chum salmon (Oncorhynchus keta) on epibenthic prey in Puget Sound. Journal of the Fisheries Research Board of Canada 32:1419-1429.

Finkenbine, J. K., J. W. Atwater, and D. S. Mavinic. 2000. Stream health after urbanization. Journal of the American Water Resources Association 35:1149-1160.

Foskett, D. R. 1951. Young salmon in the Nanaimo area. Fisheries Research Board of Canada, Pacific Progress Report 86:18-19.

Fox, M. J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Thesis, University of Washington, Seattle, Washington. 239 p.

Fraser, F. J., E. A. Perry, and D. T. Lightly. 1983. Big Qualicum River salmon development project. Volume 1: a biological assessment 1959-1972. Canadian Technical Report Fisheries and Aquatic Sciences 1189. 198 p.

Fredrickson, H. L., J. W. Talley, J. S. Furney, and S. Nicholl. 2003. Toxicological exposure of sediment-bound hydrophobic organic contaminants as a function of the quality of sediment organic carbon and microbial degradation. Long-Term Effects of Dredging Operations Program, ERDC/TN EEDP-/04-34, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. 17 p.

Garcia, S. M., A. Zerbi, C. Aliaume, T. Do Chi, and G. Lasserre. 2003. The ecosystem approach to fisheries. Food and Agricultural Organization of the United Nations, ISSN 0429-9345, FAO Fisheries Technical Paper 443, (74 p.) available at http://www.fao.org/DOCREP/006/Y4773E/y4773e00.htm#Contents

Gende, S. M., R. T. Edwards, M. F. Willson, and M. S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. Bioscience 52:917-928.

Gilliam, J. W. and R. W. Skaggs. 1986. Natural buffer areas and drainage control to remove pollutants from agricultural drainage water. In: Proceedings of National Wetland Symposium: Mitigation of Impacts and Losses, New Orleans, Louisiana.

Goetz, F. A. 2004. Presentation at Greater Lake Washington Chinook Workshop. King County, Seattle, Washington.

Goetz, F. A., D. Seiler, and P. N. Johnson. 2003. Summary of juvenile fish passage investigations at the Hiram M. Chittenden Locks: 1996-2000. Report to the Lake Washington Ecological Studies Group, Seattle, Washington.

Goldman, C. R. and A. J. Horne. 1983. Limnology. McGraw-Hill, Inc. New York, New York.

Gonor, J. J., J. R. Sedell, and P. A. Benner. 1988. What we know about trees in estuaries in the sea, and on coastal beaches. Chapter 4 (pages 83-112) in Maser, C., R. F. Tarrant, J. M. Trappe, and J. F. Franklin, editors. From the forest to the sea: a story of fallen trees. USDA Forest Service General Technical Report, GTR-PNW-229. Northwest Research Station, Portland, Oregon. 153 p.

Gray, A. N. 2000. Adaptive ecosystem management in the Pacific Northwest: a case study from coastal Oregon. Conservation Ecology 4(2): 6. Available at: http://www.consecol.org/vol4/iss2/art6

Gregory, R .S. 1994. The influence of ontogeny, perceived risk of predation, and visual ability on the foraging behavior of juvenile Chinook salmon. Pages 271-284 in Stouder, D. J., K. L. Fresh, and R. J. Feller, editors. Theory and application in fish feeding ecology, University of South Carolina Press, Columbia, South Carolina.

Gregory, R. S. 1988. Effects of turbidity on benthic foraging and predation risk in juvenile Chinook salmon. Pages 64-73 in Simenstad, C. A. Effects of dredging on anadromous Pacific Coast fishes. Washington Sea Grant Program, University of Washington, Seattle, Washington.

Gregory, R. S., and C. D. Levings. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. Transactions of the American Fisheries Society 127:275-285.

Gregory, R. S., and T. G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile Chinook salmon (Oncorhynchus tshawytscha) in turbid laboratory conditions. Canadian Journal of Fisheries and Aquatic Sciences 50:233-340.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. BioScience 41:540-551.

Gregory, S. V., G. A Laberti, T. C. Eman, K V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. Pages 233-2555 in Salo, E., and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. University of Washington, Seattle, Washington.

Grismaer, M. E. 1981. Evaluating dairy waste management systems influence on fecal coliform concentration in runoff. Thesis, Oregon State University, Corvallis, Oregon.

Grizzel, J., M. McGowan, D. Smith, and T. Beechie. 2000. Streamside buffers and large woody debris recruitment: evaluating the effectiveness of watershed analysis prescriptions in the north Cascades region. The Timber/Fish/Wildlife Monitoring Advisory Group and the Northwest Indian Fisheries Commission, Olympia, Washington. 37 p.

Groffman, P. M., A. J. Gold, T. P. Husband, R. C. Simmons and W. R. Eddleman. 1990. An investigation into multiple uses of vegetated buffer strips. Publication No. NBP-90-44, Department of Natural Resources Science, University of Rhode Island, Kingston, Road Island.

Groot, C. and L. Margolis. 1991. Pacific salmon life histories. UBC Press, Vancouver, British Columbia, Canada.

Guyette, R. P., W. G. Cole, D. C. Dey, and R.-M. Muzika. 2002. Perspectives on the age and distribution of large wood in riparian carbon pools. Canadian Journal of Fisheries and Aquatic Sciences 59:578-585.

Haberstock, A. E., H. G. Nichols, M. P. DesMeules, J. Wright, J. M. Christensen, and D. H. Hudnut. 2000. Method to identify effective riparian buffer widths for Atlantic salmon habitat protection. Journal of the American Water Resources Association 36:1271-1286.

Hall, J. L., and R. C. Wissmar. 2004. Habitat factors affecting sockeye salmon redd site selection in off-channel ponds of a river floodplain. Transactions of the American Fisheries Society 133:1480-1496.

Hallock, R. J., D. H. Fry and D. A. LaFaunce. 1957. The use of wire fyke traps to estimate the runs of adult salmon and steelhead in the Sacramento River. California Fish Game 43(4):271-298.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienjaemper, K. Cromack Jr., and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Hartman, G., J. C. Schrivener, L. B. Holtby, and L. Powell. 1987. Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia. Pages 330-370 in Salo, E. O., and T. W. Cundy. Streamside management: forestry and fishery interactions. University of Washington, Seattle, Washington

Harvery, B.C. 1998. Influence of large woody debris on retention, immigration, and growth of coastal cutthroat trout (*Oncorhynchus clarki clarki*) in stream pools. Canadian Journal of Fisheries and Aquatic Sciences. 55:1902-1908

Healey, M. C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type Chinook salmon, *Oncorhynchus tshawytscha*. Canadian Field-Naturalist 97:427-433.

Healey, M. C. 1991. Life history of Chinook salmon (Oncorhynchus tshawytscha). Pages 313-393 Groot, C., and L. Margolis, editors. Pacific Salmon Life Histories, University of British Columbia Press, Vancouver, BC.

Healey, M. C. 1998. Paradigms, policies, and prognostication about the management of watershed ecosystems. Pages 662-682 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Heede, B. H. 1985. Channel Adjustments to the Removal of Log Steps: An Experiment in a Mountain Stream. Environmental Management 9:427-432.

Hershey, A. E., and G. A. Lamberti. 1998. Stream macroinvertebrate communities. Pages 169-199 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Hession, W. C., T. E. Johnson, D. F. Charles, D. D. Hart, R. J. Horwitz, D. A. Kreeger, J. E. Pizzuto, D. J. Velinsky, J. D. Newbold, C. Cianfrani, T. Clason, A. M. Compton, N. Coulter, L. Fuselier, B. D. Marshal and J. Reed. 2000. Ecological benefits of riparian reforestation in urban watersheds: study design and preliminary results. Environmental Monitoring and Assessment 63:211-222.

Hoar, W. S. 1958. The evolution of migratory behaviour among juvenile salmon of the genus Oncorhynchus. Journal of the Fisheries Research Board of Canada 15:391-428.

Hobbie, J. E. 2000. Estuarine science: a synthetic approach to research and practice. Island Press, Washington D.C. 539 p.

Horner, R. R. 1996. Biofiltration for stormwater quality control. Engineering Program Course Manual, Center for Urban Water Resource Management, University of Washington, Seattle, Washington.

Horner, R. R. and B. W. Mar. 1982. Guide for Water Quality Impact Assessment of Highway Operations and Maintenance. Report No. WA-RD-39.14, Washington Department of Transportation, Olympia, Washington.

Horner, R. R. and C. Horner. 1995. Design, construction, and evaluation of a sand filter stormwater treatment system, Part II, performance monitoring. Alaska Marine Lines, Seattle, Washington.

Horner, R. R. and C. W. May. 2000. Watershed Urbanization and the Decline of Salmon in Puget Sound Streams. Center for Urban Water Resource Management, University of Washington, Seattle, Washington.

Horner, R. R. and C. W. May. 1999. Regional study supports natural land cover protection as leading bet management practice for maintaining stream ecological integrity. Proceedings of The Comprehensive Stormwater and Aquatic Ecosystem Management Conference, Vol. 1:233-247. Auckland, New Zealand.

Horner, R., D. Booth, A. Azous, and C. May. 1996. Watershed determinant of ecosystem functioning. Pages 251-274 in Roesner, L. A., editor. Effects of watershed development and management on aquatic ecosystems. Proceedings of the ASCE Conference, Snowbird, Utah.

Hubbard, J. P. 1977. Importance of riparian ecosystems: biotic considerations. Pages 14-19 in Johnson, R. R., and D. A. Jones, editors. Importance, preservation and management of riparian habitat: a symposium. U.S. Forest Service, Fort Collins, Colorado.

Hubbard, R. K. and R. R. Lowrance. 1994. Riparian forest buffer system research at the Coastal Plain Experimental Station, Tifton, Georgia. Water, Air, and Soil Pollution 77:409-432.

Jackson, C. R., and C. A. Sturm. 2002. Woody debris and channel morphology in fist- and second-order forested channels in Washington's coast ranges. Water Resources Research 38(9):1-14.

Jacobs, T. C. and J. W. Gilliam. 1985. Riparian Losses of Nitrate from Agricultural Drainage Waters. Journal of Environmental Quality 14: 472-478.

Jay, D. A., W. R. Geyer, and D. R. Montgomery. 2000. An ecological perspective on estuarine classification. Pages 149-176 in Hobbie, J. E., editor. Estuarine science: a synthetic approach to research and practice. Island Press, Washington D.C. 539 p.

Jeanes, E. D., and P. J. Hilgert. 2001. Juvenile salmonid use of lateral stream habitats middle Green River, Washington 200 data report. Final report by R2 Resource Consultants, Inc. to U.S. Army Corps of Engineers, Seattle District, Seattle, Washington. 63 p.

Jennings, M. J., M. A. Bozek, G. R. Hatzenbeler, E. E. Emmons, and M. D. Staggs. 1999. Cumulative effects of incremental shoreline habitat modifications on fish assemblages in north temperate lakes. North American Journal of Fisheries Management 19:18-27.

Johannessen, J. and A. MacLennan 2007. Beaches and Bluffs of Puget Sound. Technical Report 2007-04. Prepared by Coastal Geologic Services, Inc. Bellingham WA for Puget Sound Nearshore Partnership, Olympia.

Johnson, A. W. and D. M. Ryba. 1992. A literature review of recommended buffer widths to maintain various functions of stream riparian areas. King County Surface Water Management Division (SWM) Special Report.

Johnson, L. B., D. H. Breneman, and C. Richards. 2003. Macroinvertebrate community structure and function associated with large wood in low gradient streams. River Research and Applications 19:199-218.

Johnson, L. L., T. K. Collier, and J. E. Stein. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. Aquatic Conservation: Marine And Freshwater Ecosystems 12:517-538.

Johnson, P. N. 2004. Presentation at Greater Lake Washington Chinook Workshop. King County, Seattle, Washington.

Johnson, P. N., F. A. Goetz, C. J. Ebel, K Bouchard, M. E., Hanks, P. Pearson, A Fox, and L. R. Lawrence. 2003. Fish passage investigations at the Hiram M. Chittenden Lacks, Seattle, WA in 2001. Final Report, U.S. Army Corps of Engineers, Seattle, Washington. 78 p.

Johnson, P., D. Mock, E. Teachout, and A. McMillan. 2000. Washington State Wetland Mitigation Evaluation Study: Phase I, Compliance. WSDOE, Olympia, WA. Publ. No. 00-06-016.

Jones, R. C., and C. C. Clark. 1988. Impact of watershed urbanization on stream insect communities. Water Resources Bulletin 23:1047-1055.

Kaczynski, V. W., R. J. Feller, and J. Clayton. 1973. Trophic analysis of juvenile pink and chum salmon (Oncorhynchus gorbuscha and O. keta) in Puget Sound. Journal of the Fisheries Research Board of Canada 30:1003-1008.

Karr, J. R. and E. W. Chu. 2000. Sustaining living rivers. Hydrobiologia 422/423:1014.

Karr, J. R. and I. J. Schlosser. 1977. Impact of near stream vegetation and stream morphology on water quality and stream biota. U.S. Environmental Protection Agency 600-3-77-097.

Kauffman, J. B., M. Mahrt, L. Mahrt, and W. D. Edge. 2001. Wildlife of riparian habitats. Pages 361-388 in Johnson, D. H., and T. A. O'Neil editors. Wildlife-habitat relationships in Oregon and Washington. Oregon State University Press, Corvallis, Oregon.

Kelsey, K. A., and S. D. West. 1998. Riparian Wildlife. Pages 430-454 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

King County and the Washington State Conservation Commission. 2001. Salmon and steelhead habitat limiting factors and reconnaissance assessment report: executive summary. Green/Duwamish and Central Puget Sound Watersheds. Water Resource Inventory Area 9 and Vashon Island.

King County Department of Natural Resources (KCDNR). 2001. State of the nearshore ecosystem: eastern shore of central Puget Sound, including Vashon and Maury Islands (WRIAs 8 and 9). Final Review Draft. Report prepared by Battelle Marine Sciences Laboratory, Pentec Environmental, Striplin Environmental Associates, Shapiro Associates for King County Dept. of Natural Resources. KCDNR, Seattle, WA.

Knutson, K. L., and V. L. Naef. 1997. Management recommendations for Washington's priority habitats: Riparian. Washington Department of Fish and Wildlife, available at http://www.wa.gov/wdf/hab/ripxsum.htm. 181 p.

Koehler, M. E. 2002. Diet and prey resources of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) rearing in the littoral zone of an urban lake. Thesis, University of Washington, Seattle, Washington. 87 p.

Kondolf, G. M. 2000. Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals. Restoration Ecology 8(1):48-56.McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience 51(10):883-890.

Kostarev, V. L. 1970. Quantitative calculation of Okhotsk keta juveniles. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khnoz. Okeanogr. 71:145-158. (Translated from Russian; Fish Research Board of Canada, Translation Services 2589).

Kozloff, E. N. 1993. *Seashore Life of the Northern Pacific Coast*. University of Washington Press, Seattle, Washington.

Lamb, J. C. 1985. Water Quality and Its Control. John Wiley and Sonso New York.

Larkin, G. A., and P. A. Slaney. 1997. Implications of trends in marine-derived nutrient influx to south coastal British Columbia salmonid production. Fisheries 22(11):16-24.

Leavitt, J. 1998. The Functions of Riparian Buffers in Urban Watershed. Thesis, University of Washington, Seattle, Washington. 34 p.

Leopold, L.B. 1994. A view of the river. Harvard University Press. 298 p.

Levin, L. A., and T. S. Talley. 2002. Natural and manipulated sources of heterogeneity controlling early faunal development of a salt marsh. Ecological Applications 12:1785-1802.

Levings, C.D., McAllister, C.D., Cheng, B.D., 1986. Differential use of the Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish Aquat. Sci. 43, 1386–1397.

Levy, D. A. 1978. Chum salmon in a tidal creek of the Squamish River estuary, B.C. Pages 18-24 in Lipovsky, S. J., and C. A. Simenstad, editors. Gutshop '78 Fish food habits studies, Proceedings of the Second Pacific Northwest Technical Workshop. Washington Sea Grant, University of Washington, Seattle, Washington.

Likens, G. A., F. H. Bormann, N. M. Johnson, D.W. Fisher, R. S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecological Monographs 40:23-47.

Link, J. S. 2002a. Ecological considerations in fisheries management: when does it matter? Fisheries 27:10-17.

Link, J. S. 2002b. What does ecosystem-based fisheries management mean? Fisheries 27:18-21.

Locke, A. and S. Correy. 1986. Terrestrial and freshwater invertebrates in the neuston of the Bay of Fundy, Canada. Canadian Journal of Zoology. 64: 1535-1541.

Lowrance, R. R., S. McIntyre and C. Lance. 1988. Erosion and deposition in a field/forest system estimated using censium-137 activity. Journal of Soil and Water Conservation 43:195-99.

Lowrance, R., J. K Sharpe and J. M. Sheridan. 1986. Long-term sediment deposition in the riparian zone of a Coastal Plain watershed. Journal of Soil and Water Conservation 41(4):266-271.

Lowrance, R., R. Todd, J. Fail, O. Henrickson, R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.

Lucchetti, G., and R. Furstenberg. 1992. Management of coho salmon habitat in urbanizing landscapes of King County, Washington, USA. Pages 308-317 in Berg, L., and P. W. Delaney (eds.), Proceedings of the Coho Workshop, Nanaimo, B.C., Department of Fisheries and Oceans Canada, Vancouver, British Columbia.

Lynch, J. A., E. S. Corbett, and K. Mussallem. 1985. Best Management practices for controlling nonpoint source pollution on forested watershed. Journal Soil Water Conservation 40:164-167.

MacDonald, D. D., C. G. Ingersoll, and T. A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39:20-31.

MacDonald, J. S., C. D. Levings, C. D. McAllister, U. H. M. Fagerlund, and J. R. McBride. 1987. A field experiment to test the importance of estuaries for Chinook salmon (Oncorhynchus tshawytscha) survival: Short-term results. Canadian Journal of Fisheries and Aquatic Sciences 45:1366-1377.

MacDonald, K. Central Puget Sound nearshore biological data workshop. Meeting summary, King County Department of Natural Resources, Seattle, Washington. 16 p. + appendices.

Madison, C. E., R. L. Blevins, W. W. Frye, and B. J. Barfield. 1992. Tillage and grass filter strip effects upon sediment and chemical losses. In Agronomy Abstracts. American Society of Agronomy, Madison, Wisconsin.

Martin D. J., L. J. Wasserman, and V. H. Dale. 1986. Influence of Riparian vegetation on posteruption survival of coho salmon fingerlings on the west-side streams of Mount St. Helens, Washington. North American Journal of Fisheries Management 6:1-8.

Martin, D. J., and L. E. Benda. 2001. Patterns of instream wood recruitment and transport at the watershed scale. Transactions of the American Fisheries Society 130:940-958.

Maser, C., R. F. Tarrant, J. M. Trappe, and J. F. Franklin. 1988. From the forest to the sea: A story of fallen trees. USDA Forest Service PNW-GTR-229.

Mason, J. C. 1974. Aspects of the ecology of juvenile coho salmon (Oncorhynchus kisutch) in Great Central Lake, B.C. Fisheries Research Board of Canada, Technical Report 438. 7 p.

May, C. 1996. Assessment of cumulative effects of urbanization on small streams in the Puget Sound lowland ecoregion: implications for salmonid resource management. Dissertation, University of Washington, Seattle, Washington.

May, C. 1998b. The cumulative effects of urbanization on small streams in the Puget Sound lowland ecoregion. Pages 51-70 in Puget Sound Research '98, Washington Department of Ecology, Olympia, Washington.

May, C. W. 1998a. The cumulative effects of urbanization on small streams in the Puget Sound lowland ecoregion. http://www.psat.wa.gov/

May, C. W. 2003. Stream-riparian ecosystems in the Puget Sound lowland eco-region: a review of best available science. Prepared for Kitsap County Natural Resources Coordinator.

May, C. W. 2003. Streams-riparian ecosystems in the Puget Sound lowland eco-region, a review of best available science. 76 p. Appendix E in May, C. W., and G Peterson, Landscape assessment and conservation prioritization of freshwater and nearshore salmonid habitat in Kitsap County, Kitsap County, Washington.

May, C. W., E. B. Welch, R. R. Horner, J. R. Karr, and B. W. Mar. 1997b. Quality indices for urbanization effects in Puget Sound lowland streams. Water Resources Series Technical Report No. 154, Department of Civil Engineering, University of Washington, Seattle, Washington. 229 p.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, E. B. Welch. 1997a. Effects of urbanization on small streams in the Puget Sound lowland ecoregion. Watershed Protection Techniques 2:483-492.

McCarthy, S.G., J.P. Incardona, N.L. Scholz. 2008. Coastal Storms, Toxic Runoff, and the Sustainable Conservation of Fish and Fisheries. NOAA Fisheries, Seattle WA. Presented at American Fisheries Society Symposium 64:000–000, 2008

McDade, M. H., F. J. Swanson, W. A. McKee, J. F. Frankline, and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Canadian Journal of Forest Research 20:36.

McDowell, R. W. and A. N. Sharpley. 2003. Uptake Release of Phosphorous from Overland Flow in a Stream Environment. Journal of Environmental Quality 32:937-948.

McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience 52:883-890.

Meador, J. P., T. K. Collier, and J. E. Stein. 2002a. Use of tissue and sediment-based threshold concentrations of polychlorinated biphenyls (PCBs) to protect juvenile salmonids listed under the US Endangered Species Act. Aquatic Conservation: Marine And Freshwater Ecosystems 12:493-516.

Meador, J. P., T. K. Collier, and J. E. Stein. 2002b. Determination of a tissue and sediment threshold for tributyltin to protect prey species of juvenile salmonids listed under the US Endangered Species Act. Aquatic Conservation: Marine And Freshwater Ecosystems 12:539-551.

Mellina, E., R. D. Moore, S. G. Hinch, J. S. Macdonald, and G. Pearson. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. Canadian Journal of the Fisheries and Aquatic Sciences 59:1886-1900.

Mensing, D. M., S. M. Galatowitsch, J. R. Tester. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53 (1998):349-377.

Meyer, J. H., T. A. Pearce, and S. B. Patlan. 1980. Distribution and food habits of juvenile salmonids in the Duwamish Estuary, Washington, 1980. Unpublished report, U.S. Fish and Wildlife Service, Fisheries Assistance Office, Olympia, Washington. 42p.

Miller, D. E., P. G. Skidmore, and D. J. White. 2001. Channel design. A white paper developed by Inter-Fluve for the Washington Department of Transportation, Olympia, Washington. 109 p.

Milner, A. M., E. E. Knudsen, C. Soiseth, A. L. Robertson, J. Scheil, I. T. Phillips, and K. Magnusson. 2000. Colonization and development of stream communities across a 200-year gradient in Glacier Bay National Park, Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Biology 57:2319-2335.

Minton, G. R. 1993. The selection and sizing of treatment BMPs in new developments to achieve water quality objectives. Report by Herrera Environmental Consultants, Inc., and R.W. Beck, Inc. to King County Surface Water Management Division, Department of Public Works. Seattle, Washington.

Montgomery, D. R. and J. M. Buffington. 1998. Channel processes, classification and response. Pages 13-42 in Naiman, R. and R. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer, New York, New York. 705 p.

Montgomery, D. R., and S. M. Bolton. 2003. Hydrogeomorphic variability and river restoration. Pages 39-80 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Montgomery, J. M., Consulting Engineers, Inc. 1976. Forest harvest, residue treatment, reforestation and protection of water quality. Report to U.S. Environmental Protection Agency, National Technical Information Service, Springfield, Virginia. 273 p.

Morley, S. A. and J. R. Karr. 2002. Assessing and Restoring the Health of Urban Streams in the Puget Sound Basin. Conservation Biology 16:1498-1509.

Morning, J. R. 1975. Changes in environmental conditions: Part II The Alsea Watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Fishery Research Paper No. 9, Department of Fish and Wildlife, Corvallis, Oregon.

Moss, J. H. H. 2001. Development and application of a bioenergetics model for Lake Washington prickly sculpin (Cottus asper). Thesis, University of Washington, Seattle, Washington. 62 p.

Mudd, D. R. 1975. Touchet River Wildlife Study. Applied Research Section, Environmental Management Division, Washington Game Department. Bulletin No. 4.

Mundie, J. H. 1969. Ecological implications of the diet of juvenile coho in streams. Pages 135-152, in Northcote, T. G. editor. Symposium on salmon and trout streams. H. R. MacMillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia, Vancouver, British Columbia.

Murphy, M. L. Primary production. Pages 144-168 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Murphy, M. L. and K V. Koski. 1989. Input and Depletion of Woody Debris in Alaska Streams and Implication for Streamside Management. North American Journal of Fisheries Management 9:427-436.

Murphy, M. L., K V. Koski, J. M. Lorenz, and J. F. Thednga. 1989. Downstream migrations of juvenile Pacific salmon (*Oncorhynchus* spp.) in a glacial transboundary river. Canadian Journal of Fisheries and Aquatic Sciences 54:2837-2846.

Naiman, R. J. 1998. Biotic stream classification. Pages 97-119 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Naiman, R. J., and R. E. Bilby, editors. 1998. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 729 p.

Naiman, R. J., R. E. Bilby, and P. A. Bisson. 2000. Riparian ecology and management in the Pacific coastal rain forest. BioScience 50:996-1011.

Naiman, R.J., J.M. Helfield, K.K. Bartz, D.C. Drake, and J.M. Honea. 2009. Pacific Salmon, Marine-Derived Nutrients, and the Characteristics of Aquatic and Riparian Ecosystems. American Fisheries Society Symposium 69:395–425, 2009.

National Academy of Science. 2002. Riparian areas: functions and strategies for management. Prepublication copy, available to read at: http://books.npa.edu/books/0309082951/html/ 400 p.

National Marine Fisheries Service (NMFS). 1996. Coastal salmon conservation: working guidance for comprehensive salmon restoration initiatives on the Pacific Coast. National Oceanic and Atmospheric Administration, Northwest and Southwest Regions of the national Marine Fisheries Service, Seattle Washington. 29 p.

National Marine Fisheries Service (NMFS). 1999. A Citizen's Guide to the 4(d) Rule for Threatened Salmon and Steelhead on the West Coast. National Oceanic and Atmospheric Administration, Northwest and Southwest Regions of the national Marine Fisheries Service, Seattle Washington. 26 p.

Nawa, R. K., and C. A. Frissell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management 12:634-639.

Neary, D. G., P. B. Bush and J. L. Michael. 1993. Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress. Environmental Toxicology and Chemistry 12: 411-428.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4–21.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Sciences. 37:1076-1085.

Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences. 49:783-789.

NOAA (National Oceanic and Atmospheric Administration). 2013a. Status of ESA Listings & Critical Habitat Designations for West Coast Salmon and Steelhead. http://www.westcoast.fisheries.noaa.gov/publications/protected_species/salmon_steelhead/status_of_esa_salmon_listings_and_ch_designations_map.pdf. Accessed December 26, 2013.

NOAA (National Oceanic and Atmospheric Administration) Fisheries. 2013b. Endangered and Threated Species; Designation of Critical Habitat for Lower Columbia River Coho Salmon and Puget Sound Steelhead. 50 CFR Part 226. Vol. 78. No. 9. January 14, 2013.

NRC (National Research Council). 1996. Upstream. National Academy Press, Washington, D.C.

Okada, S., and A. Taniguchi. 1971. Size relationships between salmon juveniles in shore waters and their prey animals. Hokkaido Daigaku Sapporo Suisangakuba Hokodate, Bulletin 22:30-36.

Osborn, L. L. and D. A. Kovavic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29:243-258.

Palone, R. S., and A. H. Todd, editors. 1998. Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers. US Forest Service, Northeastern Area State and Private Forestry, Publication NA-TP-02-97. Morgantown, West Virginia.

Parametrix and NRC. 1999. City of Seattle Built Environment Shoreline Surveys, City of Seattle, December, 1999

Parametrix, Inc. 1985. Juvenile salmonid stomach content study, Everett Harbor, 1984. Report by Parametrix, Inc. to U.S. Navy, Naval Facilities Engineering Command, San Bruno, California. 27p + Appendices.

Pauley G. B., D. A. Armstrong, and T. W. Heun. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)–Dungeness crab. U.S. Fish and Wildlife Service, Biological Report 82(11.63), U.S. Army Corps of Engineers, TR EL-82-4. 20 p.

Pauley, G. B., B. M. Bortz, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) - steelhead trout. U.S. Fish and Wildlife Service Biological Report 82(11.62). U.S. Army Corps of Engineers, TR EL-82-4. 24p.

Pauley, G. B., K. L. Bowers, and G. L. Thomas. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) - chum salmon. U.S. Fish and Wildlife Service Biological Report 82(11.81). U.S. Army Corps of Engineers, TR EL-82-4. 17p.

Pauley, G. B., K. Oshima, K. L. Bowers, and G. L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) - sea-run cutthroat trout. U.S. Fish and Wildlife Service Biological Report 82(11.86). U.S. Army Corps of Engineers, TR EL-82-4. 21p.

Pearsons, T. D., H. W. Li, and G. A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Transactions of the American Fisheries Society 121:427-436.

Penttila, D. 2000. Grain size analysis of spawning substrates of the surf smelt (*Hypomesus*) and Pacific sand lance (*Ammodytes*) on Puget Sound Spawning beaches. Data summary, State of Washington Department of Fish and Wildlife, Marine Resources Division, La Conner, Washington.

Penttila, D. 2001. Documented spawning areas of Pacific herring (Clupea), surf smelt (Hypomesus), and the Pacific sand lance (Ammodytes) in Snohomish County Washington, Unpublished report, Washington Department of Fish and Wildlife, Olympia, Washington.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Technical Report 2007-03. Prepared by Washington Department of Fish and Wildlife, Olympia for Puget Sound Nearshore Partnership, WA.

Perkins, S. J. 1994. The shrinking Cedar River: channel changes following flow regulation and bank armoring. American Water Resources Association, June:649-659.

Pess, G. R., T. J. Beechie, J. E. Williams, D. R. Whitall, J. I. Lange, and J. R. Klochak. 2003. Watershed assessment techniques and the success of aquatic restoration activities. Pages 185-201 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Peterson, B. J., W. M. Wollheim, P. J. Mulholland, J. R. Webster, J. L. Meyer, J. L. Tank, E. Marti, W. B. Bowden, H. M. Valett, A. E. Hershey, W. H. McDowell, W. K. Dodds, S. K. Hamilton, S. Gregory and D. D. Morrall. 2001. Control of Nitrogen Export from Watersheds by Headwater Streams. Science 292: 86-89.

Peterson, N. P., A. Hendry, and T. P. Quinn. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Report TFW-F3-92-001 to Washington Department of Natural Resources and Timber Fish and Wildlife by University of Washington, Seattle, Washington.

Peterson, R. C., L. B. M. Petersen, and J. Lacoursiere. 1992. A building block model for stream restoration. In Boon, P. J., P. Calow, and G.E. Petts, editors. River conservation and management. Wiley and Sons, New York, New York. 470 p.

Pflug, D.E. 1981. Smallmouth bass (*Micropterus dolomieui*) of Lake Sammamish: a study of their age and growth, food and feeding habits, population size, movement and homing tendencies, and comparative interactions with largemouth bass. M.S. Thesis, University of Washington, Seattle, Washington. 80 p.

Pflug, D.E., and G.B. Pauley. 1984. Biology of smallmouth bass (*Micropterus dolomieui*) in Lake Sammamish, Washington. Northwest Science. 58(2): 118-130.

Pierce, R. S. 1965. Evidence of Overland Flow on Forest Watersheds. In Sopper, W. E., and H. W. Lull, editors. Forest Hydrology: Proceedings of a National Science Foundation Advanced Science Seminar. Pergamon Press, New York.

Pollock, M. M. 1998. Biodiversity. Pages 430-454 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Port of Seattle. 2009. Duwamish: Lower Duwamish River Habitat Restoration Plan- An Inventory of Port of Seattle Properties. Prepared by Seaport Planning Group. Adopted by the Port of Seattle Commission, July 7, 2009.

Poston, T. 2001. Treated Wood Issues Associated with Overwater Structures in Marine and Freshwater Environments. Prepared for the Washington Department of Fish and Wildlife. April 2001.

Price, D. 2004. Washington Department of Fish and Wildlife. Olympia, WA.

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51:37-51.

Rapp, C., and T. B. Abbe. 2003. The delineation of channel migration zones: a guidance document for the State of Washington. Unpublished draft report. 136 p.

Reed, D. J. 2000. Coastal biogeomorphology an integrated approach to understanding the evolution, morphology , and sustainability of temperate coastal marshes. Pages 347-361 in Hobbie, J. E., editor. Estuarine science: a synthetic approach to research and practice. Island Press, Washington D.C. 539 p.

Reimers, P. E. 1973. The length of residence of juvenile fall Chinook salmon in Sixes River, Oregon. Research Reports of the Fish Commission of Oregon 4:1-42.

Reisenbichler, R. R., F. M. Utter, and C. C. Krueger. Genetic concepts and uncertainties in restoring fish populations. Pages 149-183 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Reiser, D. W., and T. C. Bjorn. 1979. Habitat requirements of anadromous salmonids. General Technical Report PNW-96, US Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 54 p.

Rice, C.A. 2006. Effects of Shoreline Modification on a Northern Puget Sound Beach: Microclimate and Embryo Mortality in Surf Smelt (*Hypomesus pretiosus*). Estuaries and Coasts, Vol. 29, No 1, p 63-71.

Richey, J. S. 1982. Effects of urbanization on a lowland stream in western Washington. Dissertation, University of Washington, Seattle, Washington.

Robison, E. G. and R. L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Sciences 36:790-801

Roby, K. B., D. C. Erman, and J. D. Newbold. 1977. Biological assessment of timber management activity impacts and buffer strip effectiveness on national forest streams of northern California. U.S. Forest Service, California Region.

Roni, P. 2003. Responses of benthic fishes and giant salamanders to placement of large woody debris in small Pacific Northwest streams. North American Journal of Fisheries Management 23:1087-1097.

Roni, P., and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282-292.

Roni, P., and T. P. Quinn. 2002. Effects of wood placement on movements of trout and juvenile coho salmon in natural and artificial streams channels. Transactions of the American Fisheries Society 130:675-685.

Roni, P., T. J. Beechie, R. E. Bilby, F. E. Leonetti, M. M. Pollock, G. R. Pess. 2002. A Review Stream Restoration Techniques and a Hierarchical Strategy for Prioritization Restoration in Pacific Northwest Watersheds. North American Journal of Fisheries Management 22:1-20.

Rudolph, D. C., and J. G. Dickson. 1990. Streamside zone width and amphibian and reptile abundance. The Southwestern Naturalist 35:472-476.

Ruggerone, G. T. and C. J. Harvey. 1995. Age specific use of habitat by juvenile coho salmon and other salmonids in the Chignik Lakes Watershed, Alaska. Pages 45-60 in: M.L. Keefe (ed.). Salmon Ecosystem Restoration: Myth and Reality. Proceedings of the 1994 Northeast Pacific Chinook and Coho Salmon Workshop. American Fisheries Society, Eugene, Oregon.

Ruggerone, G.T., T.S. Nelson, J. Hall and E. Jeanes. 2006. Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River and Estuary. Prepared for WRIA 9 Technical and Steering Committees.

Salo, E. O. 1991. Life History of Chum Salmon (Oncorhynchus keta). Pages 233-309 in Groot, C., and L. Margolis, editors. Pacific Salmon Life Histories, University of British Columbia Press, Vancouver, British Columbia.

Sandercock, F. K. 1991. Life History of Coho Salmon (Oncorhynchus kisutch). Pages 397-443 in Groot, C., and L. Margolis, editors. Pacific Salmon Life Histories, University of British Columbia Press, Vancouver, British Columbia.

Scanlon, T. M., J. P. Raffensperger, G. M. Hornberger and R. B. Clapp. 2000. Shallow Subsurface Storm Flow in a Forested Headwater Catchment: Observations and Modeling Using a Modified TOPMODEL. Water Resources Research 36(9): 2575-2586.

Schindler, D. E., and M. D. Scheuerell. 2002. Habitat coupling in lake ecosystems. Oikos 98:177-189.

Schueler, T. R., and H. K. Holland. 2000. Practice of watershed protection. Center for Watershed Protection, Ellicott City, Maryland. 741 p. + appendix.

Scott, J. B., C. R. Steward, and Q. J. Stober. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society 115: 555-567.

Scrivener, J. C. and B. C. Andersen. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (Oncorhynchus kisutch) in Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 41:1097-1105.

Seattle Department of Planning and Development (Seattle DPD). 2010a. Green Shorelines: Bulkhead Alternatives for a Healthier Lake Washington.

Seattle DPD. 2010b. Shoreline Characterization Report. City of Seattle, WA.

Seattle Public Utilities (SPU). 2013a. Thornton Creek Water Quality Channel. Seattle Public Utilities, Seattle WA. http://www.seattle.gov/util/Engineering/Projects/DrainageSystem/ThorntonCreek/index.htm. Accessed on December 10, 2013.

Seattle Public Utilities. 2013b. Meadowbrook Pond & Thornton Creek Confluence Project. Seattle Public Utilities, Seattle, WA. http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/Meadowbrook&ThorntonCreek/index.htm. Accessed on December 10, 2013.

Seattle. 2007. State of the Waters 2007. Volume I: Seattle Watercourses.

Seattle. 2001. Seattle's urban blueprint for habitat protection and restoration. Review Draft, City of Seattle's Salmon Team, Seattle, Washington.

Seattle. 2003. Limiting factors, data gaps and priority actions for aquatic habitats in the City of Seattle. Draft Report, Seattle Public Utilities, Comprehensive Drainage Plan. Seattle, Washington. 59 p.

Seattle. 2003. Limiting factors, data gaps, and priority actions for aquatic habitats in the City of Seattle. Draft report by Seattle Public Utilities, Seattle, Washington. 59 p.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbance: modern fragmented and disconnected river systems. Environmental Management 14:711-724.

Shaw, P. A. and J. A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. California Fish and Game 29:29-41.

Shelton, J. M. 1955. The hatching of Chinook salmon eggs under simulated stream conditions. Progressive Fish-Culturist, vol. 17, no. 1, p. 20-35.

Shelton, J. M., and R. D. Pollock. 1966. Siltation and egg survival in incubation channels. Transactions of the American Fisheries Society 95:183-187.

Shields, D. F., C. M. Cooper Jr., S. S. Knight, and M. T. Moore. 2003. Stream corridor restoration research: a long and winding road. Ecological Engineering 20:441-454.

Shirvell, C. S. 1994. Effect of changes in streamflow on the micorhabitat use and movements of sympatric juvenile coho salmon (Oncorhynchus kisutch) and Chinook salmon (O. tshawytscha) in a natural stream. Canadian Journal of Fisheries and Aquatic Sciences 51:1644-16524

Shreffler, D. K., C. A. Simenstad, and R. M. Thom. 1992. Temporary residence by juvenile salmon in a restored estuarine wetland. Canadian Journal of Fisheries and Aquatic Sciences 47::2079-2084.

Siler, E. R., J. B. Wallace and S. L. Eggert. 2001. Long-Term Effects of Resource Limitation on Stream Invertebrate Drift. Canadian Journal of Fisheries and Aquatic Sciences 58:1624-1637.

Simenstad, C. A. 2000. Commencement Bay aquatic ecosystem assessment ecosystem-scale restoration for juvenile salmon recovery. Report to City of Tacoma, Washington. 44 p.

Simenstad, C. A., A. J. Wick, J. R. Cordell, R. M. Thom, and G. D. Williams. 2001. Decadal development of a created slough in the Chehalis River estuary: Year 2000 results. Report to U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Simon, A., and A. Collison. 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms 27:527-546.

Sloan-Richey, J., M. Perkins, and K. Malueg. 1981. The effects of urbanization and stormwater runoff on the food quality in two salmonid streams. Verh. Int. Ver. Theor. Angew. Limnol. 21:812-818.

Snyder, J. O. 1931. Salmon of the Klamath River, California. Fish Bulletin No. 34, California Fish and Game, Sacramento, California. 130 p.

Sobocinski, K. L. 2003. The impact of shoreline armoring on supratidal beach fauna of central Puget Sound. MS Thesis. University of Washington School of Aquatic Fishery Sciences. 83 pp.

Spalding, S., N. P. Peterson, and T. P. Quinn. 1995. Summer distribution, survival, and growth of juvenile coho salmon under varying experimental conditions of brushy instream cover. Transactions of the American Fisheries Society 124:124-130.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzky. 1996. An ecosystem approach to salmonid conservation. ManTech Environmental Research Services Corporation. Corvallis, Oregon.

Spromberg, J.A. and N.L. Scholz. 2011. Estimating the future decline of wild coho salmon populations resulting from early spawner die-offs in urbanizing watersheds of the Pacific Northwest, USA. Integrated Environmental Assessment and Management, Vol 7, Issue 4, p 648-656, October 2011.

SPU and USACE. 2008. Synthesis of Salmon Research and Monitoring: Investigations Conducted in the Western Lake Washington Basin. December 31, 2008.

SPU. 2013b. Meadowbrook Pond & Thornton Creek Confluence Project. Seattle Public Utilities, Seattle WA. http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/Meadowbrook&ThorntonCreek/index.htm. Accessed on November 27, 2013.

Starkes, J. 2001. Reconnaissance assessment of the state of the nearshore ecosystem: eastern shore of central Puget Sound, including Vashon and Maury Islands (WRIAS 8 and 9). Report prepared for King County Department of Natural Resources, Seattle, Washington.

Stauffer, J. C., R. M. Goldstein, and R. M. Newman. 2000. Relationship of wooded riparian zones and runoff potential to fish community composition in agricultural streams. Canadian Journal of Fisheries and Aquatic Sciences 57:307-316.

Stein, J. N. 1970. A study of the large mouth bass population in Lake Washington. M.S. Thesis, University of Washington, Seattle, Washington. 69 p.

Steinblums, I. J., H. A. Froehlich, and J. K. Lyons. 1984. Designing stable buffer strips for stream protection. Journal of Forestry 82:49-52.

Steward, C. R. 1983. Salmonid Populations in an Urban Stream Environment. Thesis, University of Washington, Seattle, Washington. 237 p.

Suberkropp, K. F. 1998. Microorganisms and organic matter decomposition. Pages 120-143 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

Swales, S., and C. D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:232-242.

Tabor , R.A., G.S. Brown,. and V.T. Luiting. 2004. The Effect of Light Intensity on Sockeye Salmon Fry Migratory Behavior and Predation by Cottids in the Cedar River, Washington. North American Journal of Fisheries Management, 24: 1, 128 — 145.

Tabor, R. A., and R. M. Piaskowski. 2002. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington Basin. Report by U.S. Fish and Wildlife Service to Seattle Public Utilities, Seattle, Washington. 57 p.

Tabor, R. A., J. A. Scheurer, H. A. Gearns, and E. F. Bixler. 2004. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin. Annual Report, 2002, to Seattle Public Utilities, Seattle, Washington. 58 p.

Tabor, R.A., B.A. Footen, K.L. Fresh, M.T. Celedonia, F. Mejia, D.L. Low, and L. Park. 2007. Smallmouth Bass and Largemouth Bass Predation on Juvenile Chinook Salmon and Other Salmonids in the Lake Washington Basin. North American Journal of Fisheries Management 27: 1174-1188.

Tabor, R.A., H.A. Gearns, C.M. McCoy III, and S. Camacho. 2006. Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems, 2003 and 2004 Report. UW Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Thesis, University of Washington, Seattle, Washington.

Tanner, C. D. 1991. Potential intertidal habitat restoration sites in the Duwamish River estuary. Report to Port of Seattle, and U.S. Environmental Protection Agency, Seattle, Washington.93 p. + appendices.

Tanner, C. D., and G. T. Williams. 1991. Terminal 91 short fill mitigation project Phase II post-construction monitoring report. Unpublished report by Parametrix, Inc. to Port of Seattle, Seattle, Washington. 43 .p

Terrell, C. R., and P. B. Perfetti. 1989. Water quality indicator guide: surface waters. U.S. Soil Conservation Service, SCS-TP-161. Washington, D.C. 129p.

Thomas, J. W., M. G. Raphael, R. G. Anthony, E. D. Forsman, A. G. Gunderson, R. S. Holthavsen, et al. 1993. Viability assessments and management considerations for species associated with successional and old-growth forests of the Pacific Northwest: the report of the scientific analysis team. U.S. Forest Service, Portland, Oregon.

Thomas, R. E., J. A. Gharrett, M. G. Carls, S. D. Rice, A. Moles, and S. Korn. 1986. Effects of fluctuating temperature on mortality, stress and energy reserves of juvenile coho salmon. Transactions of the American Fisheries Society 115:52-59.

Thompson, W. L., and D. C. Lee. 2000. Modeling relationships between landscape-level attributes and snorkel counts of Chinook salmon and steelhead parr in Idaho. Canadian Journal of Fisheries and Aquatic Sciences 57:1834-1842.

Ulrike, Z., and A. Peter. 2002. The introduction of woody debris into a channelized stream: effect on trout populations and habitat. River Research and Applications 18:355-366.

United States Army Corps of Engineers (USACE). 1991. Buffer strips for riparian zone management. Waltham, MA.

United States Fish and Wildlife Service (USFWS). 2013. Species by County Report. http://ecos.fws.gov/tess_public/countySearch!speciesByCountyReport.action?fips=53033. Accessed December 26, 2013.

Van Sickle, J. and S. V. Gregory. 1990. Modeling inputs of large woody debris to streams form falling trees. Canadian Journal of Forest Resources 20:1593-1601.

Vanderholm, D. H., and E. C. Dickey. 1978. American Society of Agricultural Engineers Paper No. 78-2570. American Society of Agricultural Engineers Winter Meeting, Chicago, Illinois.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Vought, L. B. M., J. Dahl, C. L. Pedersen, and J. O. Lacoursiere. 1984. Nutrient retention in riparian ecotones. Ambio 23:342-348.

Waldichuk, M. 1993. Fish habitat and the impact of human activity with particular reference to Pacific Salmon. Pages 295-337 in Parsons, L. S., and W. H. Lear, editors. Perspectives on Canadian marine fisheries management. Canadian Bulletin Fisheries and Aquatic Sciences. 226.

Walker, J. R. 1992. Urban stream enhancement: where to start? Thesis, University of Washington, Seattle, Washington.

Wallace, J. B., J. R. Webster, S. L. Eggert, J. L. Meyer and E. R. Siler. 2001. Large woody debris in a headwater stream: Long-term legacies of forest disturbance. International Review of Hydrobiology 86:501-513.

Wang, L. J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28(2):255-266.

Ward, J. V., and K. Tockner. 2001. Biodiversity: towards a unifying theme for river ecology. Freshwater Biology 46:807-819.

Warner, E. and B. Footen. 1999. The relationship between piscivorous fishes to juvenile salmon: Lake Washington, Lake Sammamish and the Ship Canal, February-June 1997. Working Draft. Muckleshoot Indian Tribe, Auburn, Washington.

Washington State Administrative Code (WAC) 222-16-031. 2001. Interim Water Typing System, http://www.leg.wa.gov/WAC/index.cfm?section=222-16-031&fuseaction=section

Waters, T. F. 1995. Sediment in streams – sources, biological effects and control. American Fisheries Society Monograph 7. Bethesda, Maryland

WDFW. 1998. 1997 Washington salmonid stock inventory. Appendix: bull trout and Dolly Varden. Washington Department of Fish and Wildlife, Olympia, Washington.

WDFW. 2003. Integrated streambank protection guidelines. Aquatic Habitat Guidelines: An integrated Approach to Marine, Freshwater and Riparian Habitat Protection and Restoration. Washington State Department of Fish and Wildlife, available at: http://www.wa.gov/wdfw/hab/ahg/ispgdoc.htm.

WDFW. 2012. Stream Habitat Restoration Guidelines. Prepared by the Washington State Aquatic Habitat Guidelines Program. Cramer, Michelle L. (managing editor). Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service. Olympia, Washington.

WDNR. 2000. Changing our waterways, trend in Washington's water systems. Washington State Department of Natural Resources, Olympia, Washington.

WDOE. 2001. Stormwater Management Manual for Western Washington. Publication numbers 99-11 through 99-15. Washington State Department of Ecology, Olympia, WA.

WDOE. 2007. Modeling the Effects of Riparian Buffer Width on Effective Shade and Stream Temperature. Prepared by the Washington Department of Ecology. Publication No. 07-03-028. Olympia, WA.

Weinstein, M. P, and D. A. Kreeger, editors. 2000. Concepts and controversies in tidal marsh ecology. Klewer Academic Publishers, Dortrecht, The Netherlands. 875 p.

Weitkamp, D. E., and G. T. Ruggerone. 2000. Factors affecting Chinook populations, background report. Prepared by Parametrix, Inc, Natural Resources Consultants, and Cedar River Associates for City of Seattle, Washington. 224 p.

Weitkamp, D. E., E. Gullekson, and T. H. Schadt. 1981. Shilshole Bay fisheries resources, spring 1981. Report by Parametrix, Inc. to Port of Seattle, Seattle, Washington. 15p.

Weitkamp, D. E., G. T. Ruggerone, L. Sacha, J. Howell, and B. Bachen. 2000. Factors Affecting Chinook Populations, Background Report. Prepared by Parametrix Inc., Natural Resources Consultants, and Cedar River Associates for the City of Seattle, June 2000.

Weller, D. E., T. E. Jordan, and D. L. Correll. 1998. Heuristic models for material discharge from landscapes with riparian buffers. Ecological Applications 8(4):1156-1169.

Welsh, E. B., J. M. Jacob, and C. W. May. 1998. Stream quality. Pages 6994 in Naiman, R., and R. Billby, editors. Ecology and management of streams and rivers in the Pacific Northwest coastal ecoregion. Springer-Verlag, Inc.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia.

WFPB. 2001. Environmental Impact Statement on Alternatives for Forest Practice Rules for Aquatic and Riparian Resources, Final Draft. Washington Forest Practices Board, Olympia, Washington.

White, S. W. 1975. The influence of piers and bulkheads on the aquatic organisms in Lake Washington. Thesis, University of Washington, Seattle, Washington. 115 p.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada 11:933-953.

Williams, G. D., and R.M. Thom. 2001. Marine estuarine shoreline modification issues. A white paper developed by Battelle Marine Sciences Laboratory for the Washington Department of Transportation, Olympia, Washington. 121 p.

Williams, G. D., R. M. Thom, J. E. Starkes, J. S. Brennan, J. P. Houghton, D. Woddruff, P. L. Striplin, M. Miller, Mp Pederson, A Skillman, R. Kropp, A. Borde, C. Freeland, K. McAurthur, V. Fagerness, S. Blanton, and L. Blackmore. 2001. Reconnaissance assessment of the state of the nearshore ecosystem: eastern shore of central Puget Sound, including Vashon and Maury Islands (WRIAs 8 and 9). Unpublished report by King County Department of Natural Resources, Seattle, Washington. 367 p. + appendices.

Williams, J. E., C. A. Wood, and M. P. Dombeck, editors. 1997. Watershed restoration: principles and practices. American Fisheries Society, Bethesda, Maryland. 561 p.

Williams, R. W., R. M. Laramie, and J. J. James. 1975. A Catalog of Washington Streams and Salmon Utilization: Volume 1, Puget Sound Region. Washington Department of Fisheries: Olympia, Washington.

Wilson, L. G. 1967. Sediment removal from flood water by grass filtration. Transactions of the American Society of Agricultural Engineers 1967:35-37.

Wing, M. G., and A. Skaugset. 2002. Relationships of channel characteristics, land ownership, and land use patterns to large woody debris in western Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 59:796-807.

Wipfli, M. S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 54:1259-1269.

Wissmar, R. C., and P. A. Bisson. 2003. Strategies for restoring rivers: problems and opportunities. Pages 245-262 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Wissmar, R. C., J. H. Braatne, R. L. Beschta, and S. B. Rood. 2003. Variability of riparian ecosystems: implications for restoration. Pages 107-127 in Wissmar, R. C., and P. A. Bisson, editors. Strategies for restoring river ecosystems: sources of variability and uncertainty in natural and managed systems. American Fisheries Society, Bethesda, Maryland. 276 p.

Wong, S. L. and R. H. McCuen. 1982. The design of vegetative buffer strips for runoff and sediment control. A Technical Paper Developed as Part of a Study of Stormwater Management in Coastal Areas Funded by Maryland Coastal Zone Management Program. 23 p.

Wright, A. B. and L. A. Smock. 2001. Macroinvertebrate community structure and production in a low-gradient stream in an undisturbed watershed . Archiv fur Hydrobiologie 152:297-313.

Wydoski, R. S. and R. R. Whitney. 2003. Inland fishes of Washington. University of Washington Press, Seattle, Washington.

Wydzga, A M. 1997. The effects of urbanization and fine sediment deposition in Puget Sound lowland streams. Thesis, University of Washington, Seattle, Washington. 85 p + appendices.

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. Journal of Environment Quality 9:483-497.

Ziemer, R. R., and T. E. Lisle. 1998. Hydrology. Pages 43-68 in Naiman, R. J., and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York. 705 p.

TABLE OF CONTENTS

4.1. INTRODUCTION

Fish and Wildlife Habitat Conservation Areas (FWHCAs), as defined by the GMA, are lands designated and managed for maintaining targeted species within their natural geographic distribution so that isolated subpopulations are not created. Such areas are considered to be critical for the long term viability and proliferation of certain native fish and wildlife species. FWHCAs include all areas identified by the Washington State Department of Fish and Wildlife (WDFW) as priority habitat and species areas, urban natural open space habitat areas and bodies of water that provide migration corridors and habitat for priority species of fish.

WDFW houses the Priority Habitats and Species (PHS) Program, which is the authority on existing habitat and species information in Washington. The program serves as a resource for local governments, state and federal agencies, private landowners and consultants, and tribal biologists for land use planning. The PHS Program includes an interactive website (PHS on the web) with up-to-date information on known locations of species and habitats. Program publications include a Priority Habitats and Species List in 2009, and a comprehensive library of management recommendations. Specific links to PHS resources are provided below. PHS is actively updated, thus the links below will provide the users of this document with the most up-to-date information about priority species and habitats.

- PHS on the Web. Interactive Mapping of priority habitats and species: http://wdfw.wa.gov/mapping/phs/
- Priority Habitats and Species List, WDFW's 2009 publication cataloging species and habitats considered priorities for conservation and management. http://wdfw.wa.gov/conservation/phs/list/
- Priority Species and Habitat Management Recommendations. http://wdfw.wa.gov/conservation/phs/mgmt_recommendations/

Additional resources that users of this document can reference for species information for the Seattle area include:

- Seattle Audubon Society. Birds of Washington State. http://www.birdweb.org/Birdweb/
- Burke Museum.
    - Mammals of Washington. http://collections.burkemuseum.org/mamwash/
    - Amphibians and Reptiles of Washington. http://www.burkemuseum.org/herpetology/checklist
- Washington Herp Atlas. http://www1.dnr.wa.gov/nhp/refdesk/herp/index.html
- NatureMapping. Washington Wildlife Distribution Maps. http://naturemappingfoundation.org/natmap/maps/wa/
- WDFW. Seal and Sea Lion Haulout Sites in Washington - http://wdfw.wa.gov/publications/00427/wdfw00427.pdf

The complete list of PHS species and habitat for King County can be found at: http://wdfw.wa.gov/publications/00165/2013_distribution_by_county.xls.

While the PHS program is for all of Washington, this section summarizes WDFW's priority habitats and species found in Seattle. It should be noted that management recommendations contained in this report are intended primarily for rural conditions. Given the urban nature of Seattle and the habituation of some species to urban conditions, management of these species needs to be tailored to fit Seattle's context. When appropriate, Seattle works with the Department of Fish and Wildlife to draft specific management recommendations that take into account the urban nature of the specific area.

Several PHS species and habitats listed as occurring in King County are not included herein because they either have no recorded occurrence in Seattle, or there is a lack of suitable habitat for the species.

Additionally, several aquatic (or semi-aquatic) PHS species and habitats are not included in this section because the management recommendations presented in either Section 2-1 (Wetlands) or Section 3-1 (Aquatic Areas) are considered broadly applicable to, and appropriate for, the management and protection of those species / habitats. These species / habitats include:

- All listed fishes
- Butter clam
- Native littleneck clam
- Geoduck
- Dungeness crab
- Pandalid shrimp
- Lacustrine littoral habitat
- Lacustrine limnetic habitat
- Estuarine intertidal habitat
- Riparian habitat
- Palustrine habitat

Included below are descriptions of the PHS species and habitats relevant to the City of Seattle, and management recommendations. These species include Bald Eagle, Great Blue Heron, Peregrine Falcon, Purple Martin, Breeding Concentrations of Alcids (i.e. Marbled Murrelet), Waterfowl Concentrations, Semipalmated Plover, California Sea Lion, and Western Pond Turtle. Relevant PHS habitats include Biodiversity Corridors, and Cliffs / Bluffs.

4.2. BIRDS

4.2.1. Bald Eagle

Bald eagles breed throughout most of the United States and Canada, with the highest concentrations occurring along the marine shorelines of Alaska and Canada. They winter throughout most of their breeding range, primarily south of southern Alaska and Canada (U.S. Fish and Wildlife Service 1986, Stinson et al. 2000). In Washington, bald eagles nest primarily west of the Cascade Mountains, with scattered breeding areas along major rivers in the eastern part of the state. Wintering populations are found throughout the Puget Sound region, the San Juan Islands, Hood Canal, the Olympic Peninsula, the upper and lower Columbia River and its tributaries. Major wintering concentrations are often located along rivers with salmon runs. In Seattle the Department of Fish and Wildlife reports that they have been observed nesting in locations along the Lake Washington shoreline, in the West Point/ Discovery Park area, Green Lake, Foster Island, Union Bay and Duwamish Head area.

Breeding Territories

Eagles defend breeding territories that include the active nest, alternate nests, preferred feeding sites, and perch and roost trees (Stalmaster 1987). Within a territory, snags and trees with exposed lateral limbs or dead tops are used as perches, roosts, and defense stations (U.S. Fish and Wildlife Service 1986). In Washington, breeding territories include upland woodlands and lowland riparian stands with a mature conifer or hardwood component (Grubb 1976, Garrett et al. 1993, Watson and Pierce 1998). Territory size and configuration are influenced by factors such as breeding density (Gerrard and Bortolotti 1988), quality of foraging habitat, and the availability of prey (Watson and Pierce 1998). Territories sometimes contain alternate nests. Grubb (1980) found that alternate nest trees in territories of eagles in Washington were located an average of 350 m (1,050 ft) from occupied nests. Although it is unclear why bald eagles construct alternate nests, they may facilitate successful reproduction if the primary nest is disturbed or destroyed.

The 3 main factors affecting the distribution of nests and territories are: 1) nearness of water and the availability of food; 2) the availability of suitable nesting, perching, and roosting trees; and 3) the number of breeding-age eagles in the area (Stalmaster 1987). An adequate, uncontaminated food source may be the most critical component of breeding habitat for bald eagles (U.S. Fish and Wildlife Service 1986, Stalmaster 1987). Breeding eagles in Washington primarily consume live or dead marine and fresh-water fishes, and also waterfowl and seabirds. Secondary food sources include mammals, mollusks, and crustaceans (Retfalvi 1970, Knight et al. 1990, Watson et al. 1991, Watson and Pierce 1998). Grubb (1980) found an average territory radius of 2.5 km (1.6 mi.) in western Washington. Home ranges of 50 pairs of bald eagles throughout Puget Sound averaged 6.8 km^2 (4.2 mi^2) (Watson and Pierce 1998). Ranges included areas occupied during occasional excursions beyond defended territories. Core areas of intense use averaged 1.5 km^2 (0.9 mi^2) in size. On the lower Columbia River, the mean home range size and minimum distance between eagle nests was 22 km^2 (13.6 mi^2) and 7.1 km (4.4 mi), respectively (Garrett et al. 1993). The distance eagles maintain between adjacent, occupied territories may be important for maintaining their productivity when food resources are limited (Anthony et al. 1994).

Courtship and Nest Building

In Washington, courtship and nest building activities intensify in January and February. Bald eagles commonly build large stick nests in mature trees, which are used over successive years. Eagles select nest trees for structure rather than tree species (Anthony et al. 1982, Anthony and Isaacs 1989). A typical nest tree is dominant or co-dominant within the overstory. It usually provides an unobstructed view of nearby water and has stout upper branches that form flight windows large enough to accommodate an eagle’s large wingspan (Grubb 1976). It is usually live, though it often has a dead or broken top with a limb structure that supports the nest. Bald eagle nests are usually located within the top 7 m (20 ft) of the tree (U.S. Fish and Wildlife Service 1986). Bald eagles prefer to nest along marine and freshwater shorelines. Approximately ninety-seven percent of Washington’s active bald eagle nests are within 914 m (3000 ft) of a lake, river, or marine shoreline (Stinson et al. 2001). The average distance between these nests and open water varies slightly with shore type [marine:140 m (457 ft), river:193 m (633 ft), lake:304 m (997 ft)]. In examining 218 bald eagle nests, Grubb (1980) found that their average distance from water was 86 m (282 ft). These distances ranged from 4.6 - 805 m (15 - 2,640 ft). 55% were within 46 m (150 ft) and 92% were within 183 m (600 ft) of a shoreline.

Eggs and Eaglets

Egg-laying begins in late February, with most pairs incubating by the third week of March (Watson and Pierce 1998). Eaglets hatch after a 35-day incubation period (Stalmaster 1987). Most eaglets fledge in mid-July but remain in the vicinity of the nest for several weeks prior to dispersal (Anderson et al. 1986, Watson and Pierce 1998). Most juvenile and adult bald eagles that nest in western Washington migrate to British Columbia and southeast Alaska in late summer and early fall. Adults return to their Washington territories by early winter (Watson and Pierce 1998).

Wintering

Migrant eagles from other states and provinces begin arriving at their traditional Washington wintering grounds during late October, and most disperse by March (Biosystems, Inc. 1980, 1981, Fielder and Starkey 1980, Garrett et al. 1988, Stalmaster 1989, Watson and Pierce 2001). Wintering bald eagles are attracted to western Washington by abundant prey, particularly salmon carcasses on Puget Sound tributaries.

Food Sources

Because wintering eagles often depend on dead or weakened prey, their diet may vary locally. In Washington, various types of carrion are important food items during fall and winter, including spawned salmon (primarily chum) taken from gravel bars along rivers (Stalmaster et al. 1985, Stalmaster 1987). Cattle carcasses and afterbirths, road-killed deer, and crippled waterfowl are important food sources where salmon carcasses are unavailable (J. Watson, personal observation).

Day Perches and Roosting Habitat

Wintering eagles select day perches according to their proximity to food sources (Steenhof et al. 1980). Perch trees tend to be the tallest available, and eagles will consistently use their preferred branches. A variety of tree species, both alive and dead, are used for perching (Stalmaster 1976). Bald eagles may roost communally in winter, with 3 or more eagles perching consecutive nights in the same trees. Communal roosting probably enhances food-finding in nearby foraging areas (Knight and Knight 1984). Eagles sometimes gather in staging trees located between feeding grounds and roost trees prior to entering the night roost (Hansen et al. 1980, Anthony et at. 1982, Stalmaster 1987). Because bald eagles leave little permanent sign of their presence after they depart wintering areas (i.e., no nest), emphasis in Washington state has been given to identifying the locations and describing characteristics of communal roosts during winter (Hansen 1977, Hansen et al. 1980, Keister 1981, Knight et al. 1983, Stellini 1987, Watson and Pierce 1998). Key roost components include core roost stands, buffer trees, flight corridors, staging trees, and foraging areas associated with roosts (Stalmaster 1987). Roost tree species vary with geographic area, but communal roost stands are generally uneven-aged with a multi-layered canopy, often on leeward-facing hillsides or in valleys. Such characteristics create favorable microclimates within roosts that promote energy conservation (Hansen et al. 1980, Keister 1981, Stalmaster and Gessaman 1984, Stellini 1987). Watson and Pierce (1998) documented twenty-six roosts on major tributaries of Puget Sound and found that eagle territories averaged 9 ha (22 ac) in size, were located <1.1 km (0.7 mi) from foraging areas, and contained roost trees that were larger in diameter, taller, and more decadent than random trees.

Management Issues and Recommendations

Residential development, timber harvest, and the construction of buildings, roads, and piers along shorelines are the main habitat alterations affecting breeding eagles in Washington. Habitat management for nesting bald eagles generally occurs within 400m (1320 ft) of the shores of Washington's outer coast, the Puget Sound, and major rivers and lakes. Maintaining tree and stand structure, and maintaining adequate distances between habitat alterations and nest trees, are the key factors for managing habitat near breeding eagles in Washington. The long-term goal in managing habitat alterations is to maintain suitable nest and perch trees within existing territories to insure their continued occupancy by bald eagles (Stinson et al. 2001). In Oregon, management for uneven-aged forests, dominated by Douglas-fir west of the Cascades and ponderosa pine east of the Cascades, enhance the potential for future nesting (Anthony and Isaacs 1989). Although maintaining unaltered old-growth stands may provide optimum bald eagle habitat, the necessary structural characteristics may be supplied by a carefully managed, younger forest over time. Selective logging in younger forests may be prescribed to maintain or enhance desired characteristics of nesting or roosting habitat (Stalmaster 1987). Forests that were hand-logged prior to 1940, leaving remnant old-growth trees, provided bald eagle breeding habitat along coastal British Columbia for the future in the 1980s (Hodges et al. 1984). In general, maintain as many mature trees as possible to protect forage, perch, alternate nest, and roost habitat (Anthony and Isaacs 1989).

Human Disturbance

The keys to preventing nesting bald eagles from being disturbed in Washington State are maintaining adequate distances between human activities and nest trees, and timing activities so that they don't interfere with nesting. WDFW recommends scrutiny of construction activities that result in increased pedestrian activity within 240 m (800 ft) of nests, as well as careful management of public trails and camping within this distance (Watson and Pierce 1998). Additionally, during the nesting season, activities such as tree cutting, the use of heavy machinery, pile driving, and blasting within 240 m (800ft) of active bald eagle nests should be avoided. These activities have a greater potential for disturbance beyond visual effects because they generate noise (U.S. Fish and Wildlife Service 1986). Activities that produce noise or visual effects within 120 m (400 ft) of the edges of communal roost trees or staging trees should be conducted outside of the critical roosting period (November 15 - March 15). This corresponds to the time when most eagles begin to arrive in eastern and western Washington, with numbers peaking in December and January and declining rapidly by mid-March (Biosystems, Inc. 1980, 1981, Fielder and Starkey 1980, Garrett et al. 1988, Stalmaster 1989). Furthermore, observations of adult eagles can help determine whether or not human activities are causing eagles to alter their behavior. Aggressive behavior, alarm calls, and adults flushing from their nest or perch indicate significant disturbance.

Timing

Activities within 240 m (800 ft) of nest trees that may disturb bald eagles should be conducted outside of the critical breeding period. The critical breeding period for Washington's bald eagles begins with courtship in early January and ends with juvenile dispersal in mid- to late-August (Watson and Pierce 1998, S. Zender, personal communication). Bald eagles in Oregon have a similar nesting phenology, with January 1 through August 31 identified as the time when human activities are most likely to affect breeding success (Isaacs et al. 1983). In residential areas, bald eagles that show tolerance to humans may not need the same distance or period of protection from disturbance (Bernatowicz, pers. comm., S. Negri, pers. comm.).

Screening

Maintain high tree density and moderate canopy closure to visually buffer bald eagle nests from human activities. In Washington, Watson and Pierce (1998) found that complete vegetative screening around nests dramatically reduced the time and frequency of eagles' responses to disturbance. Partial screening had less of a positive effect, although it did reduce response distance. In the same study, eagles nesting in taller trees at heights >47 m (154 ft) had significantly reduced responses to a walking pedestrian compared to nests that were lower in trees.

Windthrow

A nest stand's vulnerability to windstorms is an important consideration when determining buffer distances and minimum stand size (Anthony and Isaacs 1989). Maintain a buffer of 120-240 m (400-800 ft) from the nest in order to protect the core stand from the effects of windthrow. The shape of the buffer may vary with site topography and prevailing wind direction to maximize vegetative screening and protection of the core stand. Buffers with variable widths can be designed after conducting a windthrow hazard assessment that takes into account prevailing wind direction, soil conditions, etc. (Sathers et al. 1994). Currently, the Washington Forest Practices Regulations use forested buffers of 60-120 m (200-400 ft) for wetlands and marbled murrelet nest stands. Thinning and salvage logging is allowed within these buffers, provided that the residual forest can withstand major wind penetration. Research on the effects of windthrow indicates that the creation of abrupt forest openings may result in negative impacts to residual forest stands. Wind penetration has been documented up to 60 m (200 ft) into a conifer forest interior (Fritschen et al. 1971). Decreases in tree densities and tree canopy cover were noted up to 120 m (400 ft) into conifer forest from the clear-cut edge (Chen et al. 1992). These changes were attributed mostly to tree mortality and windthrow caused by high wind velocities along new clearcut edges. A forested buffer can mitigate these edge effects on core nest or roost stands.

Buffer Distances

Buffers between 100-1,200 m (330-4,000 ft) have been recommended throughout the United States to protect the integrity of nest trees and stands (Mathison et al. 1977, U.S. Fish and Wildlife Service 1982, 1986, Fraser et al. 1985, Anthony and Isaacs 1989, Grubb and King 1991,; Grubb et al. 1992). Nests and nest trees must be protected year round, since bald eagles typically use and maintain the same nests year after year. In addition, nests that appear to be abandoned also need protection, since bald eagles often construct alternate nests that are used periodically. When developing site management plans, WDFW recommends buffering bald eagle nests with a two-zone management system that mimics a strategy designed by the U.S. Fish and Wildlife Service (1981). The following guidelines for these zones are based on the research cited in this document:

Protected Zone (Primary Zone). This zone protects and screens the nest tree and should extend at least 120 m (400 ft) from the nest tree. Its size and shape will vary with site conditions such as topography, prevailing winds, and screening vegetation, as well as on the eagles' tolerance to human activities.

In areas where vegetation and/or topography don't provide adequate screening within 120 m (400 ft) of the nest, consider increasing the size of the protected zone. Retain all existing large trees and existing forest structure within the protected zone. Activities that significantly alter the landscape or vegetation, such as timber harvest; construction of buildings, roads, or power lines; mining; and the application of chemicals that are toxic to plants or animals, should be avoided in this zone. In some situations, noisy, non-destructive activities that can disturb eagles may need to be postponed until after the breeding and nesting seasons.

Conditioned Zone (Secondary Zone). The conditioned zone further screens and protects nest sites in the protected zone and should extend from 100 to 240 m (330-800 ft) beyond the edge of the protected zone. Alternate nest locations, perch trees, and feeding sites should be included in this zone and will influence its size and shape (Stallmaster 1987). Depending on screening vegetation, prevailing winds, topography, and the sensitivity of the nesting eagles to human activities, this zone may need to be expanded up to 800 m (2640 ft) from the edge of the protected zone. Avoid constructing facilities for noisy or intrusive activities, such as mines, log transfer and storage areas, rock crushing operations, and oil refineries, in the conditioned zone. High-density housing and multi-story buildings should also be avoided. Avoid constructing roads or trails within sight of the nest that would facilitate human or predator access to the nest. Construction activities (e.g., homes, roads, and power lines) that take place out of sight of the nest should be postponed until after the young eagles have fledged, as should forest practice activities. Timber harvest within conditioned zones should be designed to avoid blowdown and to provide future nest tree recruitment. Short term, unobtrusive activities, or those shown not to disturb nesting eagles, such as the use of existing roads, trails, and buildings, can occur year-round in the conditioned zone.

Roosting Habitat

Timber harvest, and the construction of roads and buildings are the main habitat alterations that negatively affect roosting eagles in Washington. The long-term goal in managing these alterations is to maintain suitable roost trees and roost components over time in areas inhabited by bald eagles in order to ensure their continued use. Key roost components included core roost stands, buffer trees, flight corridors and staging trees, and prey bases associated with roosts (Stalmaster 1987). Roost tree species vary with geographic area, but communal roost stands are generally uneven-aged with a multi-layered canopy and are often on leeward-facing hillsides or in valleys.

Perching and Foraging Habitat

Perches along shorelines near winter roosts or in nesting territories are important to foraging eagles. Tree structure, and the distance between habitat alterations and shorelines should be considered when managing for bald eagle wintering habitat. Chandler et al. (1995) studied the influence of shoreline perch trees on bald eagle distribution in Chesapeake Bay and found that shoreline segments used by eagles had more suitable perch trees, more forest cover, and fewer buildings than unused segments. Eagles used suitable perch trees that were less than 50 m (164 ft) from the shoreline but preferred those closer than 10 m (33 ft). This is consistent with other authors who observed bald eagles perching less than 50 m (164 ft) from shore (Stalmaster and Newman 1979, Steenhof et al. 1980, Buehler et al. 1992). Similarly, tall perch trees in leave strips that are 50-100 m (160-330 ft) wide along shorelines of major feeding areas were deemed important for foraging eagles (Stalmaster 1987). Also, Chandler et al. (1995) described how to map shoreline areas that could be managed or restored to maintain suitable bald eagle foraging habitat. They recommended protecting patches of shoreline forest, and specifically protecting live and dead trees over 20 cm (8 in) diameter at breast height (dbh) for future habitat.

Bald eagles often feed on the ground, in open areas where food resources are concentrated. They should be allowed a distance of at least 450 m (1,500 ft) from human activity and permanent structures. Buffer zones of 250-300 m (800 ft-1,000 ft) have been recommended in perching areas where little screening cover is present (Stalmaster and Newman 1978). Stalmaster and Newman (1979) found that 50% of wintering eagles in open areas flushed at 150 m (500 ft) but 98% would tolerate human activities at 300 m (1,000 ft). Activities that disturb eagles while feeding, especially during winter, can cause them to expend more energy, which increases their susceptibility to disease and poor health (Stalmaster 1987).

4.2.2 Great Blue Heron

Range and Distribution

Great blue herons are found throughout most of North America south of 55^{o} north latitude and into much of Central and South America. Breeding pairs on the Pacific coast occur only to about 52^{o} north latitude. Distribution of great blue herons within Washington is state-wide.

Need for Protection

Great blue herons can be vulnerable because of their tendency to aggregate during the breeding season. The availability of suitable great blue heron breeding habitat is declining as human population increases in Washington State. In addition, great blue herons may abandon breeding colonies or experience reduced reproductive success when disturbed by humans.

Habitat Requirements and Current Breeding Grounds in Seattle

Great blue herons occur near most types of fresh and saltwater wetlands including seashores, rivers, swamps, marshes, and ditches. They are found throughout Washington but are most common in the lowlands. In Seattle there is a major rookery in the Kiwanis Ravine located in Magnolia adjacent to Discovery Park. Other rookery locations include the area adjacent to the Hiram M. Chittenden Locks, near Union Bay/ Laurelhurst, above the Duwamish River in West Seattle and in North Beach area.

Nesting

Great blue herons are colonial breeders that nest in a variety of deciduous and evergreen tree species. Nests are usually constructed in the tallest trees available, presumably to reduce the risk of predation by mammals (Butler 1992, Carlson 1995), but may also be located in bushes and in artificial structures (Bruce 1986, Blus et al. 1980) when trees are absent (Henny and Kurtz 1978). In King and Kitsap counties, great blue herons nested at heights ranging from 9-26 m (30-85 ft) in the tallest trees available (Jensen and Boersma 1993). A British Columbia study found that most great blue heron nests occurring in trees were located >14 m (46 ft) in height. No nests were found under 10 m (33 ft) (Mark 1976). Great blue herons in western Oregon nested at heights ranging from 7-25 m (23-82 ft) (Werschkul et al. 1976).

Feeding

Great blue herons feed on a wide variety of aquatic and marine animals found in shallow waters. Great blue herons also feed on mice and voles (Calambokidis et al. 1985, Butler 1995), which are an important food for nestlings in Idaho (Collazo 1981) and may be an important food for British Columbia great blue herons during winter (Butler 1995).

At large spatial scales (e.g., great blue heron home range), the location of great blue heron colonies is probably best explained by the distribution of foraging habitat (Gibbs 1991, Jensen unpublished data, see human disturbance below for smaller scale considerations). Although great blue herons may forage up to 29 km (18 mi) from a colony, most forage within 2-5 km (1-3 mi) of the colony (Short and Cooper 1985, Butler 1995). The number of nests per colony in British Columbia (Butler 1991), Oregon (Werschkul et al. 1977, Bayer and McMahon 1981), Maine (Gibbs 1991), and Washington (Jensen unpublished data) were positively correlated with the amount of nearby foraging habitat, and in Maine were negatively correlated with the costs of foraging at greater distances (km flown/ha of wetland visited). Feeding territory size and location may vary from year to year (Hoover and Wills 1987). The availability of alternative foraging and nesting habitat within close proximity of known foraging sites is probably critical to great blue heron reproductive success. Butler (1995) suggested that food availability strongly affects great blue heron survival, the spacing of their colonies, and their use of habitat. Moreover, great blue heron food supply may be limiting, particularly in areas where foraging areas freeze during winter (Butler 1992).

Colonies usually exist at the same location for many years, and productivity (number of fledglings/nesting herons) may be positively related to the number of years colonies have been in use (Butler 1995). This has been the case in the Kiwanis Ravine which has been an active nesting site for many years. Great blue herons may relocate their colonies in response to increased predation on eggs and young by mammals and birds such as eagles (Jensen unpublished data), declines in food availability (Simpson et al. 1987), or human disturbance. Jensen (unpublished data) suggested that 2 of the 5 King County colonies monitored in 1991 were abandoned in late spring due to bald eagle predation, but Butler (1995) found that there was no relationship between the location of great blue heron colonies and the location of areas with high densities of nesting eagles. Thus, abandonment of colonial nesting areas due to predation pressure from eagles may be regionally specific. Great blue heron colonies built in spruce or Douglas-fir trees may damage host trees over time, which may also influence colony relocation (Julin 1986).

Limiting Factors

The availability of nesting habitat in close proximity to suitable foraging habitat limits great blue herons. The availability of alternative foraging sites could be critical to nesting success. Great blue herons are generally sensitive to human disturbance and are frequently the target of vandalism (Parker 1980, English 1978). The type and extent of human disturbance can affect great blue heron colony site selection (Gibbs et al. 1987, Watts and Bradshaw 1994). In

Virginia, great blue herons chose colony sites further from roads and human structures than would be expected by chance; a pattern that was apparent up to 400-800 m (1,312-2,625 ft) from colonies (Watts and Bradshaw 1994). Great blue heron colonies have been abandoned in response to housing and industrial development, highway construction, logging, vehicle traffic, and repeated human intrusions (Leonard 1985, Parker 1980, Kelsall and Simpson 1979, Werschkul et al. 1976). In King and Kitsap counties, Jensen (unpublished data) found that great blue heron colony size decreased as distance to the nearest human disturbance within 300 m (984 ft) decreased, and as the amount of human development within 300 m (984 ft) of the colony increased. Nests occupied first in each of 3 King County colonies in 1991 were furthest from development and had more than twice as many fledgling than nests closer to development (3.13 versus 1.51 young/nest) (Jensen unpublished data).
Other studies suggested that great blue herons may habituate to non-threatening repeated activities (Webb and Forbes 1982, Vos et al. 1985, Calambokidis et al. 1985, Shipe and Scott 1981). Thus, different great blue herons may have different tolerance levels to disturbance depending on disturbance history and type (Simpson 1984). Although the effects of visual and auditory buffers have not been well studied, topographic or vegetation obstructions may ameliorate some types of disturbance (Webb and Forbes 1982).

Management Recommendations

The following is a summary of the management recommendations found in Management Recommendations for Washington's Priority Species, Volume IV: Birds prepared by Timothy Quinn and Ruth Milner for the Department of Fish and Wildlife.

Wherever possible, a habitat protection buffer at least 300 m (984 ft) wide should be established around the periphery of a colony. All human activities likely to cause colony abandonment should be restricted in this buffer year-round, and all human activities likely to cause disturbance to nesting great blue herons should be restricted in this buffer area from 15 February to 31 July.

Site specific management plans should be developed for each great blue heron colony whenever activities that might affect that colony are proposed. Such plans should consider the following:

The colony's size, location, relative isolation, and degree of habituation to disturbance; Topographic or vegetative features surrounding the colony that might ameliorate the effect of human disturbance; The availability of foraging areas and their proximity to the colony site; Proximity of forest lands that could be used as alternative colony sites; and Land-use patterns and potential for long-term availability of nesting and foraging habitat.

Stands of large trees at least 17 m (56 ft) high and at least 4 ha (10 ac) in size that can be buffered from disturbance should be left in the vicinity of great blue heron breeding colonies as alternative nesting habitat.

Foraging areas, especially wetlands, within a minimum radius of 4 km (2.5 mi) of colonies should be protected from development and should have a surrounding disturbance free buffer zone of at least 100 m (328 ft). Attempts should be made to keep all pesticides out of great blue heron foraging and nesting habitat, and associated buffer zones. Activities such as logging or construction should not occur within 1,000 m (3,281 ft) of a colony, and no aircraft should fly within a vertical distance of 650 m (2,133 ft) during the nesting season. Alternative forested stands at least 4 ha (10 ac) in size with dominant trees at least 17 m (56 ft) in height should be left in the vicinity of existing great blue heron breeding colonies.

4.2.3. Purple Martin

Purple martins breed from southern Canada to central Mexico (Brown 1997) and winter in South America (Ehrlich et al. 1988). In Washington, they typically breed near the waters around the Puget Sound, along the Strait of Juan de Fuca, the southern Pacific coastline, and near the Columbia River (S. Kostka, personal communication). Unconfirmed records suggest that other potential breeding areas might also be found from the Willamette Valley up through Thurston County. In Seattle they have been identified by the Department of Fish and Wildlife as breeding in boxes in the Highlands and Blue Ridge neighborhoods, at pier 90 and in the vicinity of downtown.

Need for Protection

The purple martin is a State Candidate species. This species has a high public profile and are vulnerable to population fluctuations due to a limited distribution and loss of suitable natural nesting cavities (Brown 1997).

Habitat Requirements

Purple martins are insectivorous, colonial nesting swallows that nest in cavities (Brown 1997). In Washington, most martins have been reported nesting in artificial structures near cities and towns in the lowlands of western Washington. Historically, they probably bred in old woodpecker cavities in large dead trees, but only a few such nests are known to exist in Washington today (Brown 1997, Russell and Gauthreaux 1999). The eastern race of purple martins often nest in apartment-style nest-boxes, while the western subspecies, found here in Washington, prefer to nest individually (Pridgeon 1997). The nest site preferences of the purple martin have been studied at Fort Lewis in Pierce County (Bottorff et al. 1994). Martins nested in a variety of artificial nesting structures, including wood duck boxes. No purple martin nesting activity was detected in artificial nesting structures on land; all artificial cavities were over freshwater wetlands, ponds or saltwater. Swallows were found nesting in both natural and artificial cavities intermingled with martin nests, possibly competing for nest sites. More recent observations documented four pairs nesting in natural snag cavities near water at Fort Lewis (S. Kostka, personal communication). Martins were also recently found nesting in boxes well away from water just outside of the fort in Spanaway. Purple martins feed in flight on insects (Ehrlich et al. 1988, Brown 1997). Favorable martin foraging habitat includes open areas, often located near moist to wet sites, where flying insects are abundant.

Limiting Factors

The decline of the purple martin is attributed to the lack of snags containing nest cavities (Bottorffet al. 1994) as well as competition for nesting cavities with more aggressive European starlings (*Sturnus vulgaris*) and house sparrows (*Passer domesticus*; Bottorff et al. 1994, Brown 1997).

Management Recommendations

In Washington, purple martins are known to nest in cavities located in old pilings over water and occasionally in snags (United States Fish and Wildlife Service 1985, Milner 1987). These pilings and snags (especially snags near water) should be protected and left standing. The removal of creosote-coated pilings that contain a purple martin nest box or that possibly contain cavities used by martins should be closely coordinated with the Washington Department of Fish and Wildlife (M. Tirhi, personal communication). Snags should be retained during timber harvesting operations near saltwater and wetlands (Milner 1988), including salvage operations after burns, blow-downs, and insect infestations (United States Fish and Wildlife Service 1985). Prescribed burns can be used as a tool to create favorable martin foraging habitat. Snags can be created in forest openings, or at forest edges (e.g., by topping trees) where nesting cavities are lacking, especially within 16 km (10 mi) of an existing purple martin colony (United States Fish and Wildlife Service 1985). Because northern flickers and pileated woodpeckers excavate cavities used by martins, managing for these species will indirectly benefit martins (K. Bettinger, personal communication). Because of their dependence on insects for food, purple martins can be impacted by the broad use of pesticides (United States Fish and Wildlife Service 1985). If insecticide or herbicide use is planned for areas where this species occurs, review Appendix A for contacts to assist in assessing the use of chemicals and their alternatives. Although artificial nesting structures are an important tool for the conservation of purple martins, they should not replace the protection of natural nesting structures (e.g., snags) and the habitat used by this species (S. Kostka, personal communication). If natural sites are lacking and cannot be provided by manipulating habitat, artificial nesting structures can be provided.

4.2.4. Peregrine Falcons

Peregrine falcons occur nearly worldwide. In Washington, nesting may occur in all but the driest parts of the state. Breeding has been verified along the outer coast, in the San Juan Islands, and in the Columbia Gorge. Young birds have been introduced in unoccupied historical habitat in Skamania, Lewis, Spokane, Asotin, and Yakima counties. In Seattle they have established an eyrie on a downtown office building and near Pidgeon Point in West Seattle.

The peregrine falcon is a State Endangered species. Peregrine falcon populations have increased in Washington since chlorinated hydrocarbon pesticides were banned in the United States, and through the success of reintroduction programs.

Need for Protection

Their numbers and distribution are still limited however, due primarily to the lingering effects of pesticides and the lack of suitable nesting sites. Nest sites need to be in close proximity to adequate food sources and free from human disturbance.

Habitat Requirements

Peregrine falcons usually nest on cliffs, typically 45 m (150 ft) or more in height. They will also nest on off-shore islands and ledges on vegetated slopes. Eggs are laid and young are reared in small caves or on ledges. Nest sites are generally near water. The birds are sensitive to disturbance during all phases of the nesting season (1 March through 30 June) (Pacific Coast American Peregrine Falcon Recovery Team 1982, Towry 1987). Disturbance can cause desertion of eggs or young, and later in the breeding season can cause older nestlings to fledge prematurely.

Peregrines feed on a variety of smaller birds that are usually captured on-the-wing. Hunting territories may extend to a radius of 19-24 km (12-15 mi) from nest sites (Towry 1987).

In winter and fall, peregrines spend much of their time foraging in areas with large shorebird or waterfowl concentrations, especially in coastal areas (Dekker 1995). At least 3 western Washington areas support significant numbers of winter resident peregrines annually: the Samish Flats, Grays Harbor, and the Sequim area (Dobler 1989).

Limiting Factors

Peregrine falcon populations declined worldwide as a result of sublethal doses of chlorinated hydrocarbon pesticides, especially DDT and dieldrin. Chemical contamination of the prey base resulted in reduced eggshell thickness, and consequently poor hatching success and survival of young peregrines (Snow 1972). Although these chemicals are now banned in the United States, eggshell thinning and other effects of pesticide contamination are still seen in some peregrine pairs (Peakall and Kiff 1988). Contamination probably results from consuming prey species that winter in countries that continue to use DDT and other organochlorine pesticides, from persistent pesticide residue remaining at the breeding grounds, or from current, illegal use of these chemicals in the United States (Henny et al. 1982, Stone and Okoniewski 1988). Additionally, peregrines may be limited in some parts of their range by availability of nesting sites in proximity to an adequate food source.

Management Recommendations

Breeding peregrine falcons are most likely to be disturbed by activities taking place above their nest (eyrie) (Herbert and Herbert 1969, Ellis 1982). Ellis (1982) recommended buffer zones of "no human activity" around peregrine falcon breeding sites in Arizona that ranged from 0.8 km to 4.8 km (0.5-3.0 mi), with wider buffer zones recommended for activities above the breeding cliff. These buffer distances were based on incidental observations of peregrine responses to various disturbances. In Washington, buffer zones of 4.8 km (3.0 mi) may not be necessary. However, human access along the cliff rim should be restricted within 0.8 km (0.5 mi) of the nest from March through the end of June (F. Dobler, personal communication). Human activities on the face of, or immediately below, nest cliffs should be restricted from 0.4-0.8 km (0.25-0.5 mi) of the nest during this time (F. Dobler, personal communication).

Where falcon nests are already established in proximity to humans, there is no need to eliminate trails, picnic grounds, or other facilities except where the birds are evidently disturbed by the human activities. However, further facilities should not be established within 0.4-0.8 km (0.25-0.5 mi) of the eyries (Ellis 1982). Cliff tops above the eyrie should remain undeveloped. Ellis (1982) suggested that logging be curtailed within 1.6 km (1 mi) of occupied peregrine eyries in Arizona. In Washington, forest practices are reviewed by the Department of Fish and Wildlife when occurring within 0.4 km (0.25 mi) of an eyrie during any season, and within 0.8 km (0.5 mi) of an occupied eyrie during the breeding season (WAC 222-16-080, 1,f). Eyries occurring within non-forested lands, and those eyries not subjected to forest practices or forest practice rules, should be similarly considered through the development of a site specific peregrine management plan when activities near nests are considered. Male peregrines require perches within sight of the eyrie. Preserve all major perches around the nest and on ridges or plateaus above the nest by retaining all snags and large trees (F. Dobler, personal communication). Aircraft should not approach closer than 500 m (1,500 ft) above a nest (Fyfe and Olendorff 1976). Closer approaches may cause peregrines to attack planes or may cause a frantic departure from the nest. Falcons startled from the eyrie have been known to damage eggs or nestlings (Nelson 1970).

Powerlines and other wires may be serious hazards to peregrine falcons. Wherever possible, powerlines should be routed away from eyries (Olsen and Olsen 1980). Applications of pesticides that could potentially affect passerine birds should be avoided around occupied peregrine eyries during the breeding season. Some chemicals such as organochlorines, organophosphates, strychnine, and carbofuran can impact birds by causing toxicosis or death, or by contaminating their tissues. Other pesticides may be less toxic to birds, but will increase mortality of young passerines by directly reducing their food supply, thus indirectly reducing the prey available to peregrines (Driver 1991). Reduced or contaminated food sources will negatively affect peregrine falcons.

Wetlands, especially intertidal mudflats, estuaries, and coastal marshes, are key feeding areas in winter. Wetlands used regularly by peregrine falcons at any time of the year should receive strict protection from filling, development, or other excessive disturbances that could alter prey abundance. Do not apply pesticides to areas where winter prey species congregate. Lead shot should not be used in waterfowl areas where peregrine falcons feed. Peregrines can tolerate human presence at wintering sites if they are not harassed and if abundant prey remains. All large trees and snags in areas where peregrine falcons feed in winter should be maintained. These perches are important for roosting and for hunting at terrestrial sites. Snags and debris located on mud flats should also be left for winter perching and roosting.

4.2.5. Breeding Concentrations of Alcids

Habitat Requirements

Alcids are a family of seabirds including auklet, murres, murrelets and puffins (WDFW 2013). Alcids typically inhabit calm, shallow, coastal waters and bays. Many alcids nest near the shore, but some species nest in forested areas; the marbled murrelet nests up to 45 miles from the coast (Seattle Audubon 2013) in mature, wet forests. All alcids depend on marine waters for food resources.

In Seattle, an alcid breeding area was identified in the Seattle West waterway/Harbor Island according to PHS. According to Sound to Sage (Seattle Audubon 2006), a breeding pair of marbled murrelets was reported swimming in the Puget Sound off of West Seattle. Sound to Sage also reports another type of alcid, pigeon guillemots, in the downtown Seattle waterfront.

Management Recommendations

WDFW staff is currently updating a database of Washington's seabird colonies, including marbled murrelets. There is growing concern about declining seabird populations in Puget Sound, so it has become a particular area of focus for documentation and population analysis. The WDFW provides little information on alcids other than the marbled murrelets, so the following recommendations are derived from marbled murrelet information; however, they can be considered applicable to other alcids using the marine waters of Puget Sound for foraging.

Marbled murrelets are a listed species under the Endangered Species Act. While their nesting habitat does not occur within the city of Seattle, they spend 90% or more of their life in marine waters (USFWS 2013), including Puget Sound. Noise effects from pile driving are an increasing concern for marbled murrelet. Because marbled murrelets dive for food, both underwater and in-air noise can have an effect, such as disrupting feeding behavior or direct auditory injury. Intense noise levels are assumed to produce similar effects on other alcids exposed to the stressor.

USFWS has released effects thresholds for both underwater and in-air noise, found here: http://www.wsdot.wa.gov/NR/rdonlyres/1A1AFC72-69F6-4C91-B479-F33D9F80F8ED/0/MAMU_EffectsThresholds.pdf. Pile driving activities within marine waters of the city of Seattle should be avoided and/or minimized during marble murrelet presence. Guidance on marbled murrelet monitoring can be found here: http://www.fws.gov/wafwo/pdf/MAMUMonProtocol_Aug2012.pdf.

Diving alcids are also susceptible to oil spills and fishing gear (particularly gill nets). Restriction of oil transport and gill net fishing is recommended for concentrations of alcids (Rodrick and Milner 1991).

4.2.6. Waterfowl Concentrations

Habitat Requirements

WDFW includes the following species of waterfowl on their 2008 Priority Species list:

- Brant (*Branta bernicla*)
- Cavity-nesting ducks: Wood Duck (*Aix sponsa*), Barrow's Goldeneye (*Bucephala islandica*), Common Goldeneye (*B. clangula*), Bufflehead (*B. albeola*), Hooded Merganser (*Lophodytes cucullatus*)
- Harlequin Duck (*Histrionicus histrionicus*)
- Snow Goose (*Chen caerulescens*)

- Trumpeter Swan (*Cygnus buccinators*)
- Tundra Swan (*Cygnus columbianus*)
- Western Washington nonbreeding concentrations of: Barrow's Goldeneye, Common Goldeneye, Bufflehead

Habitat requirements for the above species are variable. Review of Sound to Sage (Seattle Audubon 2006) suggests that only the cavity nesting ducks are likely within the City of Seattle. Cavity nesting ducks primarily use late-successional forests adjacent to low-gradient, or lentic, aquatic habitats for nesting. These species nest in tree cavities that offer protection form the weather and from predators. The species forage primarily on aquatic insects, crustaceans, mollusks, and small fish. Shallow wetland or aquatic margin habitat with emergent vegetation and overhanging woody vegetation typically provides suitable brood habitat. A detailed discussion of habitat requirements is provided in WDFW 2004.

According to the PHS database, waterfowl concentrations in Seattle have been identified in Union Bay, Bitter Lake, and Green Lake.

Management Recommendations

Management recommendations for cavity nesting ducks relate predominantly to providing an adequate supply of nest cavities to support viable populations of these species. The use of pesticides and herbicides is also discouraged where these species occur. Detailed management recommendations are provided in WDFW 2004.

4.2.7. Semipalmated Plover

Habitat Requirements

Semipalmated plovers live in the artic most of the year and migrate through Washington in late April and late July. During their migration they populate coastal areas: primarily mudflats and exposed sandy beaches. They also migrate inland in smaller numbers and are found on lakeshores, alkaline ponds, sloughs, and flooded fields.

One occurrence of semipalmated plover is noted in Seattle in the PHS database on the shoreline of Magnuson Park.

Management Recommendations

Habitats important to these birds should be protected including mudflats and sandy beaches. Shoreline development including sand extraction, placement of new utility towers, and public access should be evaluated for impacts to this species. Detailed management recommendations are provided in WDFW 2004.

4.3. MAMMALS

4.3.1. California Sea Lion

Habitat Requirements

The California Sea Lion is found in shallow coastal and estuarine waters from Baja California to Alaska. It hauls out on rocky and sandy beaches, primarily islands. Haulout sites can also include marina docks, jetties, and buoys. Pups are born on rocky and sandy beaches. It is an opportunistic feeder, common foods include: squid, octopus, and fish. Studies of scat samples collected in coastal waters and the Columbia River estuary indicate that salmon comprise 10 to 30 percent of the animals' diet (WDFW 2013c). Since the mid-1980s, increasing numbers of California sea lions have been documented feeding on fish along the Washington coast and – more recently – in the Columbia River as far upstream as Bonneville Dam, 145 miles from the river mouth (WDFW 2013c).

In Seattle, California sea lions have been seen hauled out in the North Seattle area at Shilshole, West Point, and nearby areas on buoys (WDFW 2013b).

Management Recommendations

While California sea lions are managed under the Marine Mammal Protection Act (MMPA), they are not designated as a depleted population, nor are they a listed species under the Endangered Species Act. Populations of California sea lions have grown rapidly since the 1970s and are near carrying capacity levels (WDFW 2013c).

Threats to California sea lions include entanglement in fishing gear, direct human-caused injuries (such as from vessels and gunshots), and harmful algal blooms (NMFS 2013). Pinnepeds, such as California sea lions, are also susceptible to the effects of noise. Sound or noise effects on these species can cause physical injury and other effects on hearing, communication, stress response and other behavioral responses. NOAA is developing comprehensive guidance on sound characteristics likely to cause injury and behavioral disruption in the context of the MMPA, ESA and other statutes.

In general, the provisions of the MMPA should be followed including a moratorium on "taking" California sea lion species. The definition of "take" means to hunt, harass, capture, or kill.

4.4. AMPHIBIANS AND REPTILES

4.4.1. Western Pond Turtle

The range of the western pond turtle follows the Pacific coast of North America, from the Puget Sound region in Washington to northwestern Baja California. Most populations are found west of the Cascade Mountain Range (WDFW 1993). In recent years, these turtles have become virtually absent in the Puget Sound region (WDFW 1993, Storm and Leonard 1995). Populations in Washington are confirmed only in Klickitat and Skamania counties. Individual turtle sightings have recently been confirmed in Pierce and King counties, which are part of the turtle's historic range. Historic records also exist for Clark and Thurston counties (McAllister 1995). The western pond turtle is a State Listed Endangered species. Populations of western pond turtles are declining in Washington. They are in jeopardy of extirpation due to their limited distribution, low numbers, and isolated populations. This species is vulnerable to extirpation in Washington by both natural and human-caused events (WDFW 1993). In Seattle WDFW has reported sitings in the past (the last siting was in 1992 when one was found under the SR 520 ramp near Foster island), but it's unlikely that a viable population exists in Seattle. Included in *Washington's Priority Species, Volume III: Amphibians and Reptiles* (http://www.wdfw.wa.gov/hab/vol3.htm) prepared by the Department of Fish and Wildlife staff Noelle Nordstrom and Ruth Milner which outlines habitat requirements, limiting factors and management recommendations for this species.

4.5. PRIORITY HABITATS

WDFW 2008 defines "Priority habitat" as a habitat type with unique or significant value to many species. An area identified and mapped as priority habitat has one or more of the following attributes:

- comparatively high fish and wildlife density
- comparatively high fish and wildlife species diversity
- important fish and wildlife breeding habitat
- important fish and wildlife seasonal ranges
- important fish and wildlife movement corridors

- limited availability
- high vulnerability to habitat alteration
- unique or dependent species

A priority habitat may be described by a unique vegetation type or by a dominant plant species that is of primary importance to fish and wildlife (e.g., oak woodlands, juniper savannah). A priority habitat may also be described by a successional stage (e.g., old growth and mature forests). Alternatively, a priority habitat may consist of a specific habitat features (e.g., talus slopes, caves, snags) of key value to fish and wildlife.

Review of WDFW data (WDFW 2013b) indicates that the city of Seattle contains two priority habitats: Biodiversity Corridors and Cliffs / Bluffs. These areas are briefly summarized below; however, the relevant PHS publications are largely incorporated by reference for the purposes of this document.

4.5.1. Biodiversity Corridors

Habitat Description

Biodiversity areas and corridors are areas of habitat that are relatively important to various species of native fish and wildlife.

1. Biodiversity areas

a. The area has been identified as biologically diverse through a scientifically based assessment conducted over a landscape scale (e.g., ecoregion, county- or city-wide, watershed, etc.). Examples include but are not limited to WDFW Local Habitat Assessments, Pierce County Biodiversity Network, and Spokane County's Wildlife Corridors and Landscape Linkages.

OR

b. The area is within a city or an urban growth area (UGA) and contains habitat that is valuable to fish or wildlife and is mostly comprised of native vegetation. Relative to other vegetated areas in the same city or UGA, the mapped area is vertically diverse (e.g., multiple canopy layers, snags, or downed wood), horizontally diverse (e.g., contains a mosaic of native habitats), or supports a diverse community of species as identified by a qualified professional who has a degree in biology or closely related field and professional experience related to the habitats or species occurring in the biodiversity area. These areas may have more limited wildlife functions than other priority habitat areas due to the general nature and constraints of these sites in that they are often isolated or surrounded by highly urbanized lands.

2. Corridors

Corridors are areas of relatively undisturbed and unbroken tracts of vegetation that connect fish and wildlife habitat conservation areas, priority habitats, areas identified as biologically diverse (see attribute 1a), or valuable habitats within a city or UGA (see attribute 1b).

Biodiversity Corridors have been identified in PHS in many of Seattle's parks including: Madrona, Carkeek, Discovery, Washington Arboretum, Golden Gardens, Ravenna, Lakeridge, and Kubota Gardens. The Duwamish Waterway has also been identified as a biodiversity corridor.

Management Recommendations

This document incorporates by reference the relevant PHS document for this habitat type in developing areas: Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas (WDFW 2009).

4.5.2. Cliffs/Bluffs

Habitat Description

Cliffs / bluffs are simply defined as very steep landforms greater than 7.6 meters (25 feet) high and occurring below 1524 meters (5000 feet) (WDFW 2008).

In Seattle, cliffs and bluffs were recorded at Discovery Park, according to PHS. At the time of recording, the cliffs ranged from 20-240 feet in height, were sparsely vegetated, and contained snags, downed logs and seeps.

Management Recommendations

WDFW provides no management recommendations for this habitat at this time.

4.6. REFERENCES

NMFS (National Marine Fisheries Service). 2013. California Sea Lion Life History. http://www.nmfs.noaa.gov/pr/species/mammals/pinnipeds/californiasealion.htm. Accessed December 30, 2013

Rodrick, E. and R. Milner, eds. 1991. Management Recommendations for Washington's Priority Habitats and Species. Washington Department of Wildlife. Olympia, Washington, USA.

Seattle Audubon. 2013. BirdWeb. Seattle Audubon Society, Seattle, WA. Available at: http://www.birdweb.org/Birdweb/bird/marbled_murrelet. Accessed December 20, 2013.

Seattle Audubon. 2006. Sound to Sage: Breeding Bird Atlas of Island, King, Kitsap, and Kittitas Counties, Washington. Seattle Audubon Society, Seattle, WA. Available at: http://www.soundtosage.org/soundtosage/browse_birds.aspx. Accessed December 20, 2013.

WDFW. 2004. E. Larsen, J. M. Azerrad, N. Nordstrom, editors. Management recommendations for Washington's priority species, Volume IV: Birds. Washington Department of Fish and Wildlife, Olympia, Washington, USA.

WDFW. 2009. Landscape Planning for Washington's Wildlife: Managing for Biodiversity in Developing Areas. Washington Department of Fish and Wildlife. Olympia, Washington, USA.

WDFW 2013a. Columbia River Sea Lion Management, California Sea Lion Fact Sheet. WDFW, Olympia. Available at: http://wdfw.wa.gov/conservation/sealions/facts.html. Accessed December 20, 2013.

WDFW 2013b. PHS on the Web. WDFW, Olympia. http://wdfw.wa.gov/mapping/phs/. Accessed December 20, 2013.

WDFW. 2013c. Seabird Ecology. Available at: http://wdfw.wa.gov/conservation/research/projects/seabird/. Accessed December 23, 2013.

USFWS. 2013. Marbled Murrelet Fact Sheet. U.S. Fish and Wildlife Service, Washington Office, Pacific Region, Lacey. Available at: http://www.fws.gov/wafwo/species/Fact%20sheets/Factsheet%20MAMU.pdf. Accessed on December 23, 2013.

Appendix A: **Washington Administrative Code-Best Available Science Rule**

WAC 365-195-900 Background and purpose. (1) Counties and cities planning under RCW 36.70A.040 are subject to continuing review and evaluation of their comprehensive land use plan and development regulations. Every five years they must take action to review and revise their plans and regulations, if needed, to ensure they comply with the requirements of the Growth Management Act. RCW 36.70A.130.

(2) Counties and cities must include the "best available science" when developing policies and development regulations to protect the functions and values of critical areas and must give "special consideration" to conservation or protection measures necessary to preserve or enhance anadromous fisheries. RCW 36.70A.172(1). The rules in WAC 365-195-900 through 365-195-925 are intended to assist counties and cities in identifying and including the best available science in newly adopted policies and regulations and in this periodic review and evaluation and in demonstrating they have met their statutory obligations under RCW 36.70A.172(1).

(3) The inclusion of the best available science in the development of critical areas policies and regulations is especially important to salmon recovery efforts, and to other decision-making affecting threatened or endangered species.

(4) These rules are adopted under the authority of RCW 36.70A.190 (4)(b) which requires the department of community, trade, and economic development (department) to adopt rules to assist counties and cities to comply with the goals and requirements of the Growth Management Act.

WAC 365-195-905 Criteria for determining which information is the "best available science." (1) This section provides assessment criteria to assist counties and cities in determining whether information obtained during development of critical areas policies and regulations constitutes the "best available science."

(2) Counties and cities may use information that local, state or federal natural resource agencies have determined represents the best available science consistent with criteria set out in WAC 365-195-900 through 365-195-925. The department will make available a list of resources that state agencies have identified as meeting the criteria for best available science pursuant to this chapter. Such information should be reviewed for local applicability.

(3) The responsibility for including the best available science in the development and implementation of critical areas policies or regulations rests with the legislative authority of the county or city. However, when feasible, counties and cities should consult with a qualified scientific expert or team of qualified scientific experts to identify scientific information, determine the best available science, and assess its applicability to the relevant critical areas. The scientific expert or experts may rely on their professional judgment based on experience and training, but they should use the criteria set out in WAC 365-195-900 through 365-195-925 and any technical guidance provided by the department. Use of these criteria also should guide counties and cities that lack the assistance of a qualified expert or experts, but these criteria are not intended to be a substitute for an assessment and recommendation by a qualified scientific expert or team of experts.

(4) Whether a person is a qualified scientific expert with expertise appropriate to the relevant critical areas is determined by the person's professional credentials and/or certification, any advanced degrees earned in the pertinent scientific discipline from a recognized university, the number of years of experience in the pertinent scientific discipline, recognized leadership in the discipline of interest, formal training in the specific area of

expertise, and field and/or laboratory experience with evidence of the ability to produce peer-reviewed publications or other professional literature. No one factor is determinative in deciding whether a person is a qualified scientific expert. Where pertinent scientific information implicates multiple scientific disciplines, counties and cities are encouraged to consult a team of qualified scientific experts representing the various disciplines to ensure the identification and inclusion of the best available science.

(5) Scientific information can be produced only through a valid scientific process. To ensure that the best available science is being included, a county or city should consider the following:

(a) **Characteristics of a valid scientific process.** In the context of critical areas protection, a valid scientific process is one that produces reliable information useful in understanding the consequences of a local government's regulatory decisions and in developing critical areas policies and development regulations that will be effective in protecting the functions and values of critical areas. To determine whether information received during the public participation process is reliable scientific information, a county or city should determine whether the source of the information displays the characteristics of a valid scientific process. The characteristics generally to be expected in a valid scientific process are as follows:

1. **Peer review.** The information has been critically reviewed by other persons who are qualified scientific experts in that scientific discipline. The criticism of the peer reviewers has been addressed by the proponents of the information. Publication in a refereed scientific journal usually indicates that the information has been appropriately peer-reviewed.

2. **Methods.** The methods that were used to obtain the information are clearly stated and able to be replicated. The methods are standardized in the pertinent scientific discipline or, if not, the methods have been appropriately peer-reviewed to assure their reliability and validity.

3. **Logical conclusions and reasonable inferences.** The conclusions presented are based on reasonable assumptions supported by other studies and consistent with the general theory underlying the assumptions. The conclusions are logically and reasonably derived from the assumptions and supported by the data presented. Any gaps in information and inconsistencies with other pertinent scientific information are adequately explained.

4. **Quantitative analysis.** The data have been analyzed using appropriate statistical or quantitative methods.

5. **Context.** The information is placed in proper context. The assumptions, analytical techniques, data, and conclusions are appropriately framed with respect to the prevailing body of pertinent scientific knowledge.

6. **References.** The assumptions, analytical techniques, and conclusions are well referenced with citations to relevant, credible literature and other pertinent existing information.

(b) **Common sources of scientific information.** Some sources of information routinely exhibit all or some of the characteristics listed in (a) of this subsection. Information derived from one of the following sources may be considered scientific information if the source possesses the characteristics in Table 1. A county or city may consider information to be scientifically valid if the source possesses the characteristics listed in (a) of this subsection. The information found in Table 1 provides a general indication of the characteristics of a valid scientific process typically associated with common sources of scientific information.

Table 1	**CHARACTERISTICS**					
SOURCES OF SCIENTIFIC INFORMATION	Peer review	Methods	Logical conclusions & reasonable inferences	Quantitative analysis	Context	References
A. Research. Research data collected and analyzed as part of a controlled experiment (or other appropriate methodology) to test a specific hypothesis.	X	X	X	X	X	X
B. Monitoring. Monitoring data collected periodically over time to determine a resource trend or evaluate a management program.		X	X	Y	X	X
C. Inventory. Inventory data collected from an entire population or population segment (e.g., individuals in a plant or animal species) or an entire ecosystem or ecosystem segment (e.g., the species in a particular wetland).		X	X	Y	X	X
D. Survey. Survey data collected from a statistical sample from a population or ecosystem.		X	X	Y	X	X
E. Modeling. Mathematical or symbolic simulation or representation of a natural system. Models generally are used to	X	X	X	X	X	X

understand and explain occurrences that cannot be directly observed.						
F. Assessment. Inspection and evaluation of site-specific information by a qualified scientific expert. An assessment may or may not involve collection of new data.		X	X		X	X
G. Synthesis. A comprehensive review and explanation of pertinent literature and other relevant existing knowledge by a qualified scientific expert.	X	X	X		X	X
H. Expert Opinion. Statement of a qualified scientific expert based on his or her best professional judgment and experience in the pertinent scientific discipline. The opinion may or may not be based on site-specific information.			X		X	X

X = characteristic must be present for information derived to be considered scientifically valid and reliable

Y = presence of characteristic strengthens scientific validity and reliability of information derived, but is not essential to ensure scientific validity and reliability

(c) **Common sources of nonscientific information.** Many sources of information usually do not produce scientific information because they do not exhibit the necessary characteristics for scientific validity and reliability. Information from these sources may provide valuable information to supplement scientific information, but it is not an adequate substitute for scientific information. Nonscientific information should not be used as a substitute for valid and available scientific information. Common sources of nonscientific information include the following:

(i) Anecdotal information. One or more observations which are not part of an organized scientific effort (for example, "I saw a grizzly bear in that area while I was hiking").

(ii) Nonexpert opinion. Opinion of a person who is not a qualified scientific expert in a pertinent scientific discipline (for example, "I do not believe there are grizzly bears in that area").

(iii) Hearsay. Information repeated from communication with others (for example, "At a lecture last week, Dr. Smith said there were no grizzly bears in that area").

(6) Counties and cities are encouraged to monitor and evaluate their efforts in critical areas protection and incorporate new scientific information, as it becomes available.

WAC 365-195-910 Criteria for obtaining the best available science. (1) Consultation with state and federal natural resources agencies and tribes can provide a quick and cost-effective way to develop scientific information and recommendations. State natural resource agencies provide numerous guidance documents and model ordinances that incorporate the agencies' assessments of the best available science. The department can provide technical assistance in obtaining such information from state natural resources agencies, developing model GMA-compliant critical areas policies and development regulations, and related subjects. The department will make available to interested parties a current list of the best available science determined to be consistent with criteria set out in WAC 365-195-905 as identified by state or federal natural resource agencies for critical areas.

(2) A county or city may compile scientific information through its own efforts, with or without the assistance of qualified experts, and through state agency review and the Growth Management Act's required public participation process. The county or city should assess whether the scientific information it compiles constitutes the best available science applicable to the critical areas to be protected, using the criteria set out in WAC 365-195-900 through 365-195-925 and any technical guidance provided by the department. If not, the county or city should identify and assemble additional scientific information to ensure it has included the best available science.

WAC 365-195-915 Criteria for including the best available science in developing policies and development regulations. (1) To demonstrate that the best available science has been included in the development of critical areas policies and regulations, counties and cities should address each of the following on the record:

(a) The specific policies and development regulations adopted to protect the functions and values of the critical areas at issue.

(b) The relevant sources of best available scientific information included in the decision-making.

(c) Any nonscientific information -- including legal, social, cultural, economic, and political information -- used as a basis for critical area policies and regulations that depart from recommendations derived from the best available science. A county or city departing from science-based recommendations should:

(i) Identify the information in the record that supports its decision to depart from science-based recommendations;

(ii) Explain its rationale for departing from science-based recommendations; and

(iii) Identify potential risks to the functions and values of the critical area or areas at issue and any additional measures chosen to limit such risks. State Environmental Policy Act (SEPA) review often provides an opportunity to establish and publish the record of this assessment.

(2) Counties and cities should include the best available science in determining whether to grant applications for administrative variances and exemptions from generally applicable provisions in policies and development regulations adopted to protect the functions and values of critical areas. Counties and cities should adopt procedures and criteria to ensure that the best available science is included in every review of an application for an administrative variance or exemption.

WAC 365-195-920 Criteria for addressing inadequate scientific information. Where there is an absence of valid scientific information or incomplete scientific information relating to a county's or city's critical areas, leading to uncertainty about which development and land uses could lead to harm of critical areas or uncertainty about the risk to critical area function of permitting development, counties and cities should use the following approach:

(1) A "precautionary or a no risk approach," in which development and land use activities are strictly limited until the uncertainty is sufficiently resolved; and

(2) As an interim approach, an effective adaptive management program that relies on scientific methods to evaluate how well regulatory and nonregulatory actions achieve their objectives. Management, policy, and regulatory actions are treated as experiments that are purposefully monitored and evaluated to determine whether they are effective and, if not, how they should be improved to increase their effectiveness. An adaptive management program is a formal and deliberate scientific approach to taking action and obtaining information in the face of uncertainty. To effectively implement an adaptive management program, counties and cities should be willing to:

(a) Address funding for the research component of the adaptive management program;

(b) Change course based on the results and interpretation of new information that resolves uncertainties; and

(c) Commit to the appropriate timeframe and scale necessary to reliably evaluate regulatory and nonregulatory actions affecting critical areas protection and anadromous fisheries.

WAC 365-195-925 Criteria for demonstrating "special consideration" has been given to conservation or protection measures necessary to preserve or enhance anadromous fisheries. (1) RCW 36.70A.172(1) imposes two distinct but related requirements on counties and cities. Counties and cities must include the "best available science" when developing policies and development regulations to protect the functions and values of critical areas, and counties and cities must give "special consideration" to conservation or protection measures necessary to preserve or enhance anadromous fisheries. Local governments should address both requirements in RCW 36.70A.172(1) when developing their records to support their critical areas policies and development regulations.

(2) To demonstrate compliance with RCW 36.70A.172(1), a county or city adopting policies and development regulations to protect critical areas should include in the record evidence that it has given "special consideration" to conservation or protection measures necessary to preserve or enhance anadromous fisheries. The record should be developed using the criteria set out in WAC 365-195-900 through 365-195-925 to ensure that conservation or protection measures necessary to preserve or enhance anadromous fisheries are grounded in the best

available science.

(3) Conservation or protection measures necessary to preserve or enhance anadromous fisheries include measures that protect habitat important for all life stages of anadromous fish, including, but not limited to, spawning and incubation, juvenile rearing and adult residence, juvenile migration downstream to the sea, and adult migration upstream to spawning areas. Special consideration should be given to habitat protection measures based on the best available science relevant to stream flows, water quality and temperature, spawning substrates, instream structural diversity, migratory access, estuary and nearshore marine habitat quality, and the maintenance of salmon prey species. Conservation or protection measures can include the adoption of interim actions and long-term strategies to protect and enhance fisheries resources