2 LOWER COLUMBIA RIVER ENVIRONMENTAL SETTING

2.1 Section Organization

This section provides an overview of the environmental setting and conditions in the lower Columbia River that are important to listed salmonid populations. These environmental conditions collectively influence the growth and survival of the salmonid species rearing in and migrating through the lower Columbia River. The historical environmental conditions of the river, prior to nonindigenous human influence, were considerably different from existing environmental conditions. Because these differences are important in assessing the potential for natural variability and the significance of incremental changes within the river ecosystem, both the historical and existing conditions are presented and discussed separately in this section.

The lower Columbia River is a dynamic and complex system. In order to present a systematic framework for addressing this complexity, a conceptual model of the lower Columbia River ecosystem was developed and is used to describe and evaluate potential changes associated with the proposed Project. The conceptual model is described in Section 5 and in more technical detail in Appendix E. To provide consistency throughout the BA, the discussions of the historical and existing environmental conditions in this section are organized to follow the conceptual model. In addition, historical and current conditions are provided for each of the three reach types in the action area: the freshwater or riverine reach (from Bonneville Dam to RM 40), the estuary (from RM 3 to 40), and the river mouth (from RM 3 to the outer boundary of the deep water site, approximately 12 miles beyond the project area).

The basic habitat-forming processes—physical forces of the ocean and river—create the conditions that define habitats. The habitat types, in turn, provide an opportunity for the primary plant production that gives rise to complicated food webs. All of these pathways combine to influence the growth and survival and, ultimately, the production and ocean entry of juvenile salmonids moving through the lower Columbia River. These processes and pathways are developed in the conceptual model and outlined briefly in Table 2-1 and shown in Figure 2-1. Basic components, the indicators of the functioning of the system, are also listed and described in Table 2-1. The discussion of historical and existing conditions follows the table.

Table 2-1: Conceptual Model Pathways and Indicators for Juvenile Salmonid Production in the Lower Columbia River

Model Pathways	Pathway Description	Model Components (Indicators)	Indicator Description
Habitat-Forming Processes	Physical processes that define the living conditions and provide the requirements fish naturally need within the river system are included in the Habitat-Forming Processes Pathway.	Suspended Sediment	Sand, silt, and clay transported in the water column
		Bedload	Sand grains rolling along the surface of the riverbed
		Woody Debris	Downed trees, logs, root wads, limbs
		Turbidity	Quality of opacity in water, influenced by suspended solids and phytoplankton
		Salinity	Saltwater introduced into freshwater areas through tidal ocean process
		Accretion/ Erosion	Deposited/carved sediments
		Bathymetry	Topographic configuration of the riverbed

Model Pathways	Pathway Description	Model Components (Indicators)	Indicator Description
Habitat Types	This pathway describes definable areas that provide the living requirements for fish in the Lower Columbia River	Tidal Marsh and Swamp	Areas between mean lower low water (MLLW) and mean higher high water (MHHW) dominated by emergent vegetation (marsh) and low shrubs (swamp) in estuarine and riverine areas.
		Shallow Water and Flats	Areas between 6-foot bathymetric line (depth) and MLLW
		Water Column	Areas in the river where depth is greater than 6feet
Habitat Primary Productivity	This pathway describes the biological mass of plant materials that provides the fundamental nutritional base for animals in the river system.	Light	Sunlight necessary for plant growth
		Nutrients	Inorganic source materials necessary for plant growth
		Imported Phytoplankton Production	Material from single-celled plants produced upstream above the dams and carried into lower reaches of the river
		Resident Phytoplankton Production	Material from single-celled plants produced in the lower reaches of the river
		Benthic Algae Production	Material from simple plant species that inhabit the river bottom
		Tidal Marsh and Swamp Production	Material from complex wetland plants (hydrophytes) present in tidal marshes and swamps
Food Web	The Food Web pathway shows the aquatic organisms and related links in a food web that supports growth and survival of salmonids.	Deposit Feeders	Benthic organisms such as annelid worms that feed on sediments, specifically organic material and detritus
		Mobile Macroinvertebrates	Large epibenthic organisms such as sand shrimp, crayfish, and crabs that reside and feed on sediments at the bottom of the river
		Insects	Organisms such as aphids and flies that feed on vegetation in freshwater wetlands, tidal marshes, and swamps
		Suspension/Deposit Feeders	Benthic and epibenthic organisms such as bivalves and some amphipods that feed on or at the interface between sediment and the water column
		Suspension Feeders	Organisms that feed from the water column itself, including zooplankton
		Tidal Marsh Macrodetritus	Dead and decaying remains of tidal marsh and tidal swamp areas that are an important food source for benthic communities
		Resident Microdetritus	Dead and decaying remains of resident phytoplankton and benthic algae, an important food source for zooplankton

Model Pathways	Pathway Description	Model Components (Indicators)	Indicator Description
		Imported Microdetritus	Dead remains of phytoplankton from upstream that serve as a food source for suspension and deposit feeders
Growth	The Growth Pathway highlights the factors involved in producing both the amount of food and access by fish to productive feeding areas.	Habitat Complexity, Connectivity, and Conveyance	Configuration of habitat mosaics that allow for movement of salmonids between those habitats
		Velocity Field	Areas of similar flow velocity within the river
		Bathymetry and Turbidity	River bottom and water clarity conditions that influence the ability of salmonids to locate their prey
		Feeding Habitat Opportunity	Physical characteristics that affect access to locations that are important for fish feeding
		Refugia	Shallow water and other low energy habitat areas used for resting and cover
		Habitat-Specific Food Availability	Ability of complex habitats to provide feeding opportunities when fish are present
Survival	The Survival Pathway is a summary of key factors controlling or affecting growth and migration.	Contaminants	Compounds that are environ-mentally persistent and bioaccumulative in fish and invertebrates
		Disease	Pathogens (viruses, bacteria, and parasites) that pose survival risks for salmon
		Suspended Solids	Sand, silt, clay, and organics transported within the water column
		Stranding	Trapping of young salmonids in areas with no connectivity to water column habitat
		Temperature and Salinity Extremes	Temperature or salinity conditions that are problematic to salmonid survival
		Turbidity	Water clarity as it pertains to potential for juvenile salmonids to be seen by predators
		Predation	Potential for piscivorous mammals, birds, and fish to prey on salmonids
		Entrainment	Trapping of fish or invertebrates into hopper or pipeline dredges

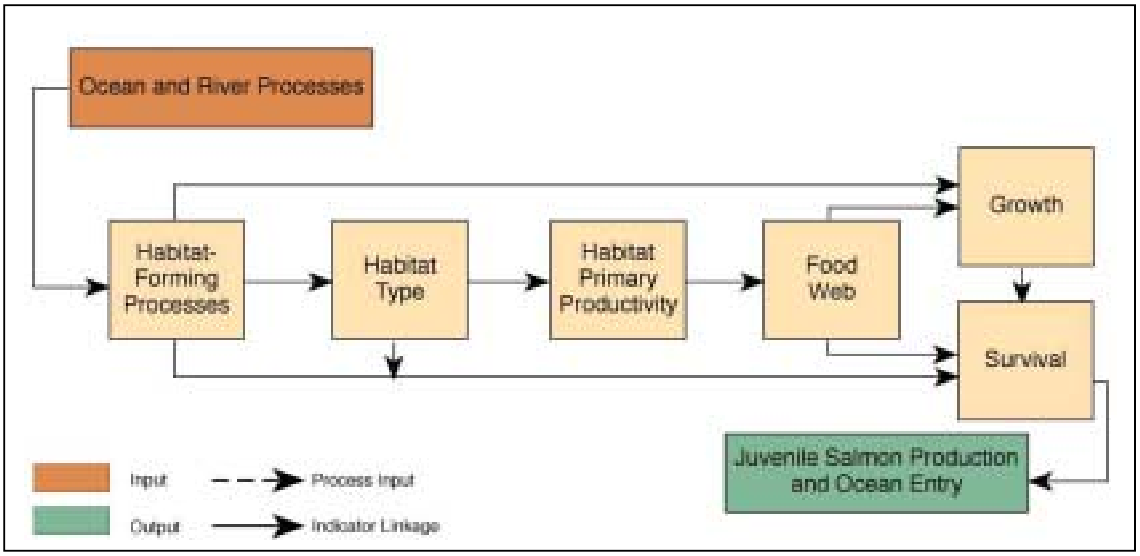

Figure 2-1: Integrated Model for Juvenile Salmonids in the Lower Columbia River

2.2 Historical Environmental Conditions

The Columbia River has been affected and shaped over eons by a variety of natural forces, including volcanic activity, floods, natural disasters, and climatological changes. These forces had and continue to have a significant influence on the biological factors (e.g., flow and temperature), habitat, inhabitants, and the whole riverine environment of the Columbia River. "Before human influence, the Columbia River estuary would have been a high-energy environment dominated by physical forces, with extensive sand-beds and highly variable river flows" (Independent Scientific Advisory Board [ISAB], 2000).

Over the past century, human activities have dampened the range of physical forces and resulted in extensive changes in the lower Columbia River and estuary system, particularly through changes to flow hydrographs, isolation of the floodplain, and development in wetland areas. Perhaps the greatest changes from human activity that influence the lower Columbia River system have been the reduction of the peak seasonal discharges and changes in the velocity and timing of flows as a result of dam controls. The riverine channel location has been very stable for centuries (Corps, 1999a). In the estuary, however, the main channel was not stable, shifting location from the north to the south side of the estuary in the 1800s.

The Columbia River estuary historically received annual spring freshet flows that were 75 to 100 percent higher on average than current freshet flows. Historical winter flows (from October through March) were also approximately 35 to 50 percent lower than current flows (Figure 2-2). The greater historical peak and variable flows encouraged greater sediment transport and more flooding of wetlands, contributing to the complex ecosystem of the estuary (ISAB, 2000).

Figure 2-2: River Flows at Bonneville Dam

The variable and unregulated river flow affected nearly every aspect of the historical ecosystem to some degree, including such diverse components as:

- Amount and distribution of woody debris
- Complexity and extent of tidal marsh vegetation
- Seasonal patterns of salinity and location of the estuarine turbidity maximum (ETM)
- Rates of sand and sediment transport
- Variations in temperature patterns
- Food web species and complexity
- Distribution and abundance of salmonid predators

"Floodwaters of the Columbia River historically inundated the margins and floodplains along the estuary, permitting juvenile salmon access to a wide expanse of low-velocity marshland and tidal channel habitats" (Bottom, et al., 2001). Flooding occurred frequently and was important to habitat diversity. Historical flooding also allowed more flow to side channels and bays and deposited more woody debris into the ecosystem.

Seasonal flooding increased the potential for salmonid feeding and resting areas in the estuary during the freshet season by creating significant tidal marsh vegetation and wetland areas. In general, the river banks were gently sloping, with riparian and wetland vegetation at the higher elevations of the river floodplain. It is estimated that the historical estuary had 75 percent more tidal swamps than the current estuary because tidal waters could reach floodplain areas that are now diked.

Prior to the river alterations initiated in the 19^{th} century, five species of salmon joined in annual runs, estimated at 11 to 16 million, in a highly evolved, complex ecosystem that supported their complex life cycles. The ecosystem pathways sustaining the salmon and trout migrating through the lower Columbia River and a historical description of the most relevant components (i.e., indicators) of each of the pathways follows.

2.2.1 Historical Condition for Indicators Affecting Habitat-Forming Processes

Dynamic physical processes continually operate to shape and maintain the lower Columbia River ecosystem. The integration of these processes in time and space results in the conditions in which salmon and trout have evolved to meet their needs for growth and survival, and for entry to the ocean. This section is a discussion of the historical conditions of the relevant processes that form these salmon and trout habitats, including suspended sediment, bedload, woody debris, turbidity, salinity, accretion/erosion, and bathymetry.

2.2.1.1 Suspended Sediment

Suspended sediment is one of the sedimentation processes that affect both habitat formation and the direct survival of the fish as they move through the system. Suspended sediment is sand, silt, and clay transported within the water column. Particles are kept in suspension by the upward components of currents and turbulence. In relation to habitat-forming processes, deposition of suspended sediment can create shallow water areas that may ultimately support vegetation and become marsh or swamp areas. Historical (unregulated by dams) flows produced suspended sediment that contributed to the formation of a complex ecosystem within the estuary (ISAB, 2000).

Many of the ecosystem components within the project area are marked by historically high natural variability. Suspended sediment is one of these factors. Major geologic events, such as earthquakes, mudflows from Mount Hood and Mount St. Helens, and landslides, historically caused sporadic significant effects on suspended sediment transport.

Riverine Reach

The large peak flows associated with interior basin spring freshets and the western subbasin winter flood events transported large volumes of suspended sediment through the action area. From year to year, the size, duration, and timing of the spring freshets and winter floods varied widely, with proportionate variations in sediment yield. Historically (pre-dam) yearly streamflow maximums ranged from approximately 350,000 cubic feet per second (cfs) to 1,236,000 cfs for spring freshet flows (Bottom, et al., 2001). The Corps has estimated the recent historical (pre-dam) average annual suspended sediment load in the main river was approximately 12 mcy per year (Corps, 1999a). Most of the suspended sediment was silt and clay size material, with sand making up less than 30 percent of the load (Corps, 1999a).

Estuary

The 12-mcy-per-year average suspended sediment load in the river was delivered to the upper estuary just downstream of Puget Island. It has been estimated that about a third of the suspended silt and clay material that entered the estuary was deposited in the estuary (Hubbell and Glenn, 1973). It is likely that most of the suspended sand was also deposited in the estuary. Suspended sediment deposition in the estuary contributed to the creation of shallow water areas that ultimately supported vegetation and became marsh or swamp areas.

River Mouth

The historical suspended sediment discharge to the ocean was probably much less than the volumes being transported in the river because of the deposition that occurred in the estuary. Most transport to the ocean likely occurred during high freshet discharges or large winter floods.

2.2.1.2 Bedload

In the Columbia River, bedload is the movement of sand grains rolling and bouncing along the surface of the riverbed. In sandy riverbeds, such as the Columbia River, bedload transport shapes the bed into a series of sand waves. These waves move downstream as sediment erodes from the upstream face, deposits in the downstream trough, and is then buried by additional material eroded from the upstream face. This movement occurs in a layer only a few sand grains thick. Through this mechanism, all the individual grains in a sand wave are exposed to flow, eroded, transported, deposited, buried, and then eventually exposed again as the sand wave migrates downstream.

The rate of downstream migration of the sand waves in the Columbia River depends on the flow in the river. Observations have found bedload transport to be quite low at discharges below 300,000 cfs and to clearly rise at discharges over 400,000 cfs. Although bedload movement is primarily focused within the river's main channel, bedload may also play a role in the creation of shallow water and swamp habitat, which supports important life stages for salmonids. As noted in Section 2.2.1.1, the historical flood discharges were highly variable, with spring freshets typically exceeding 400,000 cfs for about 6 weeks and the 2-year peak discharge being 580,000 cfs (Corps, 1999a).

Riverine Reach

Historical (unregulated) average annual bedload transport in the main river channel has been estimated at 1.5 mcy per year (Corps, 1999a).

Estuary

Historic bedload transport rates in the estuary are unknown. It is likely that the rates were highly variable and followed trends similar to those of the present estuary as described in Section 2.3.1.1.

River Mouth

The historical bedload transport to the ocean is unknown. Ocean waves and tidal currents were major factors in bedload transport at the mouth.

2.2.1.3 Woody Debris

Large woody debris is an important habitat component for salmonids in the Columbia River system. Woody debris is particularly important in the upper reaches of tributaries and within smaller side channels of the mainstem. Woody debris creates structure along the channel edges that helps fish become oriented and provides food opportunities in the form of invertebrate fauna that feed on organic matter trapped in the debris. In shallow water areas, salmon can rest and find protection behind logs.

Riverine Reach

Prior to construction of the dams, it is likely that woody debris would have floated into and through the reach from upstream sources.

Estuary

In the historical estuary, adjacent riparian zones and flooding provided a continuous source of woody debris that enhanced sediment and organic matter storage and pool habitat. The presence of woody debris caused the estuary to be "characterized by spatially complex and diverse channel systems and highly productive salmon habitat" (National Research Council, 1995).

River Mouth

Not applicable.

2.2.1.4 Turbidity

Turbidity is a measure of light penetration through water and is a natural part of the habitat to which the young salmonids are adapted. Turbidity is a function of the amount of suspended sediment and plankton within the water column. The role of turbidity in biological processes is similar to those of suspended sediment (see Section 6.1.1). As with suspended sediment, turbidity levels increase with high river flows. Heavy wind and wave activity can also increase turbidity.

Turbidity plays an important role in several aspects of the action area. Turbidity is relevant to habitat-forming processes for listed salmonids because high turbidity levels can potentially limit the water depth at which plants can grow. These plants provide a variety of habitat values, including potential refugia and primary productivity.

Riverine Reach

Turbidity levels within the Columbia River historically followed the river's hydrograph closely, rising during spring freshets and western subbasin winter floods. The highest turbidity levels occurred during western subbasin winter floods.

Estuary

In addition to the turbidity entering the estuary from the main river, turbidity was generated by waves and current actions in the shallow flats and channels in the estuary. The location and extent of the historical ETM is unknown.

River Mouth

Although levels are not known, some turbidity historically occurred in the plume.

2.2.1.5 Salinity

Salinity intrusion is important as a habitat-forming process for three reasons. First, because plants and animals prefer particular ranges of salinity, the extent, duration, and concentration of the salinity intrusion can affect the formation of the swamp and marsh areas necessary for salmon as well as the availability of necessary food sources. Second, the transition zone between freshwater and saltwater is an area where juvenile salmonids spend time while adjusting to the saltwater environment. And third, the saltwater/ freshwater interface creates a mixing zone referred to as the ETM (see Section 2.2.2.3, Water Column Habitat).

Riverine Reach

Salinity intrusion extends only to about RM 40, which divides the riverine area from the estuary. Therefore, salinity is not applicable in the river reach.

Estuary

The extent of salinity intrusion into the Columbia River estuary depends primarily on channel depth, strength of the tides, and river flows (Corps, 1999a; Columbia River Estuary Data Development Program [CREDDP], 1984). Although there are no data regarding the historical limits of salinity intrusion, salinity likely exhibited a significant seasonal range caused by the wide range of seasonal flows. It is possible that during high-volume spring freshets nearly the entire water column, to the river's mouth, was freshwater. During low flows, in late summer or fall, salinity intrusion may have extended as far upstream as RM 37.5 (CREDDP, 1984). The range of locations of the historical ETM is unknown.

River Mouth

Freshwater extrusion lowered salinity concentrations within the Columbia River plume, but the extent is unknown.

2.2.1.6 Accretion/Erosion

Accretion and erosion are the processes by which habitat types and landforms within the estuary and river are formed, shifted, and changed. Accretion typically occurs at a relatively slow rate as sediments settle from suspension in backwaters and slower-moving portions of the river channel. Erosion represents the counterbalancing process in which sediments are removed from an area.

On a geologic scale, the entire Columbia River valley downstream of Bonneville Dam is an accretion zone. The valley has been filled over the past 10,000 years as sea level rise has caused alluvial deposition. The estuary contains over 400 feet of alluvium.

Riverine Reach

Accretion and erosion occurred as sand moved around within the main river channel or entered the river from tributaries, primarily the Sandy and Willamette Rivers in Oregon and the Cowlitz River in Washington. These processes were most active during high discharge events. There was also accretion in the overbank areas during flood events. There was very little bank erosion, as the river channel's location has not changed much in 6,000 years (Corps, 1999a).

Estuary

Historically, the estuary has been an accretional zone. Spring freshets and winter floods carried significant sediment loads through the lower river, providing an opportunity for sediment deposition in the estuary. Over an extended period of time (thousands of years), this deposition led to the formation of the shallow water flats, marshes, and swamps found in and around the estuary in the late 1700s. It has been estimated that between 1858 and 1958 the average annual deposition rates in the estuary were somewhere in the range of 2 to 5 millimeters (mm) per year (CREDDP, 1984). The variability in estuarine accretion/erosion rates is illustrated by three sequential maps from the same location in Figure 2-3.

River Mouth

Historically, the river mouth has gone through cycles of accretion and erosion. Those cycles caused the entrance channel to move around and to shift between one and three main channels. The historical accretion/erosion rates are unknown. A single entrance channel was provided by the construction of the south and north jetties in 1885-1895 and 1913-1917, respectively. The construction of the jetties led to the accretion of Peacock Spit, a submerged ebb tidal delta, just outside the entrance.

Figure 2-3: Sediment Accretion and Erosion in Representative Portion of Columbia River Estuary, 1868-1982

2.2.1.7 Bathymetry

Bathymetry refers to the topographic configuration of the river, estuary, and ocean beds.

Riverine Reach

The riverbed between RM 106 and 146 was generally broad and shallow. Below RM 106, the historical bathymetry of this reach was variable, with long reaches of broad, shallow channels alternating with shorter, narrower, deeper reaches. The depth of the thalweg (the deepest portion of the channel) ranged from around 12 feet to over 50 feet (Corps, 1999a). The sandy riverbed had generally flat side-slopes and was covered with sand waves. The bathymetry shifted, especially during high discharges, as sand waves migrated downstream. There were only a few shallow side channels, such as those around Puget and Crimms Islands.

Estuary

The width of the river and its bathymetric variability increase as the river enters the estuary downstream of Puget Island. During the 1800s, the main river channel took various routes through the estuary, including courses along both the north and south sides of the estuary. In 1798, the main channel followed the north shore through much of the estuary and extensive sand flats existed in Baker, Grays, and Cathlamet Bays. By 1885, the main channel crossed from the north side near Harrington Point (RM 25) to the south shore at Tongue Point (RM 18) and followed the south shore out to the ocean. Also by 1885, the deep channel that in 1839 ran up into Baker Bay, just northeast of the entrance, had naturally filled in and Sand Island had been created. Smaller channels flowed around the many islands in Cathlamet Bay. There were also small channels through the shallow water flats in the central part of the estuary downstream of Harrington Point (RM 25). Those small channels shifted locations over time as sediment was eroded or deposited.

River Mouth

River mouth bathymetry historically shifted continuously in the river entrance and adjacent beaches. The entrance consisted of one or more channels that were generally less than 30 feet deep. A single entrance channel was provided by the construction of the south and north jetties in 1885-1895 and 1913-1917, respectively. By 1927, the entrance channel thalweg depth had increased to about 45 feet Mean Lower Low Water (MLLW). The construction of the jetties led to the formation of Peacock Spit, a submerged ebb tidal delta, just outside the entrance.

2.2.2 Historical Condition of Habitat Types

The processes discussed in Section 2.2.1 worked together to form a variety of habitats throughout the lower Columbia River. Certain habitat types are particularly important to salmon and trout in the Columbia River, including tidal marsh/swamp areas, shallow water/shoreline flats, and water column habitat (Figure 2-4). The following discussion of the historical availability of these habitat types is based primarily on surveys performed by CREDDP.

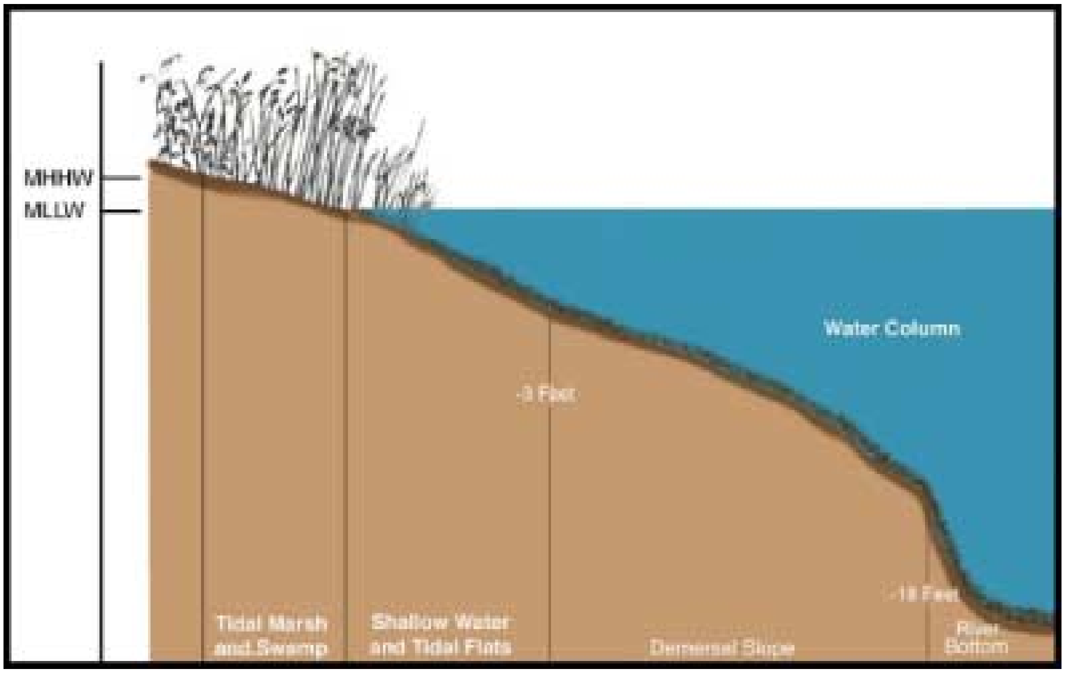

Figure 2-4: Major Habitat Types for Salmonids in the Lower Columbia River

2.2.2.1 Tidal Marsh and Swamp Habitat

Tidal marsh habitat refers to vegetated areas between MLLW and Mean Higher High Water (MHHW) that are dominated by emergent plants and low herbaceous shrubs. Tidal swamp habitat refers to vegetated areas dominated by wetland woody shrubs and trees that sometimes extend below the MHHW, but typically at elevations higher than those for tidal marshes (Thomas, 1983).

Tidal marsh and swamp habitats are the primary wetland and riparian communities adjacent to the river throughout the riverine and estuarine reaches of the action area. These habitats are designated as tidal habitats in this BA because they are subject to tidally induced inundation and include saltwater, brackish water, and freshwater components.

Riverine Reach

Historically, the lower Columbia River was characterized by large areas of tidal marsh and swamp habitat. See Estuary, below.

Estuary

The shoreline area along the lower Columbia River and estuary historically would have been subject to annual inundation from interior basin spring freshets. These annual high flows would have helped support the large areas of tidal marsh (approximately 16,000 acres) and tidal swamp (approximately 30,000 acres) habitat in freshwater and saltwater (Thomas, 1983). In addition, the large supply of suspended sediment deposition is likely to have continuously recharged marsh and swamp habitat and to have annually replenished nutrients and substrate.

River Mouth

Historically, the river mouth and shoreline of Baker Bay tended to be too exposed to wave energy to allow marsh and swamp habitat to develop (Thomas, 1983).

2.2.2.2 Shallow Water and Flats Habitat

Shallow water and flats habitat generally refers to the area between the 6-foot bathymetric line and the MHHW, approximately the outer edge of tidal marsh (Thomas, 1983). Shallow water areas shift continuously as new areas are formed through accretion and previously existing areas are eliminated by erosion.

Riverine Reach

Shallow water and tidal flat habitats are important for younger life stages of chinook and chum salmon, which may rear for up to several months in the shallow water habitats (Simenstad, et al., 1982). Thomas (1983) estimated that shallow water and flats habitat covered 40,640 acres in 1870.

Estuary

See Riverine Reach, above.

River Mouth

Historically, shallow water and tidal flat habitats were highly variable because shoaling, accretion, and erosion would create or eliminate habitat areas. An exception to the variability was the tendency for shallow water habitat areas to be maintained near the river mouth because wave energy prevented the formation of tidal marsh or swamp habitat (Thomas, 1983).

2.2.2.3 Water Column Habitat

Water column habitat encompasses those portions of the river where the depth is greater than 6 feet. Water column habitat is created and maintained by flow from the river's mainstem and tributaries. Water level and flows in the mouth and estuary are influenced by ocean tides. Tides also affect water level upstream of the estuary, but to a lesser extent. The water column, which is used primarily by stream-type juveniles and adult life stages of salmon, also serves an important function as an importer of phytoplankton and microdetritus from upstream areas.[9] In addition, the river transports sediments, most of which are fine sand and silt in suspension. Much of this sediment eventually settles out in the river, estuary, and mouth to form shoals and shallow flats.

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[9] Detritus generally refers to dead and decaying plant materials. Organic material from dead phytoplankton and benthic plants is characterized as microdetritus because it is made up of the remains of single-celled plants. Organic material from dead tidal marsh and swamp plants is characterized as macrodetritus.

Riverine Reach

Water column habitat historically was present in the riverine reach. Natural migration of the main river channel resulted in shifting of the location of the river through time. Historical river flows varied, with spring freshets and fall-winter low-flow periods. The water column likely was dominated by phytoplankton and zooplankton produced in the river.

Estuary

As with the other habitat types, the lower river water column historically had a high degree of natural variability (Thomas, 1983). During the course of years, accretion and erosion within the system would create, change, eliminate, and recreate all of the various habitat types, including deep water habitats. For example, in the late 1800s, natural processes caused Sand Island to move from the middle of the river mouth into Baker Bay, resulting in the loss of 1,350 acres of deep water habitat. Historical documentation indicates that, at one time, major flow in the estuary was through the north channel (Thomas, 1983).

Historically, the estuary was the location where riverine- and estuarine-produced phytoplankton and zooplankton mixed. Saltwater and freshwater also mix in the estuary. In the Columbia River, as in most river-dominated estuaries, tidal processes and river flow resulted in a zone of increased turbidity called the ETM. The nonlinear circulation processes created by the outflow of the river and the inflow of tides promote the trapping and increased residence of organic and inorganic matter (Simenstad, et al., 1994). Freshwater plankton encountering the saline water will break down, further adding to the organic matter concentrated in the ETM.

River Mouth

Water column habitat historically was present in the river mouth. Processes occurring in the estuary have always influenced this portion of the system. The bottom contours are known to be constantly moving and shifting under influence from both the river and the ocean currents and waves. Consequently, the depth of the water column has varied through time.

2.2.3 Historical Condition for Indicators Affecting Habitat Primary Productivity

An important quality of the relevant salmonid habitat types discussed in Section 2.2.2 is their primary productivity, or ability to store energy in organic substances that are used as food sources in plants. This primary productivity is the foundation for the transfer of food energy, through series of organisms by feeding and being eaten, to the ultimate food sources important to salmonids. The primary producers are the plants that store energy in organic substances and provide basic food sources for food chains. The plant species that function as primary producers vary in type and abundance from habitat type to habitat type (Figure 2-5). For example, in shallow water habitats of the lower Columbia River, benthic algae are the primary food

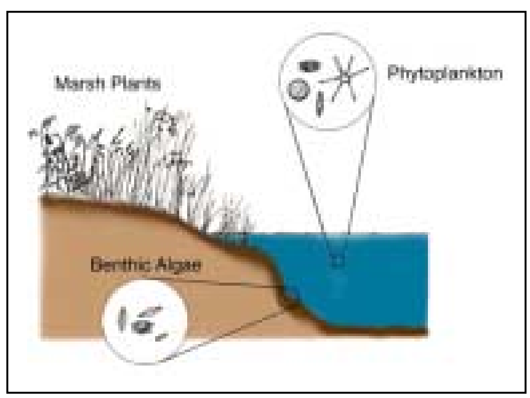

Figure 2-5: Major Primary Producers in the Lower Columbia River

source. In the water column habitat, the primary food source is phytoplankton (both resident and imported within the water column). For tidal marsh and swamp areas, the primary food source is complex vegetation, including emergent plants, shrubs, and trees.

Certain physical ecosystem components, such as light and nutrient availability, provide the energy source and material to drive primary productivity. The historical input of the necessary light and nutrients into the ecosystem and the resulting capacity of the relevant habitat to produce or provide the necessary food sources to salmon and trout are discussed below.

2.2.3.1 Light

Primary productivity and plant growth are driven by light energy. All food that is available for juvenile salmonids is made possible by the ability of plants to capture light, both at the water's edge in shallow water areas and in the water column itself. When turbidity is increased, light in the water column is reduced. This can result in less phytoplankton productivity as well as limit the depth at which submerged plants can be found.

Riverine Reach

Light limits phytoplankton productivity in the estuary section of the Columbia River (Sullivan, et al., 2001). Although it has not been studied extensively, it is reasonable to assume that this conclusion is also true for the riverine and river mouth sections. See also Estuary, below.

Estuary

Available information about historical conditions suggests that historical turbidity was greater in the water column than it is currently. The primary productivity within the shallow water and flats and the water column habitats would have decreased as turbidity increased; the depth at which photosynthesis occurred would also have decreased. Because light is currently a limiting factor in the lower Columbia River (CREDDP, 1984), it is presumed that it would have been a historical limiting factor as well. However, any decrease in primary productivity that resulted from increased turbidity was balanced by abundant organic macrodetritus from emergent plant species provided by the tidal marshes and swamps (Sherwood, et al., 1990).

Light penetration in the water column is affected by vertical mixing dynamics and turbidity resulting primarily from suspended sediments (Sullivan, et al., 2001). The current reduced flows have reduced suspended particulate matter concentrations during the spring freshet by a factor of two or more since pre-flow regulation. It is suspected that light penetration is greater now during most of the year than it was under historical conditions. This greater light penetration suggests that phytoplankton contributed less in the past to the suspended organic matter in all sections of the lower Columbia River.

River Mouth

Light limits phytoplankton productivity in the estuary section of the Columbia River (Sullivan, et al., 2001). Although this has not been studied extensively, it is reasonable to assume that this conclusion is also true for the riverine and river mouth sections. See also Estuary, above.

2.2.3.2 Nutrients

Inorganic nutrients such as nitrates and phosphates enter the system both from outside sources and as a byproduct of the breakdown of macrodetritus (Small and Morgan, 1994). Nutrients and light are required to support primary productivity in the system. If nutrients are in short supply, plant production is limited.

In the lower Columbia River, nutrient concentration varies seasonally. Inorganic nitrogen concentration is greatest in spring (March-May) and lowest in summer (June-September).

Riverine Reach

See Estuary, below.

Estuary

Historically, the breakdown of macrodetritus from the freshwater wetlands and tidal marshes and swamps provided a significant source of nutrient input to the estuary (Sullivan, et al., 2001). In addition, there are indications that resident phytoplankton production was more important than imported phytoplankton production in terms of nutrient transport to the lower Columbia River.

Light reduction caused by water column turbidity is believed to be more important in controlling phytoplankton production than is inorganic nutrient limitation (Sullivan, et al., 2001; Simenstad, pers. comm., 2001). The inverse correlation between phytoplankton production and river flow, and generally abundant nutrient levels suggest that diatom production within the action area is primarily limited by water retention time and light availability (Sullivan, et al., 2001).

River Mouth

See Estuary, above.

2.2.3.3 Imported Phytoplankton Production

Phytoplankton are microscopic, single-celled plants that float in the water column at a variety of depths (see Figure 2-5). Imported phytoplankton are phytoplankton that are produced upstream and carried into the lower Columbia River in the water column. Most of the phytoplankton within the lower Columbia are freshwater species imported from upstream locations (Small, et al., 1990). Dominant freshwater phytoplankton include *Asterionella formosa, Fragilaria crotensis, Melosira granulata*, and *Melosira italica* (Small, et al., 1990). These species mix with marine diatoms near the river mouth.

Some of the highest productivity rates for phytoplankton in the system occur in May and July, with sites nearest tributary rivers having the greatest rates. Reported productivity rates from these latter areas range from 750 to 1,000 milligrams of carbon per square centimeter per day. Rates in other areas range from 200 to 600 milligrams of carbon per square centimeter per day. Phytoplankton serve a vital role as the base of the food web on which zooplankton, benthic filter-feeding fauna, and epibenthic organisms feed.

Riverine Reach

See Estuary, below.

Estuary

While phytoplankton are the primary component of the existing Columbia estuary food web, historically it may have been less significant (Bottom and Jones, 1990). It is estimated that, with post-flow regulation, the annual input of imported phytoplankton input to the estuary (riverine and estuarine sections) has increased on the order of seven times (from 9,000 metric tons of carbon to 61,440 metric tons of carbon) compared with pre-flow regulation (Sherwood, et al., 1990). The phytoplankton species composition at any one point in the estuary was likely dynamic, shifting from marine-dominated during very low flows to freshwater-dominated during higher flows.

Imported phytoplankton had a role historically, but macrodetritus played a larger part in the food web. Marshes and swamps were historically more ubiquitous in the estuary. It is likely that the macrodetritus input from these tidal marshes and swamps was much more significant in the historical estuarine food web (Bottom and Jones, 1990).

River Mouth

See Estuary, above.

2.2.3.4 Resident Phytoplankton Production

Resident phytoplankton are those that are produced within the lower Columbia River. While phytoplankton are the primary component of the existing Columbia estuary food web, there is evidence that historically it was less significant. The most common taxa associated with the lower Columbia River are the salt-tolerant diatom species *Melosira granulata* and *Asterionella formosa* (Small, et al., 1990). As pointed out previously (Section 2.2.2.1), the marshes and swamps were historically more ubiquitous in the estuary, and macrodetritus likely played a much more significant role in the estuarine food web (Bottom and Jones, 1990).

Resident phytoplankton mix with nonresident phytoplankton in the estuary. Overall, phytoplankton production amounted to 37 percent of the total primary production in the lower Columbia system during studies conducted in the early 1980s (McIntire and Amspoker, 1984). The biomass of phytoplankton varies dramatically by season and location in the system as a result of variations in river flow, tides, and light (Small, et al., 1990). Values tend to be greatest in the upper portions of the estuary at sites near tributaries to the estuary (i.e., Lewis and Clark Rivers, Deep River).

Riverine Reach

The contribution of resident phytoplankton to the detrital food web, either before or after flow regulation, is not known. Estimates by Sherwood, et al. (1990), indicate that the amount may be similar in both pre- and post-flow regulation. The current relatively low levels of phytoplankton production within the estuary may be a result of the relatively quick flushing time associated with the lower river (CREDDP, 1984) compared with other estuarine systems. Because the freshwater phytoplankton are moving so quickly through the system, they do not have the opportunity to build up concentrated communities before they are exposed to lethal salinity levels and die. The current flushing time of the river is approximately 1 to 5 days, depending on flow and tidal conditions (CREDDP, 1984). Historical flushing times would likely have had a greater range as a result of the unregulated flow, but it is uncertain whether the greater range would have been large enough to significantly affect resident phytoplankton production.

Estuary

Production of resident phytoplankton in the Columbia River estuary is relatively low compared with other estuarine systems. There is no indication that resident phytoplankton production was ever a more significant part of primary production within the lower Columbia River than it is currently. However, because of the increased imported phytoplankton level, it is likely that the proportional, pre-flow regulation contribution of resident phytoplankton to total phytoplankton production was greater than it is currently.

Flow regulation has likely changed the spatial dynamics of resident phytoplankton production as well. The flow rates are not as seasonally variable with flow regulation, which potentially could allow phytoplankton populations to build up to greater concentrations than existed historically.

River Mouth

While marine phytoplankton predominate at the mouth of the estuary, the majority of phytoplankton within the estuary are, and likely were, merely an extension of the freshwater communities upstream (CREDDP, 1984).

2.2.3.5 Benthic Algae Production

Benthic (bottom-dwelling) algae production refers to the weight of new benthic algal organic material formed over a period of time, minus any losses during that period. Benthic algal productivity is the rate of production expressed as production divided by the period of time. Benthic primary producers can include flowering plants (*Zostera marina, Potamogeton richarsonii, Ceratophyllum demersum, Elodea canadensis*), macroalgae (*Ulva* spp., *Enteromorpha* spp.), and microalgae communities (diatoms, primarily of the genera *Navicula* and *Achnanthes*) that attach to the substrate (McIntire and Amspoker, 1984) (see Figure 2-5).

Historical data on benthic algae production are lacking. Historical rates are likely similar to current rates. Consequently, data collected in the early 1980s are used here to describe both historical and current conditions. Because of their distribution throughout the intertidal zones, diatoms are by far the most important benthic primary producer on the flats and in shallow water areas, and account for 7 percent of the primary production in the estuary. Annual benthic gross primary productivity rates in grams of carbon per square meter for various regions were 129 at Baker Bay, 94 at Youngs Bay, 34 at Grays Bay, 29 at Cathlamet Bay, and 37 in the upper estuary (McIntire and Amspoker, 1984). Diatoms are known to support production of benthic prey resources used by salmonids. The two most important factors for benthic algae production are light and sediment stability.

Riverine Reach

Benthic production within the riverine reach was likely focused in sheltered and shallow water areas. Because there were relatively fewer sheltered and shallow water areas, benthic production may have been of limited historical significance to the food web within the riverine reach. There are no published historical benthic algae production estimates from the riverine and river mouth as defined in this BA. The McIntire and Amspoker (1984) study sites extended well upstream into freshwater portions of the estuarine section. Benthic primary production rates from that study are summarized in the Estuary section below.

Estuary

Conditions in many parts of the estuary have never been conducive to production of benthic algae and flowering plants (CREDDP, 1984) because the Columbia River was historically relatively turbid, even during low-flow periods. However, sheltered areas and shallow water and flats habitat that harbored benthic algae may have been very productive and critically important to the estuarine food web. Within the estuary, most benthic primary production comes from microalgae and occurs within the shallow water and tidal flats habitat (Thomas, 1983).

Measurements of benthic algae production have been made in the estuarine portion of the study area by McIntire and Amspoker (1984, 1986). Benthic algae production was almost exclusively by benthic diatoms, although live phytoplankton cells were found in some benthic samples and may have contributed somewhat to benthic algae production. Annual benthic gross primary production averaged 72 grams of carbon per square meter. Areas with the lowest rates were the more exposed areas that contained coarse sediment grains, such as Clatsop Spit. Higher rates were recorded in more protected areas with finer grained sediments, such as inside Youngs and Baker Bays. Benthic macroalgae such as *Enteromorpha*, which are common in other Pacific Northwest estuaries, are rare in the lower Columbia River.

Total production on the tidal flats was estimated to be 2,837 metric tons of carbon per year (McIntire and Amspoker, 1986). Benthic algae associated with the lower edge of the tidal marsh accounted for an additional 2,085 metric tons of carbon annually. Of the 30,000 metric tons of carbon produced annually by phytoplankton, marshes, and benthic algae in the estuary, 7 percent (2,100 metric tons) was attributed to benthic microalgae, 37 percent (11,100 metric tons) to marsh macrophytes, and 56 percent (16,800 metric tons) to phytoplankton (Small, et al., 1990).

River Mouth

See Estuary, above.

2.2.3.6 Tidal Marsh and Swamp Production

Tidal marsh and swamp production refers to the weight (i.e., biomass) of new marsh and swamp plant organic material formed over a period of time, minus any losses during that period. Tidal marsh and swamp productivity is the rate of production expressed as production divided by the period of time. Tidal marsh and swamp production results in vegetation necessary to support insect life and, ultimately, to input macrodetritus into the system. The primary production from tidal marshes and swamps forms the basis for the macrodetrital food web that supports juvenile salmonids. Small fish forage at the edges of marsh channels for insects and benthic crustacea. The predominant tidal marsh and swamp habitats within the lower river historically would have produced macrodetritus within the system and also supported insect production (Thomas, 1983).

Riverine Reach

The river in the riverine portion of the action area historically was connected to floodplain areas, which would frequently develop tidal marsh and swamp characteristics. Seasonal inundation of these floodplain areas would promote plant growth that would support insects. In addition, inundation of floodplain areas during high spring freshet flows and large winter flood events would transport macrodetritus from the vegetated areas into the system. Total emergent plant production in the riverine and estuarine portions of the system pre-1870 was 62,629 metric tons of carbon per year (Sherwood, et al., 1990).

Estuary

See Riverine Reach, above.

River Mouth

See Riverine Reach, above.

2.2.4 Historical Condition for Indicators Affecting Food Web

The historical abundance of salmonid stocks was in part related to the complex food webs that sustained juvenile salmonids migrating to the ocean. Within each habitat type, the chains of organisms feeding and being eaten form interconnected patterns or webs that ultimately provide prey for salmonids moving through the river ecosystem.

The trophic components of the salmonid food web discussed in this section are illustrated in Figure 2-6. These include the following categories:

- Deposit feeders
- Mobile macroinvertebrates
- Insects
- Suspension/deposit feeders
- Suspension feeders

2.2.4.1 Deposit Feeders

Deposit feeders are benthic animals that feed by ingesting material on the immediate surface of sediments or the sediments themselves, thereby obtaining organic matter and detritus. The primary known deposit feeders in the lower Columbia River are annelids (segmented worms). Both marine (polychaetes) and freshwater (oligochaetes) varieties are found within the action area. Annelids are important to the system because they provide a primary link between detritus and the mobile macroinvertebrates that are a food source for some life stages of salmon and trout (CREDDP, 1984). In addition, deposit feeders include some gammarid amphipods and harpacticoid copepods. These animals are often on or very near the surface.

Riverine Reach

See Estuary, below.

Estuary

Deposit feeders historically played a large role in the riverine and estuarine food web for salmonids. The abundance of tidal marshes and swamps and freshwater wetlands provided large amounts of macrodetritus for the deposit feeders. In particular, the food web leading through the deposit feeders from marsh macrodetritus was very important historically for juvenile salmonids (Weitkamp, 1994; Bottom, et al., 2001).

River Mouth

See Estuary, above.

2.2.4.2 Mobile Macroinvertebrates

Mobile macroinvertebrates are large epibenthic organisms that reside on the bottom of the river. Examples of macroinvertebrates in the lower Columbia River include shrimp (*Crangon franciscorum*), mysids (e.g., *Neomysis mercedis*), and Dungeness crab (*Cancer magister*) (CREDDP, 1984). These species make up most of the standing crop of mobile macroinvertebrates in the estuary. *Neomysis* and Dungeness crab are primarily brackish water organisms that occur in the lower estuary and occasionally in the central estuary when river flows are low and salinity extends farther upriver. *Neomysis* has been found in shallow areas upriver as far as RM 43.2 (McCabe and Hinton, 1996). *Crangon* account for most of the density of mobile macroinvertebrates in the central and upper estuary. Density is typically less than one animal per cubic meter. They occur predominantly in the shallow areas over the tidal flats, but can be found in the channel areas during low river flows, possibly because during high flow the velocity is too great for them to be in the channel areas.

Figure 2-6: Salmonid Food Web for the Lower Columbia River

Macroinvertebrates feed on epibenthic zooplankton (e.g., copepods), benthic infauna (e.g., *Corophium* and various polychaetes), and detritus (CREDDP, 1984).[10] Mobile macroinvertebrates, particularly mysids, are an important food source for juvenile salmonids (Simenstad and Cordell, 2000; Miller and Simenstad, 1997). Planktonic larvae forms, as well as other small benthic forms of this group, can be important in the diet of salmonids (Meyer, et al., 1980; Healey, 1991; Bottom and Jones, 1990).

Riverine Reach

See Estuary, below.

Estuary

As with other benthic and epibenthic food sources within the estuary, there was apparently ample habitat available for macroinvertebrates historically. It is likely that the various epibenthic salmon food sources were a larger part of the historical food web than they are currently (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.2.4.3 Insects

Many insect species feed directly on the vegetation in freshwater wetlands and tidal marshes and swamps; consequently, they are directly dependent on marsh production and detritus. Emergent insects provide an important food source for juvenile salmonids in the estuary (Simenstad and Cordell, 2000; Miller and Simenstad, 1997). Some of the insects known to be of importance to salmonids include aphids, emergent chironomids, and other dipteran flies (Simenstad and Cordell, 2000; Miller and Simenstad, 1997). Weitkamp (1994) identified insects as an important food source for salmonids in the lower Columbia River.

Riverine Reach

See Estuary, below.

Estuary

Little is known of the historical abundance of insects within the riverine reach or estuary, but it is known that their primary habitats (freshwater wetlands and tidal marshes and swamps) were prevalent. Present-day marshes and swamps cover only 35 percent of the area covered prior to 1870 (Thomas, 1983).

River Mouth

See Estuary, above.

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[10] Epibenthic organisms occupy the area from the sediment surface to 1 meter above the sediment surface within the water column. Benthic fauna live primarily on top of or within the first layer of sediment on the river bottom. Benthic infauna refers specifically to those organisms that live within, rather than on top of, the river bottom.

2.2.4.4 Suspension/Deposit Feeders

Suspension/deposit feeders are benthic and epibenthic organisms that feed on or at the interface between the sediment and the water column. Suspension/deposit feeding typically involves some mechanism for sifting the upper level of sediment to obtain the associated organic materials. For example, *Corophium*, which are benthic infauna, construct a tube in the sediment from which they will occasionally make a foray to scoop in plant material and detritus from the surface (CREDDP, 1984). Examples of suspension/deposit feeders include some species of mysids, some species of bivalves (e.g., *Macoma balthica* and *Corbicula manilensis*), and some species of amphipoda (*e.g.*, *Corophium salmonis*, *Corophium brevis*, and *Corophium spinicorne*).

Suspension/deposit feeders are important to adult salmonids because of their role in the production of prey. *Eurytemora* and *Scottolana* are known to be important prey for planktivorous fish (e.g., Pacific herring, Pacific sand lance), which are preyed on by all adult salmonid species.

Riverine Reach

See Estuary, below.

Estuary

The benthic and epibenthic chain within the food web historically provided by suspension/deposit feeders was a prominent feature of the lower Columbia River ecosystem (Sherwood, et al., 1990). This aspect of the food web provided important support to juvenile salmonids.

River Mouth

See Estuary, above.

2.2.4.5 Suspension Feeders

Suspension feeders are organisms that feed from the water column itself. For zooplankton and benthic/epibenthic organisms, this is accomplished primarily through "filter feeding" (extracting organic matter from the water column by pumping or siphoning the water through their system). Examples of some of the significant suspension feeding organisms in the lower Columbia River include several species of copepod and freshwater cladocerans (e.g., *Bosmina* and *Daphnia* spp.).

Riverine Reach

See Estuary, below.

Estuary

Suspension feeders tend to support a water-column-based food web that favors such species as anchovy, herring, and longfin smelt, which are frequently consumed by older salmonids on their way out of the estuary (Bottom and Jones, 1990). Historically, suspension feeders most likely played an important role within the estuary and riverine sections, but may have been less abundant than now relative to suspension/deposit feeders and insects (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.2.4.6 Tidal Marsh Macrodetritus

Tidal marsh macrodetritus is the dead and decaying plant remains from both the tidal marsh and the tidal swamp areas. The macrodetritus associated with the relatively large plant material growing in the tidal marshes and swamps provides an important food source for the benthic communities adjacent to the tidal marsh and swamp areas. In turn, these benthic communities provide an important food source to juvenile salmonids.

Riverine Reach

See Estuary, below.

Estuary

The lower Columbia River historically had a large supply of macrodetritus from the abundant tidal marshes and swamps located in the estuary (Thomas, 1983).

River Mouth

See Estuary, above.

2.2.4.7 Resident Microdetritus

Resident microdetritus is the dead and decaying remains of resident phytoplankton and benthic algae. Resident microdetritus is a food source for zooplankton (small, often microscopic animals floating in the water column) and benthic and epibenthic suspension and suspension/deposit feeders.

Riverine Reach

Resident microdetritus was present historically in the riverine section of the lower Columbia River. It likely was supported primarily by resident phytoplankton production and, to a much lesser extent, by benthic microalgal production occurring in shallow flats and channels.

Estuary

As stated in Section 2.2.3.4, there is a relatively low level of phytoplankton production within the estuary, which may result from the relatively quick flushing time associated with the lower river (CREDDP, 1984). If the resident phytoplankton production were also relatively low historically, which seems likely, then the planktonic source for resident microdetritus would have been limited. Conversely, there historically would have been more side channels, oxbows, and marshes to support phytoplankton growth.

The same would not be true of benthic algae, which is the other source for resident microdetritus, because benthic algae tend to flourish primarily in sheltered locations that are not subject to strong flows (CREDDP, 1984). Accordingly, benthic sources of microdetritus, which tend to support benthic and epibenthic feeders, would not have been affected by historical estuary flushing. However, benthic algae account for a relatively small proportion of microdetritus within the estuary.

River Mouth

See Estuary, above.

2.2.4.8 Imported Microdetritus

Imported microdetritus is mostly derived from algal production upriver, including that produced above dams, and is important for suspension feeders and suspension/deposit feeders.

Riverine Reach

See Estuary, below.

Estuary

Imported microdetritus in the estuary is composed primarily of the dead phytoplankton floating in the water column from upstream. Imported microdetritus functions within the food web similar to resident microdetritus. There is no reason to believe that before the creation of the upstream reservoirs the production rates varied greatly between resident and imported microdetritus.[11]

River Mouth

See Estuary, above.

2.2.5 Historical Condition for Indicators Affecting Growth

Attaining adequate growth is vital to the survival and migration of juvenile salmonids. The primary factors that ensure adequate growth opportunities are sufficient productive feeding areas. The ecosystem components that are relevant to ensuring that adequate growth opportunities exist include:

- Habitat complexity/connectivity/conveyance
- Velocity field
- Bathymetry and turbidity
- Feeding habitat opportunity
- Refugia
- Habitat-specific food availability

This section is a discussion of the historical condition within the lower Columbia River for these important growth factors.

2.2.5.1 Habitat Complexity, Connectivity, Conveyance

Aquatic habitats function to support listed salmonids and coho in the Columbia River through their complexity, geographic connections, and conveyance of energy and nutrients. The complexity of the lower Columbia River habitat types supports a variety of salmonid life history types and stages as the young salmonids grow during their downstream migrations. Connectivity refers to the configuration of habitat mosaics in time and space in a manner that allows for movement of salmonids between habitats. Conveyance describes the transport of organics and inorganics between habitats.

Riverine Reach

Appropriate habitats need to be available when salmonids require them for feeding, resting, and cover as they move up and down the river system. The lower Columbia River historically had a rich variety of

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[11] Reservoirs on the Columbia River have caused significant increases in phytoplankton production within the river above Bonneville Dam (Sherwood, et al., 1990).

habitats in a mosaic that provided the complexity necessary for salmonids (Thomas, 1983). Permanent physical and topographical barriers among habitats or conditions that impeded habitat-forming processes were minor, and good connectivity among these habitats was likely, particularly during high-flow events.

Estuary

Juvenile salmonids moving downriver and through the estuary tend to use shallow water and tidal flats habitat. However, as water levels rise or fall, they will move into the tidal marsh areas or remain at the edges of deeper pools, respectively. The estuary historically contained large areas of tidal marsh as well as access to inundated floodplain.

River Mouth

See Estuary, above.

2.2.5.2 Velocity Field

Velocity field refers to speed and direction of flow velocity within the river. The relevant issue is whether adequate slower-moving or still shallow areas are available to salmonids while they are in the lower Columbia River. These areas are important to salmonid growth because juveniles are small and have relatively weak swimming capabilities; consequently, feeding is most effective in areas where current velocities are low.

Riverine Reach

See Estuary, below.

Estuary

The floodwaters of the Columbia River historically inundated the margins and the unimpeded floodplains along the river, providing access to marshland and tidal channel habitats with low-velocity fields (Bottom, et al., 2001). These tidal marshes and side channels were present in great abundance historically (Thomas, 1983).

River Mouth

See Estuary, above.

2.2.5.3 Bathymetry and Turbidity

In the context of growth opportunity, bathymetry and turbidity refer to the conditions that influence the ability of salmonids to locate their prey. Because salmonids are primarily visual predators, turbid waters may limit their ability to see prey, while uneven bathymetry may hide the prey from their sight.

Riverine Reach

See Estuary, below.

Estuary

Historically, the lower Columbia River had a highly variable bathymetry. In addition, the lower river was subject to high levels of turbidity, particularly during spring freshets and winter floods. These conditions may have limited the ability of salmonids to feed efficiently within the water column habitats; however, good connectivity to tidal marsh and floodplain areas mitigated the feeding conditions.

River Mouth

See Estuary, above.

2.2.5.4 Feeding Habitat Opportunity

The concept of habitat opportunity is discussed in *Salmon at River's End* (Bottom, et al., 2001). Habitat opportunity refers to those physical characteristics that affect access to geographical locations that are important to particular fish needs. "Feeding habitat opportunity" refers specifically to the ecosystem's ability to provide access to important feeding habitats. The characteristics that affect access to feeding habitats typically vary over short periods of time, often less than a day. They include water level elevation, water current speed (velocity), temperature, and salinity (see Sections 6.1.5, Salinity; 6.1.7, Bathymetry; and 6.1.26, Velocity Field). Habitat characteristics naturally vary daily with changes produced by tides, seasonally by predominant weather conditions, and over long periods with changes produced by humans such as dams, dredging, diking, and filling.

Riverine Reach

The lower Columbia River historically had significant tidal marsh and swamp areas as well as frequent flooding from spring freshets and flooding that provided access to such areas. These tidal marshes not only provided access to insects and benthic food sources, they also provided areas of low-velocity flow.

Estuary

See Riverine Reach, above.

River Mouth

Not applicable.

2.2.5.5 Refugia

Refugia refers to shallow water and other low-energy habitat areas temporarily used by salmonids for resting and cover. Lack of refugia can impede the growth of salmonids. Juvenile salmonids (particularly ocean-type, which are not strong swimmers) would expend considerable energy fighting currents without access to safe resting areas. Refugia are important to growth because the expenditure of calories to counter tides and river currents increases the amount of food that must be consumed. In addition, if refugia are not available, it is less likely that these calories will be available to salmonids for consumption because refugia also provide habitat for prey.

Riverine Reach

During times of historical high flows, when refugia from flow velocities would have been particularly important, the lower Columbia River had significant tidal marsh and floodplain areas accessible to salmonids.

Estuary

Prior to construction of the diking throughout the lower river, high flows would have extended the margins of the estuary outward, which would have increased the shallow water areas available for refuge significantly (Bottom, et al., 2001). A study conducted in 1916, which predates much of the diking, found that subyearlings collected for the study were able to remain in the estuary throughout the peak of an extremely high spring freshet (Rich, 1920).

River Mouth

Not applicable.

2.2.5.6 Habitat-Specific Food Availability

Habitat-specific food availability refers to the capability of habitat areas to provide feeding opportunities when and where they are needed by salmonids. Fish must be able to access the necessary complex habitats, but in addition these areas must support a food web that provides prey species when salmonids are feeding there. The food web within the action area is based in large part on detritus. As described in Section 2.2.3, detritus sources may include emergent plants from tidal marshes, benthic algae, resident phytoplankton, and imported phytoplankton from upstream sources.

Riverine Reach

See Estuary, below.

Estuary

The type of food web that develops within an ecosystem depends on the balance of the primary productivity sources within the system. The lower Columbia River historically had significant sources of macrodetritus and good opportunities for benthic suspension/deposit feeders (Thomas, 1983). Accordingly, it is likely that it had a balanced food web with both pelagic and benthic components.

River Mouth

See Estuary, above.

2.2.6 Historical Condition for Indicators Affecting Survival

A number of ecosystem factors influence the survival of salmonids within the lower Columbia River ecosystem. These factors include both physical and biological components that affect salmonids ability to rear and migrate through the system. Primary physical factors may include temperature and salinity extremes, stranding, and entrainment. Biological factors may include disease, predation, and competition. This section is a discussion of the historical conditions associated with the various relevant factors.

2.2.6.1 Contaminants

Contaminant levels in the Columbia River historically had some level of contamination that peaked after the turn of the century as a result of increased industrialization. State and federal laws governing the discharge of effluent into the river have resulted in the more recent decrease in contaminant levels.

Riverine Reach

See above.

Estuary

See above.

River Mouth

Contaminant buildup and increased concentrations in the river mouth are likely to be undetectable. The high-energy wave and tidal actions at the river mouth cause extreme dilution and mixing of sediment particles with potentially associated contaminants. The freshwater and brackish water river plumes are expected to transport up-river contaminants into the near ocean, where they are dispersed by seasonal ocean currents.

2.2.6.2 Disease

Pathogens (viruses, bacteria, and parasites that cause disease) have always been present within salmonid populations in the Columbia River Basin. Little is known about the historical incidence and prevalence of disease, but it is apparent that salmonids have harbored these agents for many years. For example, it has been known since the early 20th century that dogs fed raw salmon frequently became ill and died, although the fluke and its parasitic rickettsia that is the causative agent of salmon-poisoning disease were not identified until the early 1970s.

Riverine Reach

See above.

Estuary

See above.

River Mouth

See above.

2.2.6.3 Suspended Solids

Suspended solids are suspended sediments (sand, silt, and clay) and organic debris transported within the water column near the velocity of the river current. These particles can move long distances before being redeposited. Suspended solids are a factor in salmonid survival for a variety of reasons, including:

- The organic matter is a potential source of biological oxygen demand in the water column.
- The inorganic material may have a detrimental effect on fish through laceration of gills.
- The organic material may be a pathway for transfer of contaminants to fish.
- The associated turbidity may impair feeding by reducing the ability of fish to see prey.
- Suspended sediment can also benefit juvenile salmonids by making them less susceptible to predation.

See Section 2.2.1.1 for a discussion of suspended sediments.

Riverine Reach

Most of the organic matter in suspended solids historically was derived from floodplains and marsh vegetation during inundation from high spring freshets.

Estuary

The organic component of the suspended sediment is a significant source of the detritus that forms the base of the ETM food web (Sherwood, et al., 1990; Simenstad, et al., 1990). Most of the organic matter in suspended solids historically was derived from floodplains and marsh vegetation during inundation from high spring freshets.

River Mouth

At the river mouth and seaward, suspended solids are rapidly diluted and dispersed by the wind and tidally driven currents that are typical of this area.

2.2.6.4 Stranding

Stranding is caused by either water level fluctuations or waves trapping young salmonids that are rearing and migrating in the shallow waters of estuaries and lower rivers.

Riverine Reach

Wave action resulting from strong winds, particularly during storms, had the potential to affect shallow water levels quickly enough to strand fish in shoreline depressions. These depressions may have been more common historically because of the tendency for depressions to form on the land side of obstructions such as large woody debris.

Estuary

See Riverine Reach, above.

River Mouth

See Riverine Reach, above.

2.2.6.5 Temperature and Salinity Extremes

Temperature and salinity extremes can cause physiological stress to fish and other organisms within a confined system, ultimately reducing their chance of survival by making them more prone to disease or predation. Salinity and temperature extremes affect conditions for juvenile salmonid survival as well as upstream migration. Water temperatures greater than 21^{o} C may block migration (Weitkamp, SEI Presentation, 2001; Water Temperature Criteria Technical Work Group, 2001). Temperature and salinity also set the conditions for saltwater adaptation.

Riverine Reach

Salinity extremes are not applicable to the riverine reach. For temperature discussion, see Estuary, below.

Estuary

The extent of salinity intrusion into the Columbia River estuary depends primarily on channel depth, strength of tides, and river flows (Corps, 1999a). Although there are no data regarding the historical limits of salinity intrusion, salinity likely exhibited a significant seasonal range caused by the wide range of seasonal flows (Thomas, 1983). Lower Columbia River temperatures historically may have been relatively cool in the river mainstem because of unfettered river flow and freshets.

River Mouth

See Estuary, above.

2.2.6.6 Turbidity

As described previously, turbidity is a measure of light penetration through water and is a natural part of the habitat to which the young salmonids are adapted. It is a function of the amount of suspended sediment and plankton within the water column. As with suspended sediment, turbidity levels increase with high river flows. Heavy wind and wave activity can also increase turbidity. Turbidity can benefit juvenile salmonids by making them less susceptible to predation.

Turbidity, as it relates to salmonids' ability to survive within the ecosystem, can be positive or detrimental. The reduced visibility caused by fine suspended sediment may be beneficial to juvenile salmonids by hindering predation (Gregory, 1988). However, extremely high levels of suspended sediments that result in turbid conditions can produce sublethal stress (e.g., gill clogging, erosion of gill filaments) or even cause mortality by suffocating in juvenile salmonid populations (Sigler, 1984) (see Section 6.1.3, Suspended Solids).

Riverine Reach

Turbidity levels within the Columbia River historically followed the river's hydrograph closely, rising during spring freshets. Turbidity levels at this time were likely higher than current levels. Turbidity levels during low-flow periods were generally low (Corps, 1999a). The highest turbidity levels occurred during western subbasin winter floods.

Estuary

In addition to the turbidity entering the estuary from the main river, waves and current actions in the shallow flats and channels in the estuary generate turbidity.

River Mouth

See Estuary, above.

2.2.6.7 Predation

Throughout their history, salmonids have been affected by predatory forces. Salmonids have evolved in a dynamic equilibrium along with many types of predators and have responded to selection pressures from those predators. The great advantages of migrating between productive ocean-feeding areas and protected estuarine and freshwater rearing and spawning areas is counterbalanced by the predatory forces responding to the large concentrations of individuals coalescing during migration. Salmonids have adapted to predation pressures in part by maintaining high reproductive rates and developing variable life-history strategies for different populations that result in less concentrated migratory movements for salmonids as a whole throughout the year. Historically, piscivorous mammals, birds, and fish have preyed on salmonids in the near ocean and in the lower Columbia River estuary and freshwater areas.

Riverine Reach

See above.

Estuary

See above.

River Mouth

See above.

2.2.6.8 Entrainment

Entrainment historically was not an issue within the action area.

Riverine Reach

See above.

Estuary

See above.

River Mouth

See above.

2.3 Existing Environmental Conditions

The overall processes and components of the historical lower Columbia River ecosystem addressed in Section 2.2 are the same processes and components that define the existing lower Columbia River ecosystem. However, some of these processes and components have been modified as a result of non-indigenous human activities and long-term natural cycles. Human activities within the Columbia River Basin have tended to reduce the historical variability of the processes and components that characterize the lower Columbia River ecosystem such as the changes in river flows, illustrated previously in Figure 2-2. This section provides an overview of existing conditions by describing the present state of the ecosystem processes and components previously introduced.

2.3.1 Existing Condition for Indicators Affecting Habitat-Forming Processes

Human activities have influenced the physical characteristics of salmonid habitats by modifying habitat-forming processes. This section is a discussion of the current condition of these relevant processes.

2.3.1.1 Suspended Sediment

The average annual suspended sediment load in the Columbia River has been reduced from historical levels by the system of dams and reservoirs in the mainstem and tributaries. The Columbia River is still subject to sporadic large-scale events that affect suspended sediment loads in the action area, as demonstrated by the 1980 eruption of Mount St. Helens. The eruption sent mudflows down the Toutle River to the Columbia and temporarily reduced the channel depth of the Columbia River from 40 feet to 14 feet.

Riverine Reach

The primary factor controlling the suspended sediment volumes in the Columbia River is the large peak flows associated with interior basin spring freshets and the western subbasin winter flood events. These peak flows have been reduced during the latter half of the 20^{th} century by flow regulation at upstream reservoirs. Flow regulation has reduced the 2-year flood peak discharge at The Dalles from 580,000 cfs to 360,000 cfs (Corps, 1999a). These peak flow reductions stem from a variety of factors, including flow regulation, irrigation withdrawal, climate variability, and flood control operations at water storage projects. In addition to reductions in peak flow, the upstream dams have trapped some sediment in the reservoirs. However, a review of pre- and post-flow regulation data relating to suspended sediment revealed no change in the relationship between suspended sediment and river discharge, indicating that there has been no change in the sediment supply over that time period (Eriksen, SEI Presentation, 2001).

A comparison of the suspended sediment data in Figure 2-7 to that in Figure 2-8 shows no significant differences in the suspended sediment/water discharge relationship between Vancouver, Washington (upstream of the Project), and Beaver, Oregon (in the middle of the Project).

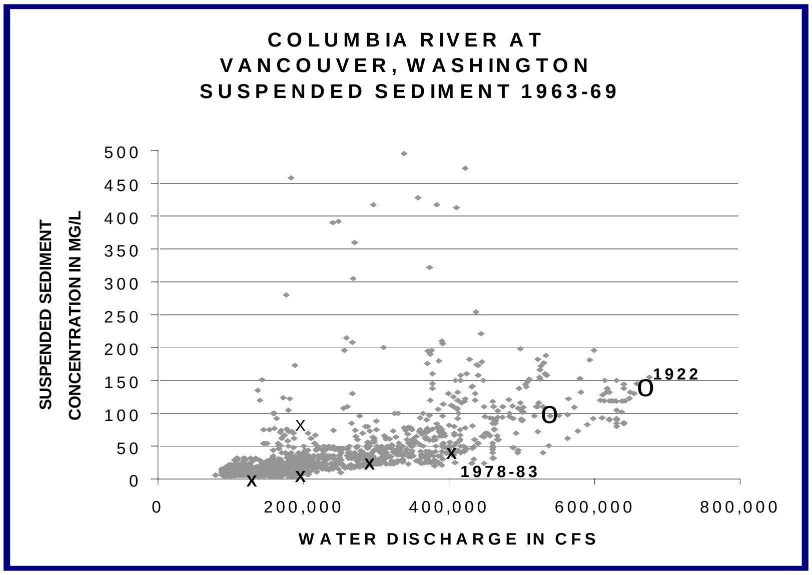
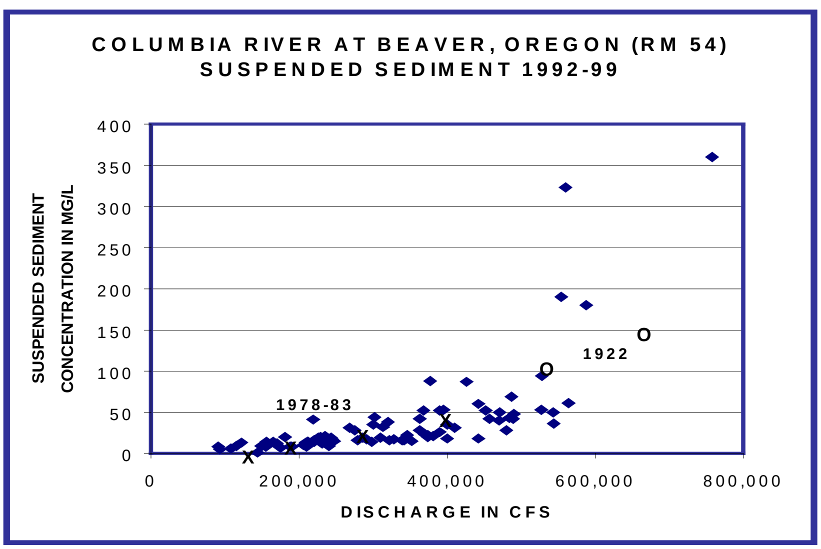


Figure 2-7: Columbia River Suspended Sediment versus River Discharge at Vancouver, Washington (RM 107). [Note: The 1963-69 and 1978-83 data are from the USGS, and the 1922 data are from the Corps.]

Figure 2-8: Columbia River Suspended Sediment versus River Discharge at Beaver, Oregon (RM 54). [Note: The 1992-99 and 1978-83 data are from the USGS. The 1922 data are from the Corps].



The suspended sediment concentrations measured by the U.S. Geological Survey (USGS) at Beaver (RM 53) have been in the ranges of less than 10 milligrams per liter (mg/L) at 100,000 cfs, around 20 mg/L at 200,000 cfs, from 20 to 50 mg/L at 300,000 cfs, and from 20 to 60 mg/L at 400,000 cfs. Those ranges equate to suspended sediment discharges of 2,000 cubic yards per day, 8,000 cubic yards per day, 12,000 to 30,000 cubic yards per day, and 16,000 to 48,000 cubic yards per day, respectively. The Corps has estimated that upstream flow regulation has reduced the average annual suspended sediment load from the historical level of 12 mcy per year to 2 mcy per year. This reduction is a result of the reduced transport potential caused by the lower discharges. The suspended sediment gradation is similar to the historical gradation, consisting mostly of silt and clay size material, with sand constituting less than 30 percent of the load for discharges less than about 400,000 cfs (Corps, 1999a).

Estuary

The 2-mcy-per-year average suspended sediment load in the river is delivered to the upper estuary just downstream of Puget Island. The inflowing suspended sediment is distributed throughout the estuary. Suspended silt and clay particles may remain in the estuary for 1 to 4 months, depending on river and tidal flows (Jay, SEI Presentation, 2001). In the estuary, local erosion and deposition processes can greatly alter the local concentrations. Wind waves and shifting tidal currents can erode material from the estuary's flats and shallow channels, causing increased suspended sediment. Suspended sediment deposition in the estuary still contributes to the creation of shallow water areas that ultimately support vegetation and become marsh or swamp areas, although the reduced sediment load probably has slowed the process. The deposition rate of silt and clay is most likely still in the range of 30 percent of the incoming volume. It is likely that most of the incoming sand is now deposited in the estuary.

River Mouth

The amount of suspended sediment discharge to the Pacific Ocean is unknown. Because of the factors discussed above, it is likely that suspended sediment discharge to the ocean has decreased from historical levels. The average annual suspended sand discharge is probably much less than 0.5 mcy per year.

2.3.1.2 Bedload

The Columbia River's bedload transport has been reduced because of the flow regulation at upstream reservoirs. Flow regulation has reduced the 2-year flood peak discharge from 580,000 cfs to 360,000 cfs (Corps, 1999a). This peak discharge reduction has had an effect on bedload transport because at discharges below 300,000 cfs the bedload transport rate is quite low and sand wave movement is typically only a few feet per day. However, when the flow exceeds 400,000 cfs, the bedload transport rate increases and sand waves can migrate downstream at around 20 feet per day (Corps, 1999a).

Riverine Reach

Sand waves in this reach downstream of Vancouver are generally large, with heights of 6 to 12 feet and up to 500 feet long. The post-regulation average annual bedload transport in the main river channel is estimated to be in the range of 0.1 to 0.4 mcy per year (Corps, 1999a).

Estuary

Bedload transport in the estuary is highly variable, but the rates are not known. Bedload processes in the estuary are influenced by location, bathymetry, river discharge, ocean waves and tidal currents. The main channel between RM 25 and 40 has sand waves comparable to those found in the riverine reach. From RM 25 to around RM 18, the main (south) channel sand waves remain downstream-oriented, but become progressively smaller. Between RM 18 and 12, sand waves are generally small (less than 50 feet long), but can be directed either downstream or upstream, depending on flow conditions. Downstream of RM 12, the main channel sand waves are small and reverse direction with the tide. In the reach around RM 7 to 12, shallower areas adjacent to the main channel have been found to have small, downstream-directed sand waves, even when the main channel sand waves were reversing (CREDDP, 1984).

River Mouth

Current bedload transport to the ocean is unknown. The CREDDP study (1984) found small, reversing sand waves in the entrance during both high- and low-river discharge seasons.

2.3.1.3 Woody Debris

The past century of activities within and adjacent to the lower river floodplains and riparian areas have reduced the amount of large woody debris available to the river and for deposition in shallow water and on tidal flats. During periods of heavy timber harvests before the mainstem dams were constructed, the availability of wood debris in the lower Columbia River increased significantly.

Riverine Reach

The dams upstream of the lower river have created an obstacle to the movement of woody debris into the riverine portion of the project from upstream tributaries. As a result, the net amount of large wood that now moves downstream has decreased. The woody debris within the riverine reach shorelines has the potential to provide structure habitat in shallow shoreline areas for both young salmonids and their potential fish predators, such as bass. However, woody debris does not perform the same channel-forming functions in the large Columbia River channel as it does in the smaller tributary channels.

Estuary

Within most estuarine areas, large woody debris tends to accumulate near the high tide line, where it is available to fish for only brief periods each day near the peaks of the tide cycle. Large woody debris is a common component of the shoreline habitat of forested marsh areas at the upstream edges of estuaries. This large woody debris appears to provide refuge habitat for both young salmonids and some of their fish predators.

River Mouth

Not applicable.

2.3.1.4 Turbidity

Turbidity levels within the Columbia River roughly follow the river's hydrograph, rising during spring freshets and western subbasin winter floods. At any given river discharge there are variations in the observed turbidity. Both the levels of turbidity and variation increase with river discharge.

Riverine Reach

For most of the year, turbidity levels are below 10 nephelometric turbidity units (NTUs). The highest turbidity levels occur during western subbasin winter floods, reflecting the shift in the primary source of streamflow. All the turbidity levels over 20 NTU shown in Figure 2-9 occurred during high winter flows, with the two highest values occurring during the February 1996 flood.

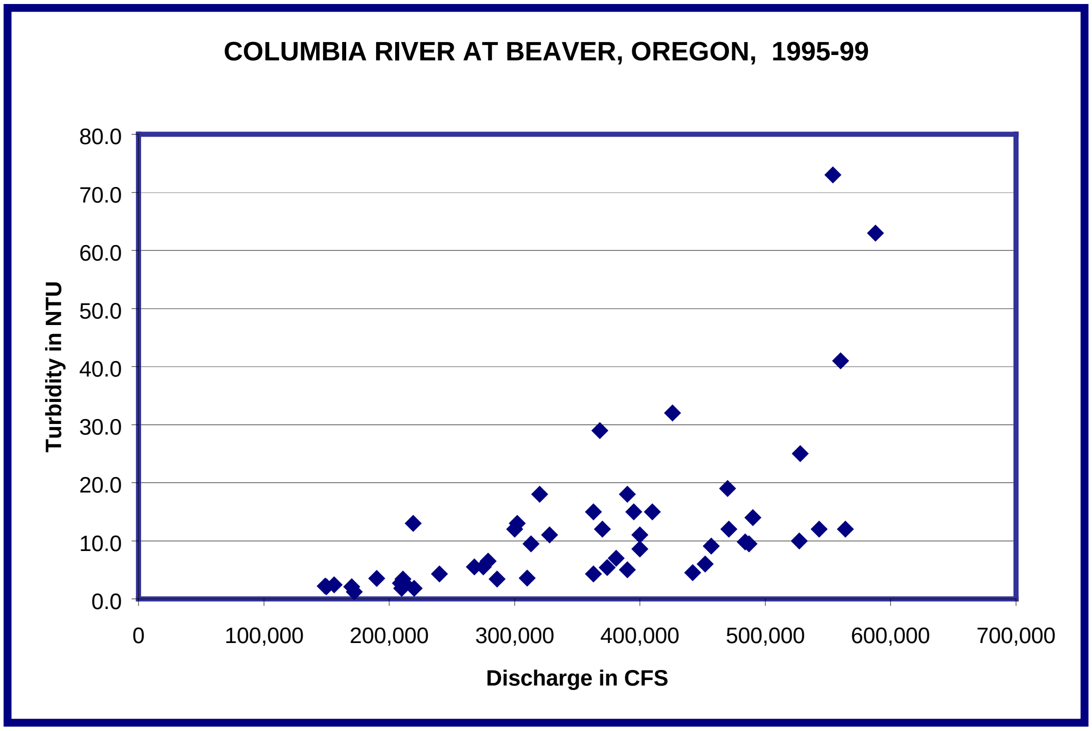


Figure 2-9: Columbia River Turbidity Measured by the USGS at Beaver, Oregon (RM 54)

Estuary

The turbid water from the riverine reach is distributed throughout the estuary. Jay (SEI Presentation, 2001) estimated the fine suspended material that causes turbidity can remain in the estuary for up to 1 to 4 months, depending on tides, river flows, and travel paths. Local erosion and deposition processes can alter the local turbidity levels. Wind waves and shifting tidal currents can erode material from the estuary's flats and shallow channels, causing increased turbidity. Turbidity generated by waves and current actions in the shallow flats and channels in the estuary has probably not changed from historical levels. The tidal hydraulics also create a traveling zone of higher turbidity related to the upstream portion of the salinity wedge. An ETM occurs in both the north and south channels of the estuary. The location of the ETM shifts with the tide and river discharge, similar to the movement of the salt wedge. Researchers have found the ETM in the south channel at various locations between RM 5 and 20 (CRETM-LMER, 2000).

River Mouth

Turbidity levels in the river mouth reach are highly variable and depend on river flow and ocean conditions.

2.3.1.5 Salinity

As stated in Section 2.2.6.5, salinity intrusion into the lower portions of the Columbia River estuary depends primarily on channel depth, strength of tides, and river flows (Corps, 1999a; CREDDP, 1984).

Because of flow regulation within the Columbia River Basin, it is likely that the seasonal variability for salinity intrusion is reduced from historical levels (Thomas, 1983).

Riverine Reach

Salinity intrusion extends only to about RM 40, which divides the riverine area from the estuary. Therefore, salinity is not applicable in the riverine reach.

Estuary

Figure 2-10 shows the range of salinity concentration profiles within the estuary's south (navigation) channel documented by CREDDP during the early 1980s. The maximum salinity intrusion – i.e., salinity greater than 0.5 parts per thousand (ppt) – extended upstream along the bottom of the main channel to near RM 30 during low flow periods. The CREDDP study (1984) also indicates that the upstream limit of salinity intrusion in the shallow waters of Cathlamet Bay was near RM 23 during low flow.

River Mouth

Freshwater extrusion lowers salinity concentrations within the Columbia River plume, but the extent is unknown.

2.3.1.6 Accretion/Erosion

Riverine Reach

Accretion and erosion in this reach have been affected by reductions in sediment inflow, sediment transport potential, and overbank flooding. Levee construction and upstream flow regulation have reduced flooding frequency, which in turn has reduced sediment accretion in the overbank areas.

There may be slightly more accretion at the mouth of the Sandy River (RM 121 to 123) as a result of the reduction in the Columbia River's ability to erode and transport sediment (see Section 2.2.1.6).

Flow regulation has likely reduced sediment inflow from the Willamette and Cowlitz Rivers, except for the 1980 eruption of Mount St. Helens. That eruption caused a large volume of sediment, 50 to 100 mcy, to be deposited in the Columbia River at the mouth of the Cowlitz River. Most of that sediment was not transported downstream because much of it was dredged from the river.

River flows continue to shift sediment around within the river channel. Shoals persistently form in the navigation channel, and significant accretion might occur if dredging was not performed. Shoreline erosion continues at sandy beaches created by past disposal. Shoreline erosion probably occurs more slowly than it would without flow regulation because high river stages occur less frequently.

Estuary

The Corps has estimated that the average annual deposition rate in the estuary has decreased from a historical level ranging from 2 to 5 mm per year. The Corps has estimated the current average accretion rate at 1 mm per year. Locally, accretion and erosion rates may be much higher and could change from year to year. Eriksen (SEI Presentation, 2001) found that the north channel between RM 6 and 7 had infilled up to 20 feet between 1982 and 2000.

Figure 2-10: Salinity Sections in the Main Navigation Channel

River Mouth

The accretion and erosion patterns in the river mouth reach have been altered from historical times. The entrance channel is now maintained to a minimum depth of -55 feet MLLW by annual dredging and the presence of the jetties. Peacock Spit has been eroding since around 1940. Recent erosion has also occurred in the entrance between the two jetties.

2.3.1.7 Bathymetry

There has been a great deal of change in the river bathymetry since the turn of the 20th century. Navigation development has deepened the channel in all three reaches, and the riverine and entrance channels have also been narrowed.

Riverine Reach

The riverbed between RM 106 and 146 remains generally broad and shallow. A shallow-draft navigation channel (currently maintained at -17 feet CRD) extends through the reach. Below RM 106, the bathymetry of this reach has changed over the past 100 years. The depth of the thalweg has increased and portions of the river are narrower. The thalweg is now consistently more than 40 feet deep, with short reaches of over 70 feet. Dredging disposal has been used to create shoreline and in-water fills that have narrowed the river and created small side channels. These fills exist throughout the riverine reach. The riverbed is still sandy and covered with sand waves. The riverbed side-slopes remain generally flat, with slightly steeper slopes near shorelines protected by pile dikes. The bathymetry shifts more slowly because of the reduction in high discharges from flow regulation. New shallow side channels flow around islands that were created by past disposal, such as those at RM 98, 95, 81, 76, and 64 to 60.

Estuary

The estuary still contains varying bathymetry. The main channel still crosses from the north to south side of the estuary between Harrington Point and Tongue Point. The remnants of the old main channel still exist along the north side of the estuary upstream to about RM 20. Shallow, tidal, and subtidal flats occupy the central part of the estuary between those two large, deep channels. Several small channels cut the shallow flats. There are numerous channels around the many islands in Cathlamet Bay. The limited shoreline disposal in this reach has had little effect on the bathymetry. Disposal has created Rice, Miller Sands, and Pillar Rock Islands in areas that were once shallow water. Because the frequency and magnitude of high-flow events in the lower Columbia River has been reduced by flow regulation within the basin, changes in estuary bathymetry occur at a much slower rate than was historically the case.

River Mouth

The entrance channel was deepened by dredging to -48 feet MLLW in 1956-57 and to -55 feet MLLW in 1984. The entrance channel is now maintained to a minimum depth of -55 feet MLLW by annual dredging and the jetties. Peacock Spit has been eroding since around 1940. Dredged material disposal has replaced some of the eroded sediment and formed two separate mounds.

2.3.2 Existing Condition of Habitat Types

Changes in flow regulation and shoreline development and diking have changed the lower river and the habitat types that are important to listed salmon and trout species. This section will discuss the changes that have occurred to these habitat types and the forces that create and nourish them. Figures 2-11 through 2-17 have been included to give a general understanding of the existing land covers for RM 106.5 to RM 3, which provides a context for the habitat changes that have occurred.

2.3.2.1 Tidal Marsh and Swamp Habitats

The existing tidal marsh and swamp habitats of the lower Columbia River are the result of past habitat-forming processes and are maintained by the same processes occurring now.

Riverine Reach

Diking and flow regulation have led to significant changes in the amount and location of tidal marsh and swamp habitats within the lower Columbia River. Highways, railroads, and diking have contributed to narrowing and confining of the river to the existing location. Diking has resulted in confinement of 84,000 acres of floodplain that likely contained large areas of tidal marshes and swamps. Between the mouth of the Willamette River and the mouth of the Columbia River, diking and other activities have resulted in an estimated loss of about 52,000 acres of wetland/marsh and 27,000 acres of forested wetland since the 1870s (Graves, et al., 1995). Much of this land is now in agricultural use. Riparian forests (cottonwood and ash-broadleaf forest) declined by approximately 14,000 acres through conversion of land to agriculture and upland development.

The remaining tidal marsh and swamp habitats currently are located in a narrow band along the river banks and around undeveloped islands. Side channel and backwater habitats occur in large islands such as Wallace, Crims, Willow Grove, Fisher, Hump Walker, Lord, Howard, Cottonwood, Sandy, Martin, Burke, and Sauvie Islands (see Figures 2-11 to 2-15).

Federal and state wildlife management areas are located in the riverine reach. These provide wetland and riparian forest habitat for wintering waterfowl, raptors, shorebirds, furbearers, and other wildlife species. The management areas include Ridgefield National Wildlife Refuge and Shillapoo Wildlife Management Area in the Vancouver lowlands, and Sauvie Island Wildlife Management Area in Oregon.

Estuary

In the estuary, tidal marshes have decreased in area from 16,180 acres in 1870 to the current 9,200 acres (a decrease of approximately 43 percent). Tidal swamps in the estuary have decreased from 32,020 acres to 6,950 acres (a decrease of approximately 77 percent) over the same period (Thomas, 1983). Losses are attributed primarily to diking and filling. Erosion accounts for a very small amount (about 150 acres) of loss.

While there has been a net loss of tidal marsh and swamp habitat since 1870, new marsh and swamp areas are continuing to form within the estuary. This is occurring because disposal of dredged material has created new shoreline areas that have colonized by vegetation and because natural accretion within shallow areas has combined with colonization by bulrush (*Scirpus* spp.) and other marsh vegetation (Thomas, 1983).

Figure 2-11:   Reach 1 Land Cover RM 98-106.5

Figure 2-12: Reach 2 Land Cover RM 84-98

Figure 2-13: Reach 3 Land Cover RM 70-84

Figure 2-14: Reach 4 Land Cover RM 56-70

Figure 2-15: Reach 5 Land Cover RM 40-56

Figure 2-16: Reach 6 Land Cover RM 29-40

Figure 2-17:   Reach 7 Land Cover RM 3-29

River Mouth

No tidal marshes or swamps were noted in this area in the 1870s. Since then, about 250 acres of tidal marshes have been added in the vicinity of Point Adams through natural vegetation colonization (Thomas, 1983). The primary reason for this increase has been removal of wave action in certain areas of the river mouth by construction of jetties, which has allowed colonization by vegetation in shoreline areas. Figures 2-18a and 2-18b show the results of a CREDDP survey (1984) of the estuary for habitat types, including marsh and swamp locations.

2.3.2.2 Shallow Water and Flats Habitat

Shallow water and flats habitat occurs along the margins of shallow water areas of the lower Columbia River, which are scattered throughout the action area. This habitat type is concentrated in the estuary and downstream portions of the riverine reach.

Riverine Reach

See above.

Estuary

Thomas (1983) estimated that shallows and flats have increased by approximately 4,130 acres since 1870.[12] Shallow water and flats habitat has increased throughout most of the estuary (Sherwood, et al., 1990). In particular, significant shoaling has occurred in Cathlamet and Baker Bays, which, in the case of Baker Bay, led to the creation of 3,620 acres of shallow water and flats habitat (Thomas, 1983).

River Mouth

Shallow water habitat at the river mouth is decreasing because jetties that have been constructed have reduced or removed much of the wave energy that previously prevented formation of shallow water areas through erosion. Sand deposited in this area now forms sand dunes in areas that were formerly shallows and flats (Thomas, 1983).

[12] Thomas defines the estuary as that portion of the river to RM 46. As stated previously, the estuary is defined as that portion of the river from RM 3 to RM 40 for purposes of this BA.

Figure 2-18a: Habitat Types (Sheet 1 of 2)

Figure 2-18b: Habitat Types (Sheet 2 of 2)

2.3.2.3 Water Column Habitat

For the Columbia River, water column habitat currently serves a particularly important function as the carrier of imported phytoplankton and microdetritus from upriver to the lower Columbia River and estuary. It also serves as a migratory corridor for adult and juvenile salmonids.

Riverine Reach

See Estuary, below.

Estuary

As a result of the long-term changes in tidal marsh and swamp habitat, and the reduced availability of macrodetritus, the water column habitat contributes a greater proportion of organic matter to the food web in the system than occurred historically. The salinity mixing zone, which is associated with the ETM, is an important part of the water column habitat. This zone is a highly productive feeding area for zooplankton and benthic and epibenthic organisms (Simenstad, et al., 1994). The location of ETM moves up and down the estuary naturally. Because of flow regulation by mainstem dams, the ETM is believed to move around the estuary less than it did in the past.

River Mouth

See Estuary, above.

2.3.3 Existing Condition for Indicators Affecting Habitat Primary Productivity

This section addresses the current status of plant growth and production in the respective habitats and how the habitats' primary productivity within the lower Columbia River has changed in response to habitat modification. As discussed previously in Section 2.2.3, various plant species in lower Columbia River habitats are the primary producers that capture solar energy in plant biomass and form the base of the salmonid food web. As in the discussion of historical habitat primary productivity, this section will address resident and imported phytoplankton (water column habitat), benthic algae (shallow water and flats habitat), and the plant growth associated with tidal marsh and swamp areas. The changing conditions have shifted the primary producers from a marsh-based macrodetrital food web to a microdetrital food web. As before, the necessary process inputs of light and nutrients will also be discussed. Figures 2-19a and 2-19b show the results of CREDDP's 1984 survey of primary productivity locations with the estuary.

2.3.3.1 Light

Primary productivity within the shallow water and flats and water column habitats depends in part on the amount of light energy fixed in the ecosystem. Light penetration can be decreased by turbidity.

Riverine Reach

See Estuary, below.

Estuary

Flow regulation and sediment trapping associated with the dams upstream of the lower Columbia River have altered the annual average suspended sediment load in the estuary. This change has resulted in somewhat lower turbidity levels than occurred historically. Nonetheless, the lower Columbia River is generally still quite turbid, with a productive photosynthesis layer that ranges from 1.5 to 4.5 meters, depending on the season and location (CREDDP, 1984). At these depths, light input can be a limiting factor for the primary production of benthic algae and phytoplankton within the lower Columbia River (CREDDP, 1984).

River Mouth

See Estuary, above.

2.3.3.2 Nutrients

Riverine Reach

See Estuary, below.

Estuary

Organic matter cycling from tidal channel tributaries to the main river channel likely continues to be a major source of nutrients within the estuary. However, substantial reductions in the tidal marshes and swamps in all sections of the action area probably have substantially reduced the contributions of this material to nutrient levels in the system. Within the Columbia River Basin, projected calculations indicate an 84 percent decline in macrodetritus input when compared with historical levels (Sherwood, et al., 1990). While this would suggest a decrease in the input from the breakdown of macrodetritus, increases from upstream sources of nitrogen or phosphates appear to provide adequate nutrient input. With the exception of occasional short periods in the late spring and summer, nutrient supply is not a limiting factor in primary productivity within the estuary (CREDDP, 1984).

Substantial loss of marsh macrodetritus, coupled with an increase in phytoplankton production in the system and an increase in imported plankton, suggests a shift from a dominance of macrophyte-derived nutrients to plankton-derived nutrients. Remineralization of nutrients from macrophyte biomass generally requires more time and energy than does that from phytoplankton. Furthermore, macrophyte detritus enters estuarine systems in fall and winter as opposed to spring and summer for phytoplankton (Thom, 1984). Consequently, the timing of the release of nutrients to the water column would have changed compared with historical conditions.

River Mouth

See Estuary, above.

Figures 2-19a: Primary Producers (Sheet 1 of 2)

Figures 2-19b: Primary Producers (Sheet 2 of 2)

2.3.3.3 Imported Phytoplankton Production

Riverine Reach

Most of the phytoplankton within the lower Columbia River are freshwater species imported from upstream locations (CREDDP, 1984) (Figure 2-20). Currently, imported freshwater phytoplankton are composed primarily of planktonic diatoms produced behind the mainstem dams (Sherwood, et al., 1990). Phytoplankton, the primary component of the current lower Columbia River food webs (Bottom and Jones, 1990), serve as the energetic base on which zooplankton, benthic fauna, and epibenthic organisms feed. However, because phytoplankton and the microdetritus produced from it are found within the water column, they tend to support a pelagic food web that is less accessible to juvenile salmonids.

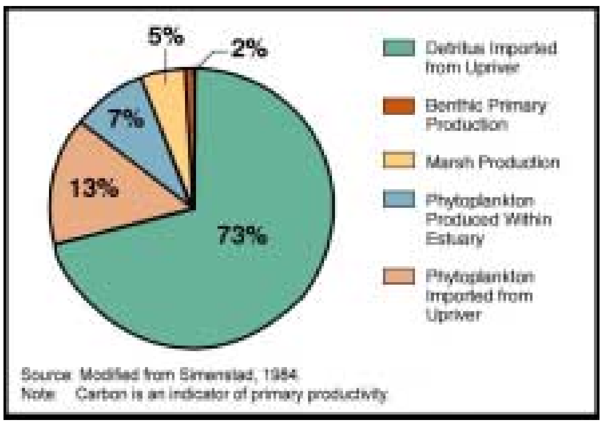


Figure 2-20: Carbon Sources in the Estuary

Estuary

Freshwater phytoplankton species generally dominate collections made in the estuary. However, during low-flow periods in summer, marine species can dominate collections in the estuary (Small, et al., 1990).

As stated in Section 2.2.3.3, estimates suggest that the annual input of imported phytoplankton to the estuary (riverine and estuarine sections) has increased on the order of seven times, going from 9,000 metric tons of carbon to 61,440 metric tons of carbon (Sherwood, et al., 1990). Production of imported phytoplankton in reservoirs above the dams accounts for the massive increase in input to the lower Columbia River system. In addition, production of imported phytoplankton in the lower Columbia River is enhanced by the increase in light penetration related to a reduction in the suspended detrital material, decreased vertical mixing, and increased retention time (Sullivan, et al., 2001).

River Mouth

See Estuary, above.

2.3.3.4 Resident Phytoplankton Production

Riverine Reach

Indirect evidence suggests that resident phytoplankton contribute much less proportionally to the food web than imported phytoplankton in the riverine portion of the action area. See Sherwood, et al. (1990) regarding fluvial import of microdetritus.

Estuary

Resident phytoplankton production does not currently appear to be a significant part of the primary production within the lower Columbia River (see Figure 2-20). An existing theory to explain this is that the low level of phytoplankton production within the estuary is a result of the relatively quick flushing time associated with the lower river (CREDDP, 1984). Because the freshwater phytoplankton are moving quickly through the lower river estuary, it is suggested that they cannot build up concentrated communities before being exposed to lethal salinity levels. The current flushing time is 1 to 5 days, depending on flow and tidal conditions (CREDDP, 1984).

Although resident phytoplankton production is not significant, increased light penetration under post-flow regulation conditions (e.g., reduced suspended detrital matter, lower vertical mixing rates) may have resulted in an increase in resident phytoplankton production (Sullivan, et al., 2001), although the amount of change is unquantified.

River Mouth

See Estuary, above.

2.3.3.5 Benthic Algae Production

Benthic algae occur throughout the action area. As with phytoplankton, changes in salinity and light will affect their productivity and distribution.

Riverine Reach

The most important primary producers within the riverine reach, as well as in the estuary, are microalgae distributed throughout the lower river on the sediments of shallow subtidal and intertidal flats (Thomas, 1983; McIntire and Amspoker, 1984).

Estuary

Benthic algae production within the estuary has always tended to be limited to shallower areas (above the MLLW) and sheltered areas such as Youngs and Trestle Bays (Thomas, 1983; CREDDP, 1984). Indications are that the percentage of these habitat areas has actually increased by approximately 7 percent from 1870 levels, including 3,620 acres in Baker Bay (Sherwood, et al., 1990; Thomas, 1983).

Benthic algae production is not believed to have changed substantially from historical conditions (Sherwood, et al., 1990), although lower turbidity may improve light conditions and enhance productivity. McIntire and Amspoker (1986) found a strong correlation between light and benthic algae production and surmised that clearer water would result in greater benthic algae production.

Benthic microalgae likely enter the particulate organic matter pool used by benthic infauna and epibenthic invertebrates. These are, in turn, important to the food web of salmonids (Simenstad, et al., 1990).

Sherwood, et al. (1990), estimated that benthic microalgae production in the fluvial through river mouth portion of the lower Columbia River has declined approximately 15 percent (from 1,825 to 1,545 metric tons of carbon) since before 1870. This loss may be related to a general decline in shallow flats and channels associated with marshes that were diked or filled. Sherwood, et al. (1990), suggest that possible reasons for this decrease are a reduction of the tidal prism, a net increase in sediment in the estuary, and reduction in river flow, resulting in:

- Decreased mixing

- Increased stratification
- Altered response to tidal forcing
- Decreased salinity intrusion length and transport of salt into the estuary

Production of benthic microalgae is vital to the current lower Columbia River salmonid food web because microalgae serve as the primary food source for the benthic infauna (e.g., *Corophium*) currently preyed on by juvenile salmon.

River Mouth

See Estuary, above.

2.3.3.6 Tidal Marsh and Swamp Production

As discussed in Section 2.3.2.1, diking and flow regulation have led to significant changes in the amount and location of tidal marsh and swamp habitat within the lower river. As these habitat areas have been reduced, the total amount of primary production has decreased, assuming similar area production rates for similar marsh and swamp types (Thomas, 1983).

Riverine Reach

Current tidal marsh and swamp production is lower than historical levels in the riverine and estuarine portions of the lower Columbia River. The decline is proportional to the loss in area of tidal marsh and swamp habitat described in Section 2.3.2.1. About 250 acres of tidal marshes have been added through natural colonization since the 1870s in the vicinity of Point Adams (Thomas, 1983). Predictably, a very slight increase in tidal marsh production has been associated with this small increase in this type of habitat in the river mouth. Diking has effectively cut off much of the historical floodplain throughout the riverine reach. Isolation of the river from the historical floodplain has likely reduced the amount of macrodetrital input to the system.

Annual production by marshes in the riverine (fluvial) section of the study area averaged 401 grams of carbon per square meter. Rates of marsh production in the post-development period are probably similar to pre-development conditions. However, because of the decline in marsh area as a result of diking and filling, total production throughout the study area has declined dramatically. Based on data from the estuary and fluvial systems, total emergent plant production has declined an estimated 72 percent (62,629 to 11,324 metric tons of carbon per year) since before 1870 (Sherwood, et al., 1990).

Estuary

See Riverine Reach, above.

River Mouth

See Riverine Reach, above.

2.3.4 Existing Condition for Indicators Affecting Food Web

There has been a shift in the available plant life within the river. Imported microdetritus has increased substantially, while tidal marsh and swamp vegetation and macrodetritus have declined. This has led to a shift within the food web for the lower river.

This section moves into a discussion of the shift that has occurred within the food web as a result of the primary production occurring within the relevant habitat areas. This section focuses on the current state of the food sources that the salmonids eat.

2.3.4.1 Deposit Feeders

Riverine Reach

See Estuary, below.

Estuary

Although deposit feeders historically played a large role in the estuarine food web for salmon and trout, the food web has shifted to emphasize suspension-feeding copepods associated with the ETM zone. This is in part because of the reduction in available tidal marshes and swamps and freshwater wetlands within the system, which supplied the macrodetritus that, in turn, supported the deposit feeders in the system (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.3.4.2 Mobile Macroinvertebrates

Riverine Reach

See Estuary, below

Estuary

In freshwater and brackish habitats, mobile macroinvertebrates, particularly mysids, currently provide an important juvenile salmon food source (Simenstad and Cordell, 2000; Miller and Simenstad, 1997). However, as with other benthic and epibenthic food sources within the estuary, there has been a reduction in availability and productivity. Accordingly, the emphasis has shifted toward a microdetritus-based food web (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.3.4.3 Insects

Riverine Reach

See Estuary, below.

Estuary

Many insect species feed directly on the vegetation in freshwater wetlands and tidal marshes and swamps. As these habitat areas have been reduced (approximately 43 percent of tidal marsh habitat and approximately 77 percent of the historical tidal swamps), so too has the primary production from these areas (Thomas, 1983). While emergent insects still provide an important food source for juvenile salmon in the estuary (Simenstad and Cordell, 2000; Miller and Simenstad, 1997), the relative importance of insects' role in the food web is believed to have diminished.

River Mouth

See Estuary, above.

2.3.4.4 Suspension/Deposit Feeders

Riverine Reach

See Estuary, below.

Estuary

Suspension/deposit feeders are benthic and epibenthic organisms that feed on or at the interface between the sediment and the water column. Although the benthic/epibenthic food web, which was a prominent feature of the historical lower Columbia River ecosystem, no longer produces as varied or as rich a food web, the food it does produce is vital to juvenile salmonid survival (Sherwood, et al., 1990). The primary suspension/deposit feeders used by salmonids in the estuary are *Corophium salmonis and Neomysis mercedis* (McCabe, 1997).

River Mouth

See Estuary, above.

2.3.4.5 Suspension Feeders

Riverine Reach

The discussion of primary productivity in the lower river habitats showed that primary productivity has shifted toward the phytoplankton and microdetritus that support suspension feeders. Many of these suspension feeders are planktonic (i.e., drifting passively with the current – e.g., *Daphnia pulex*).

Estuary

The most productive group of zooplankton suspension feeders are estuarine (e.g., *Neomysis mercedis*).[13] These zooplankton tend to dwell in the bottom waters of the estuary, which often has an upriver flow (CREDDP, 1984). The tendency is for the zooplankton to concentrate at the ETM, which is where the upriver saline flow mixes with the freshwater downstream flow. The ETM is rich with dead and dying phytoplankton that are unable to tolerate the salinity of the ETM. This provides plentiful food for the estuarine zooplankton. Because flow regulation has eliminated the high flows that tend to override the upstream saline bottom current, the estuarine zooplankton tend to remain in the estuary and multiply (CREDDP, 1984). This dynamic has turned the ETM, with its suspension feeding base, into the richest, most abundant part of the modern food web in the estuary (Bottom, et al., 2001). However, this food web tends to support pelagic species such as anchovy, herring, American shad, and longfin smelt. While some

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[13] Estuarine zooplankton are adapted to low salinity levels, but will typically tolerate freshwater. The other types of zooplankton in the lower Columbia River are marine (e.g., *Archeomysis grebnitzkii*) and freshwater (e.g., *Daphnia pulex*).

of these species may be prey for older salmon on the way out of the estuary, they do not benefit ocean-type juvenile salmonids, which tend to stay in shallow water areas (Bottom and Jones, 1990).

River Mouth

See Estuary, above.

2.3.4.6 Tidal Marsh Macrodetritus

Riverine Reach

See Estuary, below.

Estuary

As pointed out in Sections 2.3.2.1 and 2.3.3.6, habitat areas in the estuary have been reduced by approximately 43 percent for tidal marsh habitat and approximately 77 percent for tidal swamps (Thomas, 1983). As also pointed out in the discussion of tidal marsh and swamp primary productivity, the reduction in habitat area has caused a concurrent reduction in the overall amount of tidal marsh and swamp plant production in the estuary. Because there are fewer tidal marsh and swamp plants in the estuary, there is less source material for macrodetritus. The reduction in macrodetritus primarily affects the benthic communities that were previously adjacent to the tidal marsh and swamp areas. The impact to the benthic communities has played a part in shifting the estuary away from a benthic food web and towards a pelagic food web (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.3.4.7 Resident Microdetritus

Riverine Reach

See Estuary, below.

Estuary

As discussed in Section 2.3.3.4, little primary production occurs within the water column of the lower Columbia River. Figure 2-20 shows the relative production of resident phytoplankton compared with the amount of imported phytoplankton and detritus that enters the system from upstream. This figure graphically illustrates that resident phytoplankton is likely to be of limited importance in the estuarine food web. The input of microdetritus from benthic sources is still important, but the relative input of benthic microdetritus is low, as also indicated in Figure 2-20.

River Mouth

See Estuary, above.

2.3.4.8 Imported Microdetritus

Imported microdetritus is mostly derived from algal production upriver, including that produced above dams, and is important for suspension feeders and suspension/deposit feeders.

Riverine Reach

See Estuary, below.

Estuary

Imported microdetritus in the estuary is composed primarily of phytoplankton carried downstream from the reservoirs into the lower river where they die when they encounter saltwater (CREDDP, 1984). As Figure 2-20 shows, detritus imported from upriver is by far the greatest contributor of organic carbon to the estuary.

Because of the loss of tidal marshes and swamps and freshwater wetlands in the lower river and the associated loss of macrodetritus input, there has been a significant shift in the estuary to a microdetritus-based food web. There is some dispute about whether such a food web is capable of properly supporting the full array of salmonid life stages (Bottom and Jones, 1990; Sherwood, et al., 1990). The concern is that juvenile salmonids do not feed on the pelagic[14] organisms supported by a microdetrital food web. An additional concern is that the microdetrital material does not provide an adequate food resource to the benthic invertebrates that juvenile salmonids feed on.

River Mouth

See Estuary, above.

2.3.5 Existing Conditions for Indicators Affecting Growth

Attaining adequate growth is vital to the survival of juvenile salmon and trout. To grow, the fish not only need thriving food resources, but also access to those resources. Section 2.3.4 described the changes that have taken place in the lower Columbia River food web. This section is a discussion of the accessibility of those areas to the fish. The ecosystem components that are relevant to ensuring that the fish have sufficient access to food to provide adequate growth opportunities include:

- Habitat complexity/connectivity/conveyance
- Velocity field
- Bathymetry and turbidity
- Feeding habitat opportunity
- Refugia
- Habitat-specific food availability

The existing conditions within the Columbia River Basin for these important growth factors are discussed in this section.

2.3.5.1 Habitat Complexity, Connectivity, Conveyance

Flow regulation, beginning in the 1930s, and diking of the floodplains, starting in the late 1800s, have eliminated the seasonal inundation of margin and floodplain areas, which has reduced the complexity of this habitat. Although there are no particular barriers to passage that affect the remaining habitat, connectivity among habitats may be affected by a reduction in the size and number of corridors connecting the habitat areas.

[14] Organisms living within the water column habitat.

Riverine Reach

See Estuary, below.

Estuary

The lower Columbia River has lost much of the habitat complexity that it had historically, primarily as a result of diking and filling within the estuary (Thomas, 1983).

River Mouth

See Estuary, above.

2.3.5.2 Velocity Field

Velocity fields vary up and down the water column and across the river channel. Low velocities can almost always be found near the riverbed and along the shoreline. Shallow flats and estuarine side channels provide an abundance of low-velocity fields.

Riverine Reach

See Estuary, below.

Estuary

Although flow regulation and diking have reduced access to remaining low-velocity marshland and tidal channel habitat, that same flow regulation has reduced overall flow volume and velocity in the lower Columbia River, which promotes this type of habitat. In addition, while there are fewer tidal marshes to provide low-velocity habitat, there has been an increase in shallow water and flats habitat, which typically has lower flow velocities than the deeper channel areas (Thomas, 1983).

River Mouth

See Estuary, above.

2.3.5.3 Bathymetry and Turbidity

Bathymetry and turbidity are fairly consistent throughout the riverine reach, but both are highly variable in the estuary.

Riverine Reach

See Estuary, below.

Estuary

Because salmonids are visual predators, turbid waters may limit their ability to see prey, and uneven bathymetry may hide the prey from their sight. While the bathymetry and turbidity of the modern river are still highly variable, they are much less so than historically (see Section 6.1.8, Tidal Marsh and Swamp Habitat).

Evidence of the effect of turbidity on salmonid feeding patterns is suggested by dietary changes in juvenile salmonids following the eruption of Mount St. Helens in 1980. Following the eruption, the benthic amphipods commonly recorded in salmonid stomach analyses were supplanted by insects and cladocerans (McCabe, et al., 1981; Emmett, 1982; Kirn, et al., 1986). This shift in diet suggests that benthic amphipods either became less available or were less visible during very high turbidity.

River Mouth

See Estuary, above.

2.3.5.4 Feeding Habitat Opportunity

Habitat opportunity refers to those physical characteristics that affect access to geographical locations important to particular fish needs. "Feeding habitat opportunity" refers specifically to the ecosystem's ability to provide access to important feeding habitats (see Section 2.2.5.4).

Riverine Reach

The significant reduction in tidal marsh habitat and the diking of floodplains that occurred in the late 1800s and early 1900s substantially reduced the variety of feeding habitat available.

Estuary

See Riverine Reach, above.

River Mouth

See Riverine Reach, above.

2.3.5.5 Refugia

Refugia is an important aspect of the growth of juvenile salmonids (see Section 2.2.5.5, Refugia).

Riverine Reach

Significant areas throughout the riverine reach have been diked; as a result, areas that would have provided cover and rearing habitat have been lost. Consequently, overall refugia has been reduced in the riverine portion.

Estuary

The lower river has 7 percent more shallow water habitat currently than it had historically. These shallow water habitats provide low-velocity fields, allowing for energy conservation for juvenile salmonids. As in the riverine reach, significant areas have been diked. Diking restricts the amount of potential refugia provided by floodwater spillover into tidal marsh areas. It also prevents high flows from extending the margins of the estuary outward, which would increase the shallow water areas available for refuge (Bottom, et al., 2001).

River Mouth

See Estuary, above.

2.3.5.6 Habitat-Specific Food Availability

Riverine Reach

The food web in the action area is based in large part on detritus. As described in Section 2.2.3, detritus sources may include emergent plants from tidal marshes, benthic algae, resident phytoplankton in estuarine waters, and fluvial inputs of imported phytoplankton from upstream sources. Tidal marsh loss in the estuary, water impoundment in the upper river, and reduced flooding and flow variation have all contributed to reduced recruitment of macrodetritus; consequently, microdetritus has become the base of the food web. This material originates primarily from the reservoirs behind the mainstem dams above the action area.

Estuary

The statement above regarding the riverine reach applies to the estuary as well. In the estuary, microdetritus tends to accumulate within the ETM (CREDDP, 1984). Juvenile salmonids benefit less from good food sources in the water column of the central estuary because their habitats generally are peripheral flats and marshes.

River Mouth

See Estuary, above.

2.3.6 Existing Conditions for Indicators Affecting Survival

The number of ecosystem factors that have an important effect on the ability of salmon and trout to survive within the Columbia River Basin has increased since human development in the basin began. Historical factors for survival included predation, stranding, disease, and the effects of contaminants, suspended sediments, and temperature and salinity extremes on salmon and trout. Issues like disease, which were not historically issues of concern, have become more significant in the present. In addition, entrainment of fish and contamination, which were not historical survival issues, are now issues for discussion. This section addresses the changes that have occurred to the various survival factors subsequent to human development in the basin.

2.3.6.1 Contaminants

Current levels of sediment contamination from polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dichlorodiphenyl trichloroethane (DDT) and its metabolites are discussed in Appendix B. Within a short-term historical perspective, two of the contaminants assessed, PCBs and DDT, were much more prevalent historically (1960s and early 1970s) than they are today and their concentrations are continuing to decline gradually since 1972, when use of DDT was banned. Apart from increased sediment contamination associated with point sources of pollutants, the most notable feature of the sediment contamination in the lower Columbia River is its uniformity. This reflects the non-point source origin of contaminants and the high energy of the Columbia River, which tends to uniformly mix contaminants within the main river channel, resulting in little difference upstream to downstream. Differences in contamination are greatest when contamination in the navigation channel is compared to that in the shoreline sediments. Shoreline sediments, especially in areas where fine particulates deposit, contain higher concentrations of contaminants because they contain higher concentrations of the organic matter to which the contaminants sorb.

The physical and chemical test results for sediment in the Columbia River are discussed in Appendix B.

Riverine Reach

Because PCBs and DDT are distributed widely via atmospheric transport and non-point sources, such as soils and sediments representing large reservoirs in which these contaminants persist, the concentrations found in the environment apart from point sources of pollution do not change greatly in the lower Columbia River. Use of DDT peaked in the 1960s, then slowly declined since it was banned in December 1972. Correspondingly, use of PCBs peaked in the 1970s, then it was abruptly banned in 1977. Because both of these contaminants break down extremely slowly in the environment, their concentrations have declined very gradually over the past 25 years.

PAHs differ from the organochlorine hydrocarbons in that they are generated by internal combustion engines and are derived from natural sources (e.g., forest fires). Their concentrations have been increasing over time due to population and economic expansion. They represent a broad group of contaminants that range from ones that are rapidly broken down in the environment (e.g., benzene, naphthalene) under most conditions to those that tend to persist in some circumstances, such as benzo-a-pyrene in anaerobic sediments.

Overall contamination in the riverine reach reflects the increased number of sources from municipalities and industries. Contamination in the navigation channel is negligible due to extremely low organic carbon content.

Estuary

Contamination in the estuary is less than in the riverine reach because there are fewer and smaller urban and industrial sources of contamination (see Appendix B). Increased dilution of both water and sediment from tidal mixing also lowers contaminant concentrations. As discussed above, the navigation channel contains negligible contamination.

River Mouth

Contamination is lowest in the river mouth, principally because there are no sources other than transient shipping and the influence of upstream sources is greatly diluted by tidal mixing with ocean water.

2.3.6.2 Disease

The number and types of pathogens occurring in Columbia River salmonids have increased in recent years through the introduction of hatchery fish and the movement of fish and water among river basins. The recent introduction of whirling disease to Oregon waters is an example. Diseases in salmon within the Columbia River Basin have been documented for the past half-century.

Riverine Reach

See above.

Estuary

See above.

River Mouth

See above.

2.3.6.3 Suspended Solids

Riverine Reach

See Estuary, below.

Estuary

Shoreline dikes and levees, as well as the hydroelectric dams, have reduced the amount of suspended solids in the river. While the lower turbidity associated with reduced suspended sediments means that salmonids can identify prey more easily, it also means that they can be preyed on more easily.

In addition to the effects on prey and predation, the role of suspended solids in food production has changed from historical conditions. The organic material that provided the base of the food web is now composed of phytoplankton from the upstream reservoirs rather than the recruited organic material from inundated floodplains and marshes (Sherwood, et al., 1990).

River Mouth

See Estuary, above.

2.3.6.4 Stranding

The natural processes historically influencing the susceptibility of juvenile salmonids to stranding in the lower Columbia River are the same physical processes that currently exist. However, upstream peaking flow fluctuations and ship wakes, which were not factors historically, are additional contributors to modern stranding.

Riverine Reach

River flow in the study area is significantly altered by the operation of the upstream reservoirs. Flow is determined by electricity demand, so flows rise and fall to meet that demand. Studies have shown that this fluctuation can strand juvenile fish both in the pools above the dams and in the lower river. In addition, the wakes of ships navigating the lower river can strand fish on exposed sand or behind structures on the beach.

A 1977 report listed observations of stranded juvenile salmonids from both peaking flows and ship wakes. The total mortality rates for observation sites between the mouth of the Columbia River and the Cowlitz River were 145,003 chinook, 1,359 coho, 4,771 chum, and 537 steelhead from February to July 1975 (Bauserfeld, 1977).

Estuary

See Riverine Reach, above.

River Mouth

See Riverine Reach, above.

2.3.6.5 Temperature and Salinity Extremes

River temperature within the basin varies depending on flow, season, and climate conditions. As stated in Section 2.3.1.5, salinity intrusion into the lower portions of the Columbia River estuary depends primarily on channel depth, strength of tides, and river flows (Corps, 1999a; CREDDP, 1984).

Riverine Reach

Salinity intrusion extends only to about RM 40, which divides the riverine reach from the estuary; therefore, salinity is not applicable in the riverine reach. For temperature discussion see Estuary, below.

Estuary

Temperatures within the action area have generally been affected by the following Columbia River Basin-wide changes:

- Slowed river flow (both above upstream reservoirs and seasonally downstream as a result of reduced freshet flow volumes)
- Reduced riparian canopies over streamside vegetation
- Agricultural runoff
- Industrial discharges
- Climate variations such as El Nino

These changes have combined to create river temperatures that will stress fish.

Because of flow regulation within the Columbia River Basin, it is likely that the seasonal variability for salinity intrusion is reduced from historical levels (CREDDP, 1984; Thomas, 1983). Accordingly, it is likely that salinity extremes within the estuary are not as great as they were during historical extreme summer low flow and tidal conditions. For additional discussions of salinity, see Sections 2.2.1.5, 2.3.1.5, and 6.1.5.

River Mouth

See Estuary, above.

2.3.6.6 Turbidity

Turbidity levels within the action area are still influenced by the river's hydrograph rising during spring freshets; however, because dams upstream of the lower river act as sediment traps and because variability of the hydrograph has been reduced by flow regulation, interior basin spring freshets now cause only moderate increases in turbidity levels (Corps, 1999a). Theoretically, lower turbidity levels might affect survival of salmonids by increasing predation, though there is no documentation of this happening.

Riverine Reach

Turbidity levels were likely higher prior to increased development in the Columbia River Basin. High turbidity levels arise from high-suspended sediment levels. However, hydroelectric dam construction has created sediment traps. Based on observed concentrations and appropriate flow-duration curves, the Corps estimated that the average annual suspended sediment yield at Vancouver has been reduced from 12 mcy per year before any dams were built to only 2 mcy per year under today's conditions (Corps, 1999a).

Estuary

Turbidity generated by waves and current actions in the shallow flats and channels in the estuary has probably not changed from historical levels, but turbidity caused by upstream events, as noted above, would vary seasonally.

River Mouth

Because extreme seasonal flows have been reduced, there is less likelihood of high seasonal flows causing plumes with high turbidity.

2.3.6.7 Predation

Salmonids have adapted to predation pressures in part by maintaining high reproductive rates and developing variable life-history strategies for different populations that result in less concentrated migratory movements for salmonids as a whole throughout the year. Salmonids are currently preyed on by piscivorous mammals, birds, and fish in the near ocean and in the lower Columbia River estuary and freshwater areas.

Riverine Reach

See Estuary, below.

Estuary

Predation on juvenile and adult salmonids has received recent attention as increased concentrations of terns and cormorants have settled in the estuary from other locations as the birds became aware of available habitat and food sources. The number of nesting pairs increased from a few hundred pairs in 1984 to an estimated 1,200 to 2,400 cormorants and 14,000 to 16,000 Caspian terns in 1997 (Collis, et al., 2001). These numbers are much larger than those found in the historical estuary. In addition, predation by mammals such as seals and sea lions has become a concern for recreational and commercial fishermen, who regard them as competition for a scarce resource.

While estimates have ranged widely, recent analysis of passive integrated transponder tags recovered from colonies have shown that approximately 17 percent of all salmon tagged in 1998 were consumed by the cormorants and terns on Rice Island. The study also indicated that tern predation in the estuary may focus primarily on hatchery fish because they tend to reside near the surface where tern foraging occurs (Collis, et al., 2001).

Pacific harbor seals are present year-round in Washington and Oregon. Harbor seal populations on the West Coast have been increasing at a rate of about 5 to 7 percent annually since the mid-1970s. The estimated seal population from 1993 to 1995 was 34,134 in Washington and 9,251 in Oregon. Pacific harbor seals are opportunistic feeders, preying on a wide variety of benthic and epibenthic fish and cephalopods. Their diet also varies regionally, seasonally, and annually.

From October to April, California sea lions are also found in the Columbia River from Astoria to Bonneville Dam. They congregate in the river at Astoria at the east mooring basin and near fish processing plants, near the mouths of the Cowlitz and Lewis Rivers, and in the Multnomah Channel at the mouth of the Willamette River.

Although the impact of marine mammals on salmonid populations is uncertain, the presence of California sea lions and Pacific harbor seals in rivers and estuaries is a concern because pinniped predation can have a greater effect on salmonid runs that are already decreased.

Humans are also predators on salmonids in the action area. Tribal, commercial, and recreational fisheries harvest adult salmonids based on allocations set by federal, state, and tribal harvest management bodies. It is widely accepted that overharvest of salmonids occurred in the late 19^{th} and throughout the 20^{th} centuries. Harvest rates have been reduced over the last few decades, but the effect of such harvest on salmonid populations remains controversial.

River Mouth

See Estuary, above.

2.3.6.8 Entrainment

Entrainment refers to the process that increases mortality when fish are trapped by the force of suction in hopper or pipeline dredges. A number of entrainment studies have been performed to assess the potential for entrainment of salmonids. The consensus of these studies is essentially that dredging occurs below the depth where salmonids migrate and in different locations (Buell, 1992; Larson and Moehl, 1990; McGraw and Armstrong, 1990; R2 Resource Consultants, 1999). Salmonids typically migrate in the upper 15 feet of the water column and juveniles, in particular, tend to stay in the channel margins or shallow, shoreline areas.

Riverine Reach

See above.

Estuary

See above.

River Mouth

See above.