5 CURRENT SYSTEM FUNCTION

Section 5 describes the relationships among ecosystem components and the factors that determine salmonid production and ocean entry. A conceptual model was constructed of the lower Columbia River ecosystem relationships that are significant for juvenile salmonids. The model provides a framework for evaluating potential environmental effects on listed salmonid species. In discussions of the complex nature of the lower Columbia River and its estuary, the science panel convened by SEI identified the need for a consistent framework for understanding the lower Columbia River ecosystem. The conceptual model discussed in this chapter is based on the agencies' discussions of a common framework. The framework is to be used to understand and explain the estuarine ecosystem and its functions as they relate to salmonids.

Figure 5-1 depicts flows from the general processes (ocean and river) through the more specific characteristics of this ecosystem. It is also compatible with other conceptual tools that may be used in biological assessments, including the NMFS' concept of Properly Functioning Conditions (PFC). The PFC format for large river estuarine ecosystems is discussed further in Section 5.2. A technical discussion of the conceptual model characteristics is presented in Appendix E.

5.1 The Conceptual Model

The conceptual model for juvenile salmonids of the lower Columbia River provides an integrated diagram of the major ecosystem links that affect ecosystem structure and function as they relate to juvenile salmonid production and ocean entry. The specific objectives of the lower Columbia River model are to:

- Provide an ecosystem-level scientific framework for evaluating the Project
- Identify links among physical-chemical and biological indicators
- Aid in the identification of ecosystem-based processes that link salmon and potential effects of the Project
- Develop a systematic methodology to evaluate monitoring and adaptive management opportunities

The conceptual model is generally formatted to describe the present state of the ecosystem, using general factors and identifying how they influence a specific function, as shown below:

Controlling Factors →
Ecosystem Structure →
Ecosystem Function →

The **controlling factors** refer to those general physical processes that influence all river conditions. The **ecosystem structure** refers to how those factors are manifest, specifically in the lower Columbia River system. The **ecosystem function** is then determined by output of indicators specific to the ways in which the ecosystem structure functions to produce salmonids for ocean entry.

The goal of the model is to present a clear, scientifically based hypothesis in diagram form that illustrates major connections among processes, indicators, and pathways within the system. Because of the complexity of the ecosystem, these connections are illustrated in a series of figures representing a set of linked submodels based on the functional pathways of the system. These pathways include processes within the river system (e.g., habitat formation, tides, bedload transport, accretion/erosion); specific components, or indicators, within the system (e.g., habitat types, food types, physical properties); and the pathways through which these processes and indicators combine to affect the ecosystem (e.g., primary productivity, food web). The processes and indicators used in the conceptual model are introduced in bold type throughout this chapter. Habitat types are shown in italics on first reference.

Figure 5-1 illustrates the relationships among the major functional pathways that affect salmonids in the lower Columbia River. These pathways support the growth and survival of juvenile salmonids, which then result in the output shown in Figure 5-1 and in the model – i.e., juvenile salmonid production and ocean entry. Salmonid production and ocean entry depend on several functions, including development of habitats, production of food to fuel the food web, and ability of salmonids to access and use these habitats. The culmination of these functions results in growth and survival of salmonids and their ultimate entry into the ocean.

Figures 5-2a and 5-2b illustrate the habitat-forming processes and the various indicators that lead to development of the habitat types that support juvenile salmonid growth and survival, again leading to the output of juvenile salmonid production and ocean entry. These figures depict the ecosystem function as it relates to salmonids in the action area. Figure 5-2a presents these processes for the ocean areas, while Figure 5-2b presents them for the areas that lie within the Columbia River system. Other figures in this section illustrate each of the major function pathways, with additional supporting information for the conceptual model located in Appendix E.

The requisites provided to salmonids in the lower Columbia River ecosystem are a function of the ability of salmonids to access habitats (i.e., habitat opportunity) and the amount of food available within these habitats (i.e., habitat capacity) (Bottom, et al., 2001). In turn, opportunity and capacity depend on the development and functioning of viable habitats. These habitats are formed and maintained by physical and chemical forcing factors. Significant interactions affect both the development of habitat and the support provided by habitats to salmonids. These interactions include habitat succession rates and patterns, disturbance regimes, landscape connectivity, and diversity among salmonid ESUs and DPSs. The model highlights the complexity of the factors supporting juvenile salmonid production and ocean entry.

5.1.1 Habitat-Forming Processes

Habitats are formed primarily by the interaction of hydrodynamic forces and sediment supply. In the lower Columbia River, both the river and the ocean influence the estuarine hydrodynamics. River discharges and volumes are regulated by precipitation, temperature (i.e., freeze and thaw), and reservoir operations. Ocean processes, including tidal action and waves, interact with river processes, including currents and sediment transport, in the lower Columbia to produce the estuary's complex hydrodynamics. The net result is deposition (accretion) of suspended sediments to form flats and carving (erosion) to form shallow and deep channels. Where sediment deposits can form islands, marsh and swamp vegetation can develop. These marshes and swamps are dissected by shallow channels, which allow fish access to edges of the vegetated areas.

The indicators and processes involved in the formation and maintenance of lower Columbia River habitats are illustrated in the Habitat-Forming Processes Pathway shown in Figures 5-2a and 5-2b. The main factors affecting or explaining habitat development include salinity and bathymetry (i.e., elevation of substrate). Salinity and bathymetry are indicators of system function. Additional indicators include **suspended sediment, bedload, woody debris, turbidity,** and **accretion/erosion**. **Woody debris** is a special case of a habitat-forming indicator that is directly input into the estuary from upstream sources.

Figure 5-1: Integrated Model for Juvenile Salmonids in the Lower Columbia River

Figure 5-2a: Habitat-Forming Process Pathway – Ocean

Figure 5-2b: Habitat-Forming Process Pathway – River

Shallow water and flats form in intertidal sandy or muddy areas where sediments are somewhat unstable and where the elevation is not high enough for emergent marshes to develop. If the **turbidity** levels are low enough to allow sufficient light penetration for plant growth, these areas may develop submerged vegetation such as eelgrass.

Bedload transport describes the process through which the channel bottom sands are moved along the surface of the riverbed. In sandy riverbeds, like those in the lower Columbia River, **bedload transport** shapes portions of the bed into a series of sand waves. The hydraulic forces of the river move these waves 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. The topography created by these sand waves is the **bathymetry** of the river.

The movement and deposition of large **woody debris** are also affected by the hydrologic process. It is deposited on the flats, along channel edges, and in marshes and swamps. **Woody debris** creates a vertical structure to which fish often orient and also provides “micro” habitats that can trap organic matter, which can be rich in invertebrates.

Another important factor in habitat development is the mixing of freshwater and saltwater in the lower river, which results in a **salinity** gradient in the estuary (Figure 5-3). The zone of mixing varies significantly in location, depending on river flow and tides. Because it is denser than freshwater, saltwater moves upstream along the bottom where it forms a salt “wedge” below the overlying layer of freshwater. Intense mixing proportional to river depth occurs at the area between freshwater and saltwater. Because plants and animals are adapted to certain salinity ranges, the salinity level, as well as seasonal and spatial patterns, strongly influences where species occur in the lower Columbia River.

As in many other estuaries, turbidity from suspended sediment and plankton is moderate to high in the lower Columbia River. High river flows and heavy wind and wave activity can increase turbidity significantly. Because plants require light to grow, turbidity affects how deep plants can grow below the water surface. Higher turbidity means that plants can grow only very near the surface of the water. Rooted aquatic plants, such as eelgrass (*Zostera marina*), are generally limited to very shallow depths in the estuary because of turbid water (Dennison, et al., 1993).

Table 5-1 is a list of salinity ranges that occur in estuaries. Of relevance to juvenile salmonids is the oligohaline zone, brackish water areas of only slight salinity, where juvenile salmonids go through a physiological transition to a saltwater environment. Juvenile ocean-type salmon may spend a considerable period of time in the oligohaline zone, where they require adequate food supplies and refuge from predators to survive and grow.

Table 5-1: Salinity Zones

Zones	Salinity Range (ppt)
Hyperhaline	> 40
Euhaline	30.0 – 40
Mixohaline (brackish):	0.5 – 30
Polyhaline	18.0 – 30
Mesohaline	5.0 – 18
Oligohaline	0.5 – 5
Fresh water	< 0.5

Source: Modified from Cowardin, et al., 1979.

Figure 5-3: Mixing Zone Between Freshwater and Saltwater

In the Habitat-Forming Processes Pathway (see Figures 5-2a and 5-2b), all of these dynamics and interactions culminate in the expression of habitat types important to salmon in the lower Columbia River. The habitats created are shown in the Habitat Type Pathway (Figure 5-4).

5.1.2 Habitat Types

The habitats most directly linked to salmonid in the lower Columbia River include the *tidal marshes and swamps, shallow water and flats*, and the *water column.* As described in Section 5.1.1, these habitats are the result of highly dynamic physical processes interacting in the river and ocean of the action area. Habitat types are generally defined by specific elevation ranges (Figure 5-5).

Tidal marshes and swamps generally occur from about MHHW. Tidal marshes begin at lower tidal elevations, slightly above MLLW although rare at lower than these elevations, and swamps occur at or above MHHW (Thomas, 1983). Thomas (1983) based these characteristics on a comparison of 19 vegetation types where low, medium and high elevations are based on a diurnal range (MLLW-MHHW) averaging 8 feet (where low equals 2.5 to 4 feet above MLLW; medium equals 4 to 6.5 feet above MLLW; and high equals above 6.5 feet). Ocean-type juvenile salmonids use the edges of these marshes to feed, and the edges of shallow channels within the marshes as refugia and feeding areas (Figure 5-6). Consequently, access to the edges at high tide and development of low-tide refuge areas near or within marshes are critical to lower river ocean-type juveniles. Channel order (the number and width of channels) and channel depth are also functional characteristics of a marsh area. The aquatic edge is considered to be an important factor governing the exchange of organisms, and the connectivity associated with the channels offers more opportunity to marsh access (Shafer and Yozzo, 1998). Although there are no empirical data on this relationship for the lower Columbia River, smaller marshes would provide limited salmonid access and only limited nearby low-tide refuge areas. Large marshes provide access to a much greater amount of edge and provide low-tide refuge.

Tidal marshes can be divided into saltwater marshes and freshwater marshes, each characterized by a distinctive vegetation type. Tidal marshes include tidally influenced areas all the way up to Bonneville Dam, as well as extensive tidal freshwater marshes in the lower Columbia River, particularly those in Cathlamet Bay.

Shallow water and flats occur throughout the intertidal zone and into the shallow subtidal zone in waters up to 6 feet deep. Benthic algae (largely benthic diatoms) develop on tidal flats and in the shallow subtidal zone within the system.

Water column habitat refers to waters that are greater than 6 feet deep and can be characterized by depth. For example, the upper 3 to 10 feet of the water column can have a very different community from that found at greater depths. The stratification is caused both by the salinity variation and the light penetration by depth.

The water column habitat is essentially the location where phytoplankton and floatable organic matter occur within the lower Columbia River system. Both phytoplankton and zooplankton respond to salinity changes within the habitat. Freshwater plankton dominate the fresh and oligohaline portions of the water column upstream, and plankton tolerant of greater salinity dominate the estuary and the river mouth of water column habitats.

5.1.3 Habitat Primary Productivity Pathway

A major function of the habitats is to produce food used by the ecosystem. Habitat **primary productivity** refers to the amount of material (biomass) produced over time during plant growth that occurs within each habitat type. Primary productivity is driven by **light** (Figure 5-7) and is supported by inorganic nutrients (e.g., nitrate, phosphate). Inorganic nutrients enter the system from the upstream watershed and the downstream ocean currents and through the breakdown and recycling of organic matter within the system. Factors that affect the distribution of the plants within the system include the habitat-forming processes of **sedimentation, erosion, salinity**, and **turbidity** (see Figures 5-2a and 5-2b). One example of the interaction of these processes is that, as turbidity is increased, light in the water column is reduced (Figure 5-7). This can result in less plant growth as well as limit the depth at which plants will grow. The Habitat Primary Productivity Pathway is illustrated in Figure 5-8.

Phytoplankton are the primary producers within water column habitat. Phytoplankton are single-celled plants, primarily diatoms, that drift within the water column. There are two types of phytoplankton in the lower Columbia River: **imported phytoplankton**, which are freshwater species produced in large quantities in the upstream watershed (particularly in the reservoirs behind the mainstem dams), and **resident phytoplankton**, which are produced within the lower Columbia River. Resident species can be freshwater, euryhaline, or marine species.

Primary productivity within the *shallow water and flats habitat* results mostly from benthic algae, single-celled plants in or on the sediments. Shallow water habitats can also produce filamentous algae and flowering grasses such as eelgrass; however, the majority of primary productivity within the river's shallow water areas comes from benthic algae.

Primary productivity within *tidal marsh and swamp habitat* comes from the marsh and swamp vegetation, which includes emergent plants, shrubs, and trees.

As illustrated in the Food Web Pathway (Figure 5-9), live plant material and detritus are the primary sources of organic matter in the food web used by salmonids in the lower Columbia River.

5.1.4 Food Web Pathway

Another key function of the lower Columbia River is to provide for salmonids. A food web reflects who eats what in an ecosystem. It helps develop an understanding of the pathways by which trophic groups of the food web obtain food. In addition, when habitat types and habitat-forming processes change over time and affect productivity patterns, the resulting food web shifts can provide insight about processes that potentially limit the growth of groups within the food web.

The base of any food web is the plant material produced over time or the **primary productivity** within each habitat type. This food web base also includes detritus (dead plant material). Macrodetritus in the system are large, complex forms of dead plants, primarily in tidal marsh macrodetritus. Microdetritus are dead, simple-celled plant materials or organic particles. Microdetritus can be in the form of **imported microdetritus** if they are derived from imported phytoplankton, or **resident microdetritus** if they are derived from resident phytoplankton. Small animals that shred the larger plant matter and microbes, including bacteria, protozoa, and fungi, facilitate the breakdown of detritus. In addition to making the organic matter useful to the food web, these breakdown processes recycle inorganic nutrients needed by the plants for primary production.

As illustrated in the Food Web Pathway (Figure 5-9), juvenile salmonids are members of a complex food web in the lower Columbia River. The model represents only the salmonid portion of the total food web for the system, which is far more complex. The organic energy sources at the base of this web are shown on the left side of the figure and, as stated above, are from the primary producers of biomass as depicted in the Habitat Primary Productivity Pathway (Figure 5-8). The model illustrates energy transfers through live plants that can be eaten directly or detritus that can be incorporated into the food web through detritivores (animals that eat dead and decaying plants and animals).

Although the Food Web Pathway does not show the relative amounts of food energy derived from each primary producer type, it does illustrate that salmonids can and do eat invertebrate prey species that are supported by resident and imported plankton, detritus, and tidal marsh and swamp plant material. The relative amount of food and food energy depends on the abundance of each resident habitat type (e.g., tidal marshes) and the input of nonresident material from upstream sources. Input of nonresident material is determined from upstream production, primarily by production in the reservoirs behind the dams, which is regulated by Bonneville Dam flow rates.

Several types of feeders make up the next level up the food chain from the primary producers and their detritus. For purposes of the conceptual model, the next level has been grouped as follows:

Mobile macroinvertebrates are large epibenthic organisms that reside on the river bottom and feed on bottom sediments. The main examples of macroinvertebrates in the lower river include sand shrimp (*Crangon franciscorum*), mysids (*Neomysis mercedis*), and Dungeness crab (*Cancer magister*). Mysids are the primary macroinvertebrates that are relevant to the salmonid food web.

Deposit feeders are benthic animals that feed by consuming organic matter in sediments. For this conceptual model, the term deposit feeders refers to both surface and subsurface deposit feeders, which include marine annelids (polychaetes), and freshwater annelids (oligochaetes), and benthic crustaceans.

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 systems). Among the most abundant species found in the stomachs of salmonids is the planktonic cladocera suspension feeder *Daphnia pulex*.

Suspension/deposit feeders are benthic and epibenthic organisms that feed on or at the interface between the sediment and the water column. Perhaps the most abundant species found in the stomachs of salmonids is the benthic amphipod *Corophium salmonis*.

Floating insects (larvae and adults) appear to be important in the diet of most of the species and age classes in the salmonid food web. Many of these insect types feed on live tidal marsh plants.

As described in Section 4, subyearling chinook, an example of juvenile salmonids in general, feed primarily on the bottom but in shallow water while they are in the lower Columbia River, whereas older (yearling) fish of all species feed primarily on zooplankton in the water column.

Where these prey species are found is also important. Because outmigrating juvenile salmon are often found in the upper 6 feet of the water column, they probably do not eat benthic (bottom dwelling) prey in deeper parts of the estuary (i.e., more than 6 feet deep). Consequently, the primary depth range for salmonids feeding on benthic prey is the intertidal zone and down to a depth of about 6 feet below Extreme Lower Low Water. Insects, *Corophium*, and mysids located in shallow habitats such as tidal marshes, tidal channels, and flats are more available to salmonids at higher tides. On the other hand, planktonic prey such as *Daphnia* and copepods are available at any stage of the tide.

Figure 5-4: Habitat Type Pathway

Figure 5-5: Major Habitat Types in the System

Figure 5-6: General Pattern of Lower Columbia River Use by Juvenile Salmonids

Figure 5-7: Effect of Turbidity on Light Penetration Through the Water Column

Figure 5-8: Habitat Primary Productivity Pathway

Figure 5-9: Food Web Pathway

5.1.5 Growth Pathway

Salmonid feeding results in growth of the animals in preparation for their outmigration to the north Pacific. The Growth Pathway depicted in Figure 5-10 incorporates feeding as well as other factors that are involved in producing salmonid growth in the lower Columbia River.

The inputs leading to the Growth Pathway (Figure 5-10) indicate the progression from physical factors involved in defining habitats in the lower Columbia River through the way in which these habitats work to produce food for salmonids. The Growth Pathway highlights the factors involved in producing both the appropriate amount and type of food prey and the access by juvenile salmonids to productive feeding areas.

The characteristics of the food web, such as the abundance of insects versus the biomass of nonresident microdetritus and where prey and other nutrients are distributed, are important in determining the relative contribution of these food sources to the growth of salmonids. The "Food Abundance and Distribution" and "Habitat-Specific Food Availability" boxes in the Growth Pathway (Figure 5-10) address these feeding factors. The actual location and structure of feeding habitats are important because salmonids need first to be able to access feeding habitat and, while there, be able to find the prey items.

Salmonids are adapted for using a complex mosaic of many habitat areas as they migrate downstream and during their residence in riverine and estuarine systems in the Pacific Northwest. Therefore, coupled with **habitat-specific food availability, feeding habitat opportunity** needs to exist for salmonids to feed within the set of habitats. As described in Section 4, juvenile salmonids primarily frequent very shallow water areas, especially the subyearling chinook. They benefit most from prey produced in tidal marshes and marsh channels, on the edges of natural side channels, and on flats (Figure 5-6). When water level is low, salmonids are believed to congregate at the edges of natural side channels and pools, which become low-tide refuges.

This mosaic of habitats used by salmonids is referred to as **habitat complexity**. An absence or reduction in the natural complexity of habitats available may affect the salmonids' ability to reach food resources needed for growth. **Conveyance** is the opportunity for salmonids to move over flats and into tidal marsh systems as the water level rises and falls with the tide and with river flow (Figure 5-6).

Connectivity refers to links and spatial arrangements among habitats in the mosaic of changing habitat areas. For juvenile salmonids in the lower Columbia River, this refers to favorable access among viable feeding, rearing, and refuge habitats along the migratory corridor. Blockages, interruptions of corridors, or modifications of habitat may prevent or limit access to productive feeding habitats. For example, a culvert may block fish access to tidal marsh behind a river levee. Large numbers of overwater structures may limit the ability to migrate or the migration habits of fish traveling along the shoreline. Because fish are adapted to use a wide but linked set of habitats, maintaining access among habitat types is important to feeding habitat opportunity. **Connectivity** is illustrated in the Growth Pathway (Figure 5-10).

Low current, shallow areas provide productive feeding areas for salmonids. Available information suggests that velocities of 30 centimeters per second or less are best for optimal foraging opportunity (Bottom, et al., 2001). Because salmonids are visual predators, **turbidity** and uneven **bathymetry** may limit their ability to prey (see Section 4). The concepts of **velocity field,** shallow **bathymetry**, and **turbidity** are illustrated in boxes at the left of the Growth Pathway (Figure 5-10).

Figure 5-10: Growth Pathway

Finally, there are **energy costs** that each individual animal expends to feed. These include locating prey, feeding behavior, avoiding predators, and processing energy from prey consumed. In general, fish prefer high-energy food that provides the most energy per unit of effort. Anything less than this will, theoretically, produce suboptimal growth rates.

5.1.6 Survival Pathway

Besides growth, a variety of factors interact to affect the ultimate survival of salmonids in the lower Columbia River. The Survival Pathway (Figure 5-11) shows the links among these factors.

Salmonid survival depends on the ability of fish to grow and migrate through the lower Columbia River system. As shown in the previous pathways, a complex set of factors can control or affect growth and migration.

Factors that can negatively affect survival include contaminants, predation, suspended solids, temperature and salinity extremes, stranding, entrainment, and competition. These factors are discussed below.

Contaminants include chemicals that can affect the health of salmonids. They can be taken up directly through the water column or through contaminated prey (food web). The prey of juvenile salmonids may obtain contaminants via their food. For example, contaminants deposited on the bottom along with organic matter may be ingested by deposit-feeding animals, which are in turn eaten by juvenile salmonids. These contaminants may affect the health (physiological integrity) of fish and may result in **disease** as well as a reduced ability to physiologically adapt to saltwater, avoid predators, forage effectively, and seek and find shelter.

Predation is a major factor affecting salmonid survival in the lower Columbia River. Birds, including Western grebes, cormorants, gulls, terns, and great blue herons, are known to prey on small fish that may include young salmon. Fish predators are less well known, but larger fish, including sculpins, have been documented as having salmon in their guts.

Suspended solids, which can be a major contributor to **turbidity**, affect migratory ability by reducing the ability of salmonids to see prey. Data indicate that the threshold concentration for survival of ocean-type salmonids is on the order of 1 g/L.

Temperature and salinity extremes typically stress fish. Salinity extremes can occur during extreme low-flow conditions, which allow more salt farther up into the estuary. Temperature extremes can occur in the summer over shallow flats and channels during low tides.

Stranding can occur when fish are washed up onto higher ground by waves or ship wakes, or if they are caught for extended periods of time in a shallow pool during an extended low tide. Fisheries biologists have observed stranding of salmonids in the lower Columbia River system.

Entrainment refers to the uptake of fish during dredging. Because dredging occurs primarily in the deepest portions of the channel, bottom-dwelling fish would be more susceptible to being entrained. Surface-oriented fish, such as salmonids, may be less susceptible.

Finally, **competition** among members of the outmigrating population may play a role in survival; however, little is understood or documented regarding the effects of competition in the lower Columbia River.

Figure 5-11: Survival Pathway

Adaptive behavior improves the probability that salmonids will survive. The adaptive behaviors of predator avoidance, feeding optimally in the system, and ability to find refuge are all enhanced if fish are healthy. As described in several pathways above, salmonid health depends on physiological integrity, as well as the availability and quality of habitats.

5.2 Pathways and Indicators

The conceptual model is a way to show the interactions and relationships within a system that, when they are operating properly, help to characterize the system as a whole. This conceptual model for juvenile salmonids consists of several submodels that represent the primary functions of the system. Each of these submodels is composed of several components that link together common relationships associated with maintaining the primary functions. These submodels are the "pathways" in which the components operate for a common function. Each of the components, in turn, may have many states, values, or characteristics that are indicative of the function of the pathway at a particular time; therefore, these components are called "indicators."

Baseline conditions used here are representative of the current state of the indicators used in the conceptual model for the lower Columbia River ecosystem. The effects of the proposed Project are determined by measuring the incremental changes caused by the Project. However, the evaluation of whether the incremental changes are important to the ecosystem functions as a whole depends on an understanding of how current conditions and the proposed incremental changes to those conditions deviate from optimal conditions or PFCs for the ecosystem as a whole.

The concept of PFCs is used by NMFS to assess the effects of proposed incremental changes to the ecosystems used by salmonids. The pathways and indicators of the conceptual model follow the NMFS PFC concept, although NMFS-approved guidelines for PFCs in large rivers and estuaries are not yet available. A PFC format, which is currently being drafted, is an effort to establish estuarine and shoreline PFCs in Washington. For river mouth estuaries such as the Columbia River, the PFC is defined as the sustained presence of natural habitat-forming processes in an estuary and associated tributary rivers, upslope, and marine environs to create conditions conducive to the long-term survival of native species. The PFCs produce conditions where the carrying capacity of a native species population is met, the population is resilient to environmental change, and it is allowed to follow its natural evolutionary pathways. "Natural" in this context is not intended to imply pristine.