Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead

National Marine Fisheries Service
Northwest Region

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NOTE TO READERS:

This *Columbia River Estuary Recovery Plan Module* will be the basis of estuary recovery actions for Endangered Species Act-listed salmon and steelhead in the Columbia River Basin. The module will be incorporated by reference into recovery plans for listed Columbia Basin salmon evolutionarily significant units (ESUs) and steelhead distinct population segments (DPSs). It is important to have a unified set of actions for the Columbia River estuary to address the needs of all listed Columbia Basin ESUs and DPSs.

This *Columbia River Estuary Recovery Plan Module* was prepared for NOAA's National Marine Fisheries Service (NMFS) by the Lower Columbia River Estuary Partnership, (contractor) and PC Trask & Associates, Inc. (subcontractor).

DISCLAIMER:

Recovery plans delineate such reasonable actions as may be necessary, based upon the best scientific and commercial data available, for the conservation and survival of listed species. Plans are published by the National Marine Fisheries Service (NMFS), sometimes prepared with the assistance of recovery teams, contractors, State agencies, and others. Recovery plans do not necessarily represent the views, official positions, or approval of any individual or agencies involved in the plan formulation, other than NMFS. They represent the official position of NMFS only after they have been signed by the Assistant Administrator. Recovery plans are guidance and planning documents only; identification of an action to be implemented by any public or private party does not create a legal obligation beyond existing legal requirements. Nothing in this plan should be construed as a commitment or requirement that any Federal agency obligate or pay funds in any one fiscal year in excess of appropriations made by Congress for that fiscal year in contravention of the Anti-Deficiency Act, 31 U.S.C. 1341, or any other law or regulation. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions.

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Acronyms and Abbreviations

BACI	before-after-control-impact
BiOp	Biological Opinion
BMP	best management practice
BMPs	best management practices
cfs	cubic feet per second
CRE	Columbia River estuary
CSMEP	Collaborative Systemwide Monitoring and Evaluation Project
DDT	dichlorodiphenyltricholoroethane
DEQ	Oregon Department of Environmental Quality
DPS	distinct population segment
EDT	Ecosystem Diagnosis and Treatment
ENSO	El Niño/Southern Oscillation
EPA	U.S. Environmental Protection Agency
ERME	estuary research, monitoring, and evaluation
ESA	Endangered Species Act
ESU	evolutionarily significant unit
ETM	estuarine turbidity maximum
FCRPS	Federal Columbia River Power System
GIS	geographic information system
HUC	hydrologic unit code
ISAP	Independent Science Advisory Panel
ISRP	Independent Science Review Panel
LCFRB	Lower Columbia Fish Recovery Board
LCRANS	Lower Columbia River Aquatic Nonindigenous Species Survey
LIDAR	Light Detection and Ranging
MMPA	Marine Mammal Protection Act
MR&E	monitoring, research, and evaluation
NASQAN	National Stream Quality Accounting Network
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls

PDO	Pacific Decadel Oscillation
PIT	passive integrated transponder
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
RM	river mile
RME	research, monitoring, and evaluation
TMDL	total maximum daily load
VGP	vessel general permit
WDF	Washington Department of Fisheries
WDFW	Washington Department of Fish and Wildlife

Glossary

Accretion: The accumulation of sediment deposited by natural fluid flow processes.

Alevins: Salmonids at the life stage between egg and fry.

Amphipods: Benthic invertebrates, particularly the amphipod *Americorophium salmonis,* which is found in intertidal and shallow subtidal habitats of the Columbia River estuary and is seasonally important in the diet of juvenile salmonids.

Ancient marshes: Marshes formed between 6,000 and 10,000 years ago.

Bar: A ridge or succession of ridges of sand or other substances, especially a formation extending across the mouth of a river or harbor that may obstruct navigation.

Bathymetry: The measure of the depths of oceans, seas, or other large bodies of water.

Beach erosion: The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

Beach nourishment: The process of replenishing a beach by artificial means, such as through deposition of dredged materials; also called beach replenishment or beach feeding.

Bedload: Sand that rolls and bounces along the surface of the riverbed, usually downstream, although there may be a small displacement toward deeper water caused by the side slopes of the riverbed. In sandy riverbeds, bedload transport shapes the bed into a series of sand waves.

Beneficial use: Placement or use of dredged material for some productive purpose. Examples of beneficial uses include habitat development, beach nourishment, aquaculture, parks and recreation, shoreline stabilization, and erosion control.

Benthic: Of or relating to the bottom of a body of water.

Buffer area: A parcel or strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from upland impacts, to provide habitat for wildlife.

Centennial marshes: Marshes formed over the last century.

Continental shelf: The zone bordering a continent extending from the line of permanent immersion to the depth (usually about 100 to 200 meters) at which there is a marked or steep descent toward greater depths.

Delta: An alluvial deposit, usually triangular, at the mouth of a river. It is normally built up only where there is no tidal or current action capable of removing the sediment as fast as it is deposited.

Deposition: The deposit of sediment in an area through natural means, such as wave action or currents, or mechanical means.

Detritus: A loose mixture of organic material (dead plants and animals) and inorganic material (rock fragments) that results directly from disintegration of the material.

Dikes: Earthen walls constructed to contain water; sometimes constructed around dredged material disposal sites but more commonly constructed as flood protection.

Dredging: The removal or redistribution of sediments from a watercourse.

Ecosystem: A community of organisms in a given area together with their physical environment and its characteristic climate.

El Niño/Southern Oscillation: A shorter term climate effect that alternates between cold and warm phases approximately every 3 to 7 years; is associated with a warm-water current that periodically flows southward along the coast of Ecuador, and the southern oscillation in the atmosphere; affects climatic and ocean conditions throughout the Pacific region.

Emergent marsh: A wet, springy peatland that occurs along the edges of lakes and streams and is covered by grass-like sedges and fed by minerals washing in from surrounding lands.

Emergent vegetation: Rooted plants that can tolerate some inundation by water and that extend photosynthesis parts above the water surface for at least part of the year; emergent vegetation is intolerant of complete inundation over prolonged periods.

Estuarine turbidity maximum (ETM): A circulation phenomenon in an estuary that traps particles and promotes biochemical, microbial, and ecological processes that sustain an important pathway in the estuary's food web.

Estuary: A semi-enclosed coastal body of water with a free connection to the open ocean in which sea water is diluted with runoff from the land.

Exotic species: A non-native plant or animal deliberately or accidentally introduced into a habitat.

Fill: Sand, sediment, or other earth materials that are placed, deposited, or stockpiled.

Fingerling: A juvenile salmonid less than 1 year old.

Floodplain: A flat tract of land bordering a river, mainly in its lower reaches, and consisting of alluvium deposited by the river during flooding.

Fluvial: Involving running water; usually pertains to stream processes.

Forested wetlands: Wetlands that occur in palustrine and estuarine areas and possess an over story of trees, an understory of young trees or shrubs, and a herbaceous layer.

Freshet: High stream flow caused by rains or snowmelt and resulting in the sudden influx of a large volume of freshwater in the estuary.

Fresh water: Water that is less than 0.5 part salt per thousand.

Fry: Juvenile salmonids that have absorbed their egg sac.

Genetic diversity: Variation at the level of individual genes (polymorphism); provides a mechanism for populations to adapt to their ever-changing environment.

Habitat: The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal; the place where an organism naturally lives.

Habitat capacity: A category of habitat assessment metrics, including "habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality" (Fresh et al. 2005).

Habitat connectivity: A measure of how connected or spatially continuous habitats occur in a larger ecosystem.

Habitat opportunity: A category of habitat assessment metrics that evaluate the capability of juvenile salmon to access and benefit from the habitat's capacity (Fresh et al. 2005).

High marsh: A wetland ecosystem influenced by a marsh surface elevation at approximately mean higher high water that is inundated by only the most extreme high tides and is characterized by salt-tolerant emergent vegetation.

Intertidal: Of or relating to the substrate that is exposed and flooded by tides; includes the associated splash zone.

In-water disposal: Placement of dredged material along the riverbed in or adjacent to the navigational channel or in designated in-water sites; commonly referred to as flow-lane disposal.

Limiting factor: Physical, chemical, or biological features that impede species and their independent populations from reaching viability status.

Littoral: Of, relating to, or situated or growing on or near a shore; especially of the sea.

Littoral current: A current running parallel to the beach and generally caused by waves striking the shore at an angle.

Low marsh: A wetland ecosystem characterized by salt-tolerant emergent vegetation and twice-daily inundation of high tides.

Macroinvertebrates: Invertebrates that are of visible size, such as clams and worms.

Marsh: An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

Mean high water: The average height of all high waters over 19 years.

Mean higher high water: The average height of the higher of two unequal daily high tides over 19 years.

Mean low water: The average height of all low waters over 19 years.

Mean lower low water: The average height of the lower of two unequal daily low tides over 19 years.

Macrodetritus: Dead or dying matter from a plant or animal that is visible to the unaided eye; usually larger than 1 to 2 mm in diameter.

Microdetritus: Dead or dying matter from a plant or animal; usually smaller than 1 to 2 mm in diameter.

Navigational channels: Channels in estuaries and other water bodies that are created, deepened, and maintained by dredging to enable vessels to navigate safely between, into and out of ports, harbors, and marinas without running aground.

Nearshore: An indefinite zone extending seaward from the shoreline well beyond the breaker zone.

Ocean-type: Of or relating to salmonid juveniles that enter the estuary as fry or fingerlings and stay in the estuary for weeks or months before entering the ocean; examples are chum and subyearling Chinook.

Oligohaline: Of or relating to water having low salinity.

Overbank flooding: Out-of-bank flooding resulting from flow events that exceed the bankfull.

Over-water structures: Human-made structures, such as a pier, that extend over all or part of the surface of a body of water.

Pacific Decadal Oscillation: A longer term climate effect that alternates between cold and warm phases approximately every 30 years.

Pelagic: Pertaining to the open ocean.

Pinnipeds: Seals, sea lions, and walruses that belong to the taxonomic suborder called Pinnipedia, or the "fin-footed." Pinnipeds are carnivorous aquatic mammals that use flippers for movement on land and in the water. The pinnipeds referred to in this document are Pacific harbor seals, California sea lions, and Stellar sea lions.

Pier: A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place, recreational facility, etc., rather than to afford coastal protection.

Piling: A long, heavy timber or section of concrete or metal that is driven into the earth or bottom of a water body to serve as a structural support or protection.

Pile dike: Two parallel rows of piling that are tied together and extend 300 to 500 feet into the river.

Pile dike field: Several pile dikes spaced about 1,200 to 1,500 feet apart, typically built to concentrate flow and stabilize the channel; within the dike field, current velocities are slowed and flow is deflected away from the river bank.

Plume: The layer of Columbia River water in the nearshore Pacific Ocean.

Polychlorinated biphenyls (PCBs): A group of synthetic, toxic industrial chemical compounds that are chemically inert and not biodegradable; they once were used in making paint and electrical transformers.

Polycyclic aromatic hydrocarbons (PAHs): A group of more than 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat.

Population: A distinct breeding unit of a species that exhibits similar life history strategies.

Redds: Spawning nests used by trout and salmon.

Revetment: A facing of stone, concrete, etc., to protect an embankment or shore structure from erosion by wave action or currents.

Salmonid: Any member of the family Salmonidae, which includes the salmon, trout, char, whitefishes, and grayling of North America.

Salmonid population viability: Measure of the status of anadromous salmonids that uses four performance criteria: abundance, productivity, spatial distribution, and diversity.

Sand: An unconsolidated mixture of inorganic soil (possibly including disintegrated shells and coral) consisting of small but easily distinguishable grains ranging in size from about 0.062 mm to 2.0 mm.

Sand waves: Waves of sand on the bottom of a riverbed that move in response to river discharge and bedload transport. In the Columbia, sand waves cover the riverbed and are typically 4 to 8 feet high and 300 to 400 feet long. When the river discharge is less than 300,000 cfs, sand waves move only a few feet per day; however, when discharge exceeds 400,000 cfs, sand wave movement can reach 20 feet per day or more.

Scour: The removal of underwater material by waves and currents, especially at the base or toe of a structure.

Sediment: Material in suspension in water or recently deposited from suspension; in the plural, all kinds of deposits from the waters of streams, lakes, or seas.

Sediment trapping: The capture of sediments behind structures such as dams and shoreline armoring, which restrict sediments from entering systems.

Shallows and flats: Areas from the 6-foot bathymetric contour line up to the edge of tidal marsh or swamp vegetation, or to mean higher high water where vegetation is absent.

Shoaling: A gradual decrease in water depth as the result of the accretion of sediments.

Smolts: Juvenile salmonids that have left their natal stream and are headed downriver toward the ocean.

Stream-type: Of or relating to salmonid juveniles that rear in freshwater for a year or more before entering the ocean.

Threat: A human action or natural event that causes or contributes to limiting factors; threats may be caused by past, present, or future actions or events.

Tidal marshes: Areas dominated by emergent vegetation and low shrubs; are typically found from mean lower low water to slightly above mean higher high water, although they are rare at the lowest elevations.

Tidal prism: The difference in the volume of water covering an area, such as a wetland, during low tide and the volume covering it during the subsequent high tide.

Tidal swamps: Shrub- and forest-dominated wetlands that extend up to the line of non-aquatic vegetation (the line at which excess water ceases to be a factor controlling the composition of the vegetation); tidal swamps may be of sufficiently high elevation that they are inundated only during spring tides, but they may also extend down below mean higher high water.

Tide: The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting on the rotating earth.

Turbidity: A condition in bodies of water where high sediment loads cause clouding of the water to varying extents; turbidity is an optical phenomenon and does not necessarily have a direct linear relationship to particulate concentration.

Viable salmonid population: An independent population of Pacific salmon or steelhead trout that has a negligible (generally ≤5 percent) risk of extinction over a 100-year timeframe.

Executive Summary

What is the Estuary Recovery Module?

This estuary recovery plan module is one element of a larger regional planning effort to develop recovery plans for Endangered Species Act-listed salmon and steelhead trout in the Columbia River basin. Recovery plans are being developed for each of the 13 listed evolutionarily significant units (ESUs) in the Columbia.[1] Figure ES-1 shows the 13 listed ESUs in the Columbia River basin grouped by region. The regions include the Lower Columbia, Upper Willamette, Middle Columbia, Snake, and Upper Columbia River ESUs. Within each of the regions, the ESUs have unique geographical boundaries that are based on similarities among populations.

This estuary recovery plan module complements other recovery plans in the region. The planning area for the module is all tidally influenced areas of the Columbia River. The upstream boundary of this area is Bonneville Dam, at River Mile 146, and the downstream boundary includes the Columbia River plume.[2] With few exceptions, the module's focus is limited to habitat conditions and processes in the Columbia River estuary and plume, rather than hatchery or harvest practices, hydroelectricity production, or tributary habitats in the Columbia River basin. The goal of the module is to identify and prioritize management actions that, if implemented, would reduce the impacts of limiting factors, meaning the physical, biological, or chemical conditions that impede salmon and steelhead survival during their migration through and rearing in the estuary and plume ecosystems. To accomplish this, changes in the physical, biological, or chemical conditions in the estuary are reviewed for their potential to affect salmon and steelhead. Then, the underlying causes of limiting factors are identified and prioritized based on the significance of the limiting factor and each cause's contribution to one or more limiting factors. These causes are referred to as threats and can be either human or environmental in origin. Finally, management actions are identified that are intended to reduce the threats and increase the survival potential of salmon and steelhead during estuarine rearing and migration. Costs are developed for each of the actions using an estimated level of effort to implement actions.

This estuary recovery plan module is intended to help answer questions about the degree to which the estuary and plume can contribute to salmon and steelhead recovery efforts throughout the Columbia River basin. The state of the science surrounding the estuary and plume is such that quantitative answers to questions about estuarine ecology are not necessarily available at this time. This is true in part because of the complexity of the ecological processes in the estuary and plume. However, it is also true because the Columbia River estuary and plume are only now being studied at a level of detail that

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[1] NOAA's National Marine Fisheries Service (NMFS) has revised its species determinations for West Coast steelhead under the Endangered Species Act (ESA), delineating steelhead-only "distinct population segments" (DPSs). The former steelhead ESUs included both anadromous steelhead trout and resident, non-anadromous rainbow trout, but NMFS listed only the anadromous steelhead. The steelhead DPS does not include rainbow trout, which are under the jurisdiction of the U.S. Fish and Wildlife Service. In January 2006, NMFS listed five Columbia River basin steelhead DPSs as threatened (71 FR 834). To avoid confusion, references to ESUs in this estuary recovery plan module imply the steelhead DPSs as well.

[2] See Figures 1-1 and 1-2 for a depiction of the planning area.

allows knowledge about this portion of the Columbia River ecosystem to be integrated into the understanding of life history patterns that have been well documented in the upstream portions of the basin.

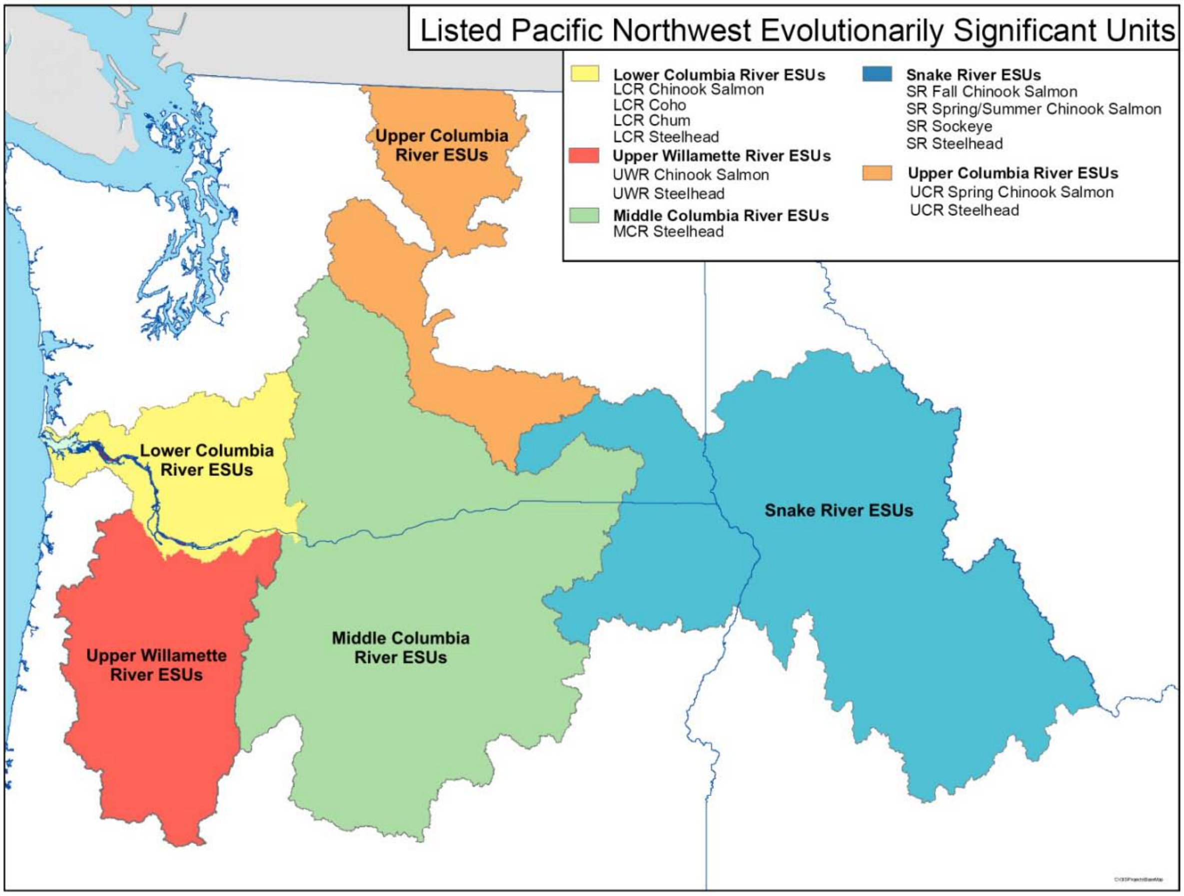

FIGURE ES-1
Listed Pacific Northwest ESUs

This estuary recovery plan module is a synthesis of diverse literature sources and the direct input of estuary scientists. The module was developed by the Lower Columbia Estuary Partnership and a private consultant, PC Trask & Associates, Inc. The primary author was PC Trask & Associates, Inc., with significant involvement from Lower Columbia River Estuary Partnership staff. The author used several key documents as a platform for the module. One of those documents is the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan," which the Lower Columbia River Estuary Partnership developed, along with its supplement, for the Northwest Power and Conservation Council's *Columbia River Basin Fish and Wildlife Program* (Northwest Power and Conservation Council 2004). In 2005, the Northwest Fisheries Science Center of NOAA's National Marine Fisheries Service (NMFS) produced two important technical memoranda for the estuary: *Salmon at River's End* (Bottom et al. 2005) and *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead* (Fresh et al. 2005). The author used these two memoranda extensively and consulted other sources as well, including many primary sources. Area experts from the

NMFS Northwest Fisheries Science Center and Northwest Regional Office, the Lower Columbia River Estuary Partnership, and the Lower Columbia Fish Recovery Board provided input and advice on scoring and evaluation processes. Additionally, the author briefed the Northwest Power and Conservation Council, Mid-Columbia Sounding Board, Upper Willamette Recovery Planning Stakeholder Team, and Lower Columbia River Recovery Planning Stakeholder Team and took their feedback into account when refining the module. Lastly, PC Trask & Associates, Inc., and Lower Columbia River Estuary Partnership staff worked with NMFS Northwest Regional Office staff to revise the module in response to comments received during the public comment period.

Why Are the Estuary and Plume Important?

The Columbia River estuary and plume represent one of three major stages in the life cycle of salmon and steelhead. In tributaries, adults spawn and juveniles rear in freshwater. In the ocean, juveniles grow to adults as they forage in food-rich environments. The estuary is where juveniles and adults undergo vast physiological changes needed to transition to and from saltwater. In addition, a properly functioning estuary provides high growth opportunities and refugia from predators.

But why are the estuary and plume so important? The answer lies in the very reason that salmonids grew in numbers to an estimated 16 million over the past 4,000 years. Salmon and steelhead were successful because they exploited a wide array of the habitat niches available to them. They did this by employing a variety of strategies that allowed them to use many diverse habitats across a wide geographic space. In fact, the distribution of salmon and steelhead historically spanned thousands of river miles throughout the basin.

If this were not remarkable enough, salmon and steelhead's traits allowed them to use habitats at varying times, and this is one of the primary reasons the estuary and plume are so important. Every downstream-migrating juvenile salmon or steelhead must use the habitats of the estuary to complete its life cycle. If the progeny of the 16 million adult salmon and steelhead that historically made use of the estuary had converged on the estuary at one time, there likely would not have been enough habitat and food to sustain them. So they developed strategies to enter the estuary at different times, at different sizes, using unique habitats. In fact, it has been hypothesized that each individual population's use of estuarine habitats is discrete in terms of time and location of use. The implication of this for the estuary and plume today is that the area's habitats must be available through time and space and at sufficient quantities to support more than 150 distinct salmon and steelhead populations, which represent 13 ESUs that use many diverse life history strategies.

The number of adult salmon and steelhead that return to the Columbia River basin each year varies, but in recent years, average returns have been about 1.7 million, with approximately 65 to 75 percent of those fish being of hatchery origin.[3] For 2006, scientists from the NMFS Northwest Fisheries Science Center estimated that about 168 million juveniles would enter the estuary (Ferguson 2006b). This suggests that only 1 percent of the juveniles entering the estuary will return as adults and 99 percent are lost as a result of all the limiting factors (human and natural) in the estuary, plume, nearshore, and ocean.

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[3] This is an informal estimate; determining the ratio of hatchery-origin fish with more certainty would require stock-by-stock run calculations averaged over many years.

Understanding the extent to which the estuary and plume contribute to these losses is essential to the ultimate recovery of salmon and steelhead ESUs throughout the basin.

What Is the Condition of the Estuary Now?

Flows, Dikes and Filling, and Sediment

The estuary and plume are considerably degraded compared to 200 years ago. In terms of absolute size, the estuary tidal prism is about 20 percent smaller than it was when Lewis and Clark camped along the Columbia's shore (Northwest Power and Conservation Council 2004). This reduction in estuary size is due mostly to dike and filling practices used to convert the floodplain to agricultural, industrial, commercial, and residential uses. Instream flows entering the estuary also have changed dramatically—there has been a 44 percent decrease in spring freshets or floods, and the annual timing, magnitude, and duration of flows no longer resemble those that historically occurred in the Columbia River (Jay and Kukulka 2003). Changes to flow volume and timing are attributed to hydrosystem regulation; water withdrawal for agricultural, municipal, and industrial purposes; and climate fluctuations. Further alterations in flow are likely to occur during the next century as a result of global climate change, the effects of which are expected to include more precipitation falling as rain rather than snow, less snow storage, and—in the estuary—higher peak flows and reduced late-summer/early-fall stream flows (Independent Scientific Advisory Board 2007).

Flow alterations and dike and filling practices are significant to salmon and steelhead in several ways. Historically, vegetated wetlands within the floodplain supplied the estuary with its base-level food source: macrodetritus. The near elimination of overbank events and the separation of the river from its floodplain have altered the food web by reducing macrodetrital inputs by approximately 84 percent (Bottom et al. 2005). At the same time, phytoplankton detrital sources from upstream reservoirs now dominate the base of the food chain. The substitution of food sources likely has profound effects on the estuary ecosystem. In addition, access to and use of floodplain habitats by ocean-type ESUs (salmonids that typically rear for a shorter time in tributaries and a longer time in the estuary) have been severely compromised through alterations in the presence and availability of these critical habitats.

The timing, magnitude, and duration of flows also have important ramifications to in-channel habitat availability and connectivity. Sand transport along the river bottom is highly correlated to flow. With reductions in the magnitude and duration of flows, erosion and accretion processes no longer function as they have for thousands of years. This may have far-reaching consequences to the estuary, plume, and nearshore lands north and south of the river's mouth. At the same time, upstream dams have prevented sediments from entering the estuary, while dredging activities have exported sand and gravel out of the estuary. Studies have shown that sand is exported from the estuary at a rate three times higher than that at which it enters the estuary. The full impact of these changes is unknown; however, sediment transport is a primary habitat-shaping force that determines the type, location, and availability of habitats distributed in the estuary and plume. In addition, decreases in sediments have improved water clarity and increased the effectiveness of predators that consume juvenile and adult salmon and steelhead.

Water Quality

Water quality in the estuary and plume has been degraded by human practices from within the estuary and also from upstream sources. Today, elevated water temperatures and toxic contaminants both pose risks to salmon and steelhead in the estuary. Summer water temperatures entering the estuary are on average 4° F (2.2° C) warmer today than they were in 1938 (Lower Columbia Fish Recovery Board 2004). The upper thermal tolerance range for cold-water fish, including salmon and steelhead, is about 20° to 24° Celsius (68° to 75° Fahrenheit). Temperatures exceeding this threshold have been occurring earlier in the year and more frequently since 1938 (as measured at Bonneville Dam). Degradation of tributary riparian habitat caused by forest, residential, commercial, and industrial practices, as well as reservoir heating and global climate change are responsible for increased temperatures. During the next century, it is likely that the expected effects of global climate change will continue to increase water temperatures.

Another important indicator of water quality degradation in the estuary is the presence of toxic contaminants. One study of contaminant impacts on juvenile salmon estimated disease-induced mortalities of 1.5 and 9 percent as a result of contaminant stressors for residencies in the Columbia River estuary of 30 to 120 days, respectively (Loge et al. 2005). If this estimate is accurate, threats from contaminants may exceed those from Caspian tern predation.

Toxic contaminants are widespread in the estuary, both geographically and in the food chain, with the urban and industrial portions of the estuary contributing significantly to juvenile salmon’s toxic load (Lower Columbia River Estuary Partnership 2007). Some of these contaminants are water-soluble agricultural pesticides and fertilizers, such as simazine, atrazine, and diazinon. Industrial contaminants include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Also present are pharmaceuticals, personal care products, brominated fire retardants, and other emerging contaminants. Concentrations of toxic contaminants in the bodies of juvenile salmonids in the estuary sometimes are above levels estimated to cause health effects. In a 2007 study, this was the case for PCBs, PAHs, and DDT, and juveniles showed evidence of exposure to hormone-disrupting compounds (Lower Columbia River Estuary Partnership 2007). Salmon and steelhead experience both short-term exposure to toxic substances and long-term exposure to contaminants that accumulate over time and magnify through the food chain. Even when exposures are sublethal, they can cause significant developmental, behavioral, health, and reproductive impairments. Ocean-type ESUs are more susceptible to bioaccumulation than stream-type ESUs; however, both are equally vulnerable to acute exposures (stream-type ESUs are those ESUs that typically spend longer periods in tributaries and less time in the estuary).

Food Web and Species Interactions

The Columbia River estuary represents a distinct ecosystem that is a unique expression of biological and physical interactions. As physical and biological changes occur in the estuary, the ecosystem responds to those changes. There is general agreement that the estuary ecosystem is degraded and no longer provides the same level of support to native species assemblages that it did historically. Unfortunately, this field of research is perhaps the least understood, and its impact on salmon and steelhead is not well documented or studied.

Limiting factors related to the food web and species interactions can be thought of as the product of all the threats to salmon and steelhead in the estuary. Some examples of food web and species interactions-related limiting factors are easy to understand, but others are subtle and far-reaching. Caspian terns are a good example of an ecosystem shift that is easy to understand. New islands formed through the disposal of dredged materials attracted terns away from their traditional habitats, which may be being degraded. Reduced sediment in the river may have increased terns' efficiency in capturing steelhead juveniles migrating to saltwater at the same time that the birds need additional food for their broods. The result is a predator/prey shift in the estuary that has increased mortality for steelhead juveniles. Double-crested cormorants also prey on juvenile salmonids, in similar numbers as terns.

Other shifts in the ecosystem are more complex, and it can be difficult to understand whether or how they affect salmon and steelhead. For example, the shift in the food base of the estuary—from local macrodetrital sources to imported microdetrital sources such as phytoplankton—has fundamentally changed the food web and species relationships; however, what this means to salmon and steelhead—or, for that matter, to the entire estuarine ecosystem—is unknown. The introduction of exotic species is another poorly understood ecosystem alteration. Examples of exotic species thriving in the estuary include 21 new invertebrates, such as Asian clams and copepods, plant species such as Eurasian water milfoil, and exotic fish such as shad. Shad in particular, because of the sheer tonnage of their biomass, undoubtedly play a large role in the degradation of the estuary ecosystem and may compete with juvenile salmonids for food resources. Natural-origin juvenile salmonids may compete with large pulses of hatchery fish for food and space in the estuary if they overlap in space and time. Given the decreases in habitat opportunity and capacity in the estuary, it may be that too many fish—both salmonids and other species—are competing for too few estuarine resources at key times, with the resulting stressors translating into reduced salmonid survival. It is likely that this density-dependent mortality is manifesting itself in the estuary through limiting factors such as reduced off-channel habitat availability, competition with other fish species, and predation by fish and birds.

Other Threats

The estuary also is influenced by a number of physical structures that contribute to its overall degradation, but the extent of their impacts to salmon and steelhead is poorly understood. Over-water and instream structures in the estuary number in the thousands and alter river circulation patterns, sediment deposition, and light penetration; they also form microhabitats that often benefit predators. In some cases, structures reduce juvenile access to low-velocity habitats. Examples of structures include jetties, pilings, pile dikes, rafts, docks, breakwaters, bulkheads, revetments, groins, and ramps.

Ship wake stranding is an example of another threat to salmon and steelhead in the estuary. A study in 1977 by the Washington Department of Fisheries estimated that more than 150,000 juvenile salmonids, mostly Chinook, were stranded on five test sites as a result of ship bow waves striking shorelines (Bauersfeld 1977). Additional studies since the Bauersfeld study have not documented the same level of mortality. Light Detection and Radar (LIDAR) analysis and results from a new study by the University of Washington and the Portland District of the U.S. Army Corps of Engineers may help characterize this threat in the near future. This threat is most detrimental to ocean-type juvenile fry that are less than 60 millimeters long and that rear inches from shore.

What Can We Do to Improve Salmon and Steelhead Survival?

Identification of Management Actions and Monitoring Activities

This estuary recovery module identifies 23 management actions to improve the survival of salmon and steelhead migrating through and rearing in the estuary and plume environments. Table ES-1 lists these management actions and shows their relationship to threats to salmonid survival; this information is presented by topic, rather than priority.

TABLE ES-1
Management Actions to Address Threats

	Threat	Management Action
Flow-related threats	Climate cycles and global climate change[2]	**CRE[1]-1:** Protect intact riparian areas in the estuary and restore riparian areas that are degraded.[2] **CRE-2:** Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.[2] **CRE-3:** Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.[2]
	Water withdrawal	***CRE-3:*** *Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries*
	Flow regulation	**CRE-4**: Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume. ***CRE-3:*** *Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.*
Sediment-related threats	Entrapment of fine sediment in reservoirs	**CRE-5:** Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.
	Impaired transport of coarse sediment	**CRE-6:** Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially. **CRE-8:** Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health. ***CRE-4:*** *Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.*
	Dredging	**CRE-7:** Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.

[1] CRE = Columbia River estuary.

[2] Study of the impacts of global climate change is an evolving field, and additional research is needed to understand the phenomenon's likely effects on estuarine habitats and processes with specificity. At this time, the Independent Scientific Advisory Board of the Northwest Power and Conservation Council expects that the regional effects of global climate change in the next century will include more precipitation falling as rain rather than snow, reduced snow pack, and late-summer/early-fall stream flows, and associated rises in stream temperature (Independent Scientific Advisory Board 2007). The climate-related management actions in Table ES-1 reflect these expected impacts. Although the management actions clearly would not change the threat of global climate change itself, they have the potential to lessen its impact on salmonids in the estuary. Even if climate cycles and global climate change have effects different from those assumed in this document, the management actions that Table ES-1 associates with climate would provide benefits to salmonids by addressing other threats, such as water withdrawal, urban and industrial practices, and reservoir heating. All three of the management actions associated with climate in Table ES-1 are associated with other threats listed in Table ES-1.

Note: Italics indicate an action's second occurrence in the table, in connection with a different threat.

	Threat	Management Action
Structural threats	Pilings and pile dike structures	***CRE-8:*** *Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health.*
	Dikes and filling	**CRE-9:** Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat. **CRE-10:** Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.
	Reservoir-related temperature changes	***CRE-2:*** *Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.*
	Over-water structures	**CRE-11:** Reduce the square footage of over-water structures in the estuary.
Food web-related threats	Increased phytoplankton production	***CRE-10:*** *Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.*
	Altered predator/prey relationships	**CRE-13:** Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids. **CRE-14:** Identify and implement actions to reduce salmonid predation by pinnipeds. **CRE-15:** Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants. **CRE-16:** Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island. **CRE-17:** Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations. **CRE-18:** Reduce the abundance of shad in the estuary. ***CRE-8:*** *Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health.*
	Ship ballast practices	**CRE-19:** Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations ***CRE-7:*** *Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.*
Water quality-related threats	Agricultural practices	**CRE-20:** Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.[3] ***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.* ***CRE-9:*** *Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.*
	Urban and industrial practices	**CRE-21:** Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants. **CRE-22:** Restore or mitigate contaminated sites. **CRE-23:** Implement stormwater best management practices in cities and towns.[3] ***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.* ***CRE-9:*** *Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.*
Other threats	Riparian practices	***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.*
	Ship wakes	**CRE-12:** Reduce the effects of vessel wake stranding in the estuary.

[3] Unless otherwise noted, the term *best management practices* is used in this document to indicate general methods or techniques found to be most effective in achieving an objective. NMFS envisions that in implementation, specific best management practices would be developed or recommended.

Research, monitoring, and evaluation (RME) needs related to the 23 management actions are discussed in Chapter 6. As noted there, some of these needs are addressed in an existing document, *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program* (Johnson et al. 2008), while others are identified as new needs specific to the management actions in the module. Together, the existing and new RME activities will provide crucial information on salmonid performance in the estuary, the effectiveness of actions that are implemented in the estuary, associated changes in the ecology of the estuary, and scientific uncertainties that affect implementation of the actions.

Evaluating Management Actions: Relationship of Implementation Constraints to Cost and Survival Improvements

Identifying management actions that could reduce threats to salmon and steelhead as they rear in or migrate through the estuary is an important step toward improving conditions for salmonids during a critical stage in their life cycles. However, actual implementation of management actions is constrained by a variety of factors, such as technical, economic, public health and safety, and property rights considerations. In fact, in some cases it will be impossible to realize an action's full potential because its implementation is constrained by past societal decisions that are functionally irreversible. For example, reclaiming off-channel habitats in the lower Cowlitz River floodplain is constrained by the development of the city of Longview decades ago. An important assumption of the estuary recovery plan module is that the implementation of each of the 23 management actions identified in the module is constrained in some manner.

The module makes another important assumption about implementation: although implementation of actions is constrained, even constrained implementation can make important contributions to the survival of salmonids in the estuary and plume.

It is within the context of these two fundamental assumptions that recovery actions are evaluated in the module, in terms of their costs and potential benefits. The evaluation of survival benefits and costs is highly uncertain because it relies on estimates not only of what is technically feasible, but also of what is socially and politically practical. To help characterize survival improvements, the estuary recovery module uses a planning exercise that involves distributing a plausible survival target across the actions to hypothesize a potential amount of improvement that would result from each action. Costs then are developed by identifying projects for each action and units and per-unit costs for each project. Both the survival improvements and costs reflect assumptions about the constraints to implementation and the degree to which those constraints can be reduced given the technical, social, and political context in the Columbia River basin.

Evaluation Results

The estuary recovery plan module estimates the cost of constrained implementation of all 23 actions over a 25-year time period at $528.05 million. This represents an order-of-magnitude increase over the current level of investment in the estuary and reflects a significant level of effort needed to improve ecosystem health in the estuary and plume over the next 25 years. An additional $64.1 million is identified in Chapter 6 for research, monitoring, and evaluation activities. This effort is necessary because (1) scientific understanding of the estuary and how salmonids respond to conditions there is not yet mature, and (2) the module proposes some innovative management actions whose effectiveness should be explored before they are fully implemented. Thus the total implementation costs for the module are $592.15 million.

Table ES-2 shows the most important management actions for ocean- and stream-type salmonids that emerged from the analysis and planning exercises in the estuary recovery plan module. Many of these key actions are the same for ocean and stream types.

Implementing the suite of key actions in Table ES-2 for ocean-type salmonids would cost approximately $392 million and be expected to achieve approximately 88 percent of the survival target for ocean-type juveniles. (See Chapter 5 for a description of survival targets.) Implementing the suite of key actions for stream-type salmonids would cost approximately $408 million and be expected to achieve 90 percent of the survival target. Additionally, an estimated annual gain of about 1,000 adult salmon and steelhead is associated with the implementation of CRE-14, "Reduce predation by pinnipeds." The lists of priority actions in Table ES-2 for ocean- and stream-type salmonids contain eight actions that are predicted to benefit both types of salmonids. Implementing this common set of actions would cost approximately $372 million and would be expected to yield survival improvements of roughly 3 million juveniles.

TABLE ES-2
Management Actions Most Important for Survival of Ocean- and Stream-type Salmonids

For Ocean Types	For Stream Types
CRE-01: Protect/restore riparian areas.	CRE-01: Protect/restore riparian areas.
CRE-04: Adjust the timing, magnitude, and frequency of hydrosystem flows.	CRE-04: Adjust the timing, magnitude, and frequency of hydrosystem flows
CRE-08: Remove or modify pilings and pile dikes.	CRE-08: Remove or modify pilings and pile dikes.
CRE-09: Protect/restore high-quality off-channel habitat.	CRE-09: Protect/restore high-quality off-channel habitat.
CRE-10: Breach, lower, or relocate dikes and levees.	CRE-10: Breach, lower, or relocate dikes and levees.
CRE-13: Manage pikeminnow and other piscivorous fish.	CRE-13: Manage pikeminnow and other piscivorous fish.
CRE-21: Identify and reduce sources of pollutants.	CRE-21: Identify and reduce sources of pollutants.
CRE-22: Restore or mitigate contaminated sites.	CRE-22: Restore or mitigate contaminated sites.
CRE-02: Mitigate/reduce reservoir-related temperature changes.	***CRE-14: Reduce predation by pinnipeds.***
	CRE-16: Redistribute Caspian terns.
	CRE-17: Redistribute cormorants.

Note: Bold-face italics indicate management actions that would benefit primarily ocean- or stream-type salmonids, rather than both types.

Other Implementation Considerations: Life History Diversity, Cost-Effectiveness, and Achieving Maximum Benefit

It is tempting to pick and choose among the management actions, looking for the path of least resistance to achieve the desired survival improvements. For example, using the results of the Chapter 7 survival improvement planning exercise, it appears obvious that significant improvements in the survival of stream-type salmonids can be achieved by reducing threats associated with predators such as terns, cormorants, pikeminnow, and pinnipeds. However, addressing these threats would improve survival primarily for the dominant life-history strategy displayed by stream-type salmonids; in terms of recovery of ESUs, less dominant stream-type life history strategies also must be addressed. This points to the need to implement additional management actions in the estuary not directly related to predation.

For ocean-type juveniles, management actions that improve the health of the estuarine ecosystem appear to be the linchpin. Ocean-type juveniles reside in the estuary longer than stream types do. As a result, they rely more heavily on a healthy estuarine ecosystem to provide them with food and habitat (Bottom et al 2005). Given the challenges of making wide-scale ecosystem change, significant improvements for ocean-type juveniles may depend largely on three of the most constrained actions: adjusting hydrosystem flows (CRE–4), establishing or improving access to off-channel habitats (CRE-10), and restoring contaminated sites (CRE-22). Although these are some of the most expensive actions, their effects could be far-reaching enough that their potential benefits would be at least commensurate with their high costs.

Finally, because the estuary recovery module (by design) takes an optimistic view about what is possible in terms of reducing the constraints to implementation of management actions, in actuality specific actions probably will not be implemented with the level of effort needed to elicit the desired response. In fact, the most important take-home message of the estuary plan module is that recovery of listed ESUs in the Columbia River may not be possible without properly functioning estuary and plume ecosystems. To achieve a meaningful boost in survival from these ecosystems, every ounce of an action's potential benefit should be explored, and serious consideration should be given to implementing all of the 23 management actions to the fullest extent possible.

CHAPTER 1

The Columbia River Estuary and Plume

Purpose and Development of the Estuary Recovery Plan Module

This estuary recovery plan module is a planning document intended to complement other recovery plans in the region. With few exceptions, the module's focus is limited to habitat conditions and processes in the Columbia River estuary and plume, rather than hatchery or harvest practices, hydroelectricity production, or tributary habitats in the Columbia River basin. The purpose of this estuary recovery plan module is to identify and prioritize habitat-related management actions that, if implemented, would reduce threats to salmon and steelhead in the Columbia River estuary and plume.[1]

Chapter 2 provides background information on salmonid use of the estuary and plume within the context of the entire Columbia River basin. Chapter 3 identifies and prioritizes habitat-related salmon and steelhead limiting factors, and Chapter 4 links these limiting factors to the underlying environmental and human threats that have contributed to declines in abundance in the estuary. Chapter 4 also prioritizes threats based on the priority of the limiting factors they contribute to and their relative contribution to those limiting factors. Chapter 5 describes management actions that have the potential to reduce threats and evaluates the actions in terms of their implementation constraints, potential benefits, and costs. Chapter 6 describes research, monitoring, and evaluation needs, while Chapter 7 integrates elements of the earlier chapters to help characterize scenarios for improving the survival of salmonids as they rear in and migrate through the estuary and plume.

This estuary recovery plan module was developed by PC Trask & Associates, Inc., with participation of staff at the Lower Columbia River Estuary Partnership. The author also coordinated closely with staff at NOAA's National Marine Fisheries Service (NMFS) Northwest Regional Office throughout the module development process and obtained additional guidance and input from NMFS Northwest Fisheries Science Center staff and other regional experts (see Acknowledgements).

In drafting the module, the author reviewed and synthesized information from three main source documents:

- *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon* (Bottom et al. 2005)—Technical memorandum by the NMFS Northwest Fisheries Science Center

[1] Although current scientific information on the effects of limiting factors and actions does not differentiate between hatchery- and natural-origin salmon and steelhead, or between salmon and steelhead that are listed under the Endangered Species Act (ESA) and those that are not, the intent of the module is to improve the survival of ESA-listed salmon and steelhead. ESA recovery is determined by the status of naturally produced salmon and steelhead.

- *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability* (Fresh et al. 2005)—Technical memorandum by the NMFS Northwest Fisheries Science Center
- "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" and its supplement—Northwest Power and Conservation Council (2004)

NMFS Northwest Regional Office staff considered these documents to be timely, comprehensive, and accurate summaries of existing scientific knowledge about the estuary; they proved particularly valuable in providing information about threats and limiting factors affecting salmonids in the estuary.

To clarify key points or address topics that were not included in Bottom et al. (2005), Fresh et al. (2005), and Northwest Power and Conservation Council (2004), the author reviewed additional literature and contacted researchers whose findings were relevant but as yet unpublished; this included researchers at the NMFS Northwest Fisheries Science Center. Area experts (see Acknowledgements) reviewed and helped refine the author's draft products; thus, the module relies heavily on expert opinion rather than an expert panel or "Delphi" process. The author also worked with NMFS Northwest Regional Office and Lower Columbia River Estuary Partnership staff to further revise the module based on comments received during a *Federal Register* public review period. In summary, the final module is a broader, more comprehensive document than the three key source documents and has evolved with input from a diversity of scientists, other specialists, and the public.

Although the estuary recovery plan module is scientifically based, it is primarily a planning document and has important relationships to other planning processes and documents in the region. In the context of Columbia River basin recovery planning, the estuary module provides information on how conditions in the estuary and plume affect the 13 listed Columbia Basin evolutionarily significant units (ESUs). It was distributed in draft form to recovery planning forums around the Columbia River basin, and presentations on the module were made to Oregon's Mid-Columbia Sounding Board, the Upper Willamette Recovery Planning Stakeholder Team, and the Oregon Lower Columbia River Recovery Planning Stakeholder Team.

In the context of lower Columbia River management plans, the estuary recovery plan module is consistent with information in the Northwest Power and Conservation Council's "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" (in *Columbia River Basin Fish and Wildlife Program*, Northwest Power and Conservation Council 2004), the Lower Columbia River Estuary Partnership's *Comprehensive Conservation and Management Plan*, and the Columbia River Estuary Study Taskforce's Columbia River Estuary Data Development Program. In addition, information in the module was used in the Federal Columbia River Power System (FCRPS) 2008 Biological Opinion (BiOp) and later incorporated into the 2010 Supplemental BiOp; information from the module also was used in Washington's Lower Columbia Fish Recovery Board planning process, Oregon's Lower Columbia River recovery planning process, and other recovery planning efforts throughout the Columbia River basin.

The process of identifying and prioritizing management actions in the estuary module has inherent difficulties. Although scientific knowledge about the estuary is advancing, it is still incomplete. In addition, effective management solutions must acknowledge irreversible changes in estuary conditions over time, reflect the social and political will of the region, and focus on the biological and physical needs of the fish. In the final analysis, it is likely that science will never fully explain how every action affects the viability of fish. It will be up to current and future residents of the basin to determine how much they are willing to pay or do without in order to return salmon and steelhead to viable levels.

Formation and Current Characteristics of the Estuary

The geographic scope of the estuary recovery module encompasses areas from Bonneville Dam (River Mile [RM] 146; River Kilometer [RKm] 235) to the mouth of the Columbia River, including the Columbia River plume. The scope includes the lower portion of the Willamette River (from Willamette Falls, at RM 26.6 [RKm 42.6], to the Willamette's confluence with the Columbia River), along with the tidally influenced portions of other tributaries below Bonneville Dam. (Tidal portions of tributaries entering the estuary also are addressed in the Lower Columbia Fish Recovery Board's *Washington Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan* [2010] and Oregon's *Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead* [ODFW 2010] in a manner consistent with the overall framework of this module.)

The Columbia River estuary is a former river valley that, during the last ice age, was carved to 110 meters (360 feet) below current sea level. As sea levels subsequently rose, the floor of the valley was submerged and began to fill with sediments—initially from eastern drainages and then from the Cascade Range. The Missoula Floods, which occurred roughly 15,000 to 13,000 years ago, filled the valley with sand. This was followed by rapid sea level rise, which increased the size of the estuary and allowed further accumulation of mud and sand. By about 9,500 years ago, the rate of sea level rise had declined, the former river valley had filled with sediments, and most suspended sediment and bed load sand arriving from the Columbia River were being transported through the estuary to marine areas via the action of ebb tides and spring freshets, with some suspended sediment being deposited in floodplains and peripheral bays. This pattern continued to the historical period (Petersen et al. 2003).

The historical (circa 1880) total surface area of the Columbia River estuary has been estimated at up to 186 square miles (482 square kilometers) (Thomas 1983, Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004). The current estuary surface area is approximately 159 square miles (412 square kilometers) (Northwest Power and Conservation Council 2004). The Willamette River is the largest tributary to the lower Columbia River. Other major tributaries originating in the Cascade Mountains include the Sandy River in Oregon and the Washougal, Lewis, Kalama, and Cowlitz rivers in Washington. Coastal range tributaries include the Elochoman and Grays rivers in Washington and the Lewis and Clark, Youngs, and Clatskanie rivers in Oregon. The general geography of the estuary is shown in Figure 1-1.

FIGURE 1-1
The Columbia River Estuary and Its Major Tributaries
(Reprinted from Bottom et al. 2005.)

Tidal impacts in water levels are observed as far upstream as Bonneville Dam at RM 146 (RKm 235). During low flows, reversal of river flow has been measured as far upstream as Oak Point at RM 53 (RKm 84.8). The intrusion of saltwater is generally limited to Harrington Point at RM 23 (RKm 36.8); however, at lower daily flows saltwater intrusion can extend past Pillar Rock at RM 28 (RKm 44.8).

Today, the lowest river flows occur during September and October, when rainfall and snowmelt are lowest (Northwest Power and Conservation Council 2004). The highest flows occur from April to June and result from snowmelt runoff. High flows also occur between November and March and are caused by heavy winter precipitation. Discharge at the mouth of the river typically ranges from 100,000 to 500,000 cubic feet per second (cfs). Historically, unregulated flows were both lower and higher—79,000 and 1 million cfs, respectively (Neal 1972 and Lower Columbia River Estuary Partnership 2002 as cited in Northwest Power and Conservation Council 2004).

Estuary Reaches

For the purposes of this estuary recovery plan module, the estuary is broadly defined to include the entire continuum where tidal forces and river flows interact, regardless of the extent of saltwater intrusion (Fresh et al. 2005, Northwest Power and Conservation Council 2004). For planning purposes, the upstream boundary is Bonneville Dam and the downstream boundary includes the Columbia River plume. These two divisions—the estuary and plume—have been used extensively in this estuary recovery plan module as distinct zones. Further delineation of the estuary has occurred, including efforts by Thomas (1983), Johnson et al. (2003), and the Lower Columbia River Estuary Partnership (2005).

In this estuary recovery plan module, limiting factors, threats, and management actions are identified at the finest reach level possible. In some cases, this may be as general as making a distinction between the estuary and plume. In other cases, additional definition is available at the reach scale. The Lower Columbia River Estuary Partnership, in conjunction with the University of Washington and U.S. Geological Survey, has developed and is continuing to refine several estuary landscape classifications. Of these overlaying classifications, the estuary recovery module uses the Level 3 Stratum, which organizes the estuary between the mouth and Bonneville Dam into eight lettered reaches (Lower Columbia River Estuary Partnership 2005).

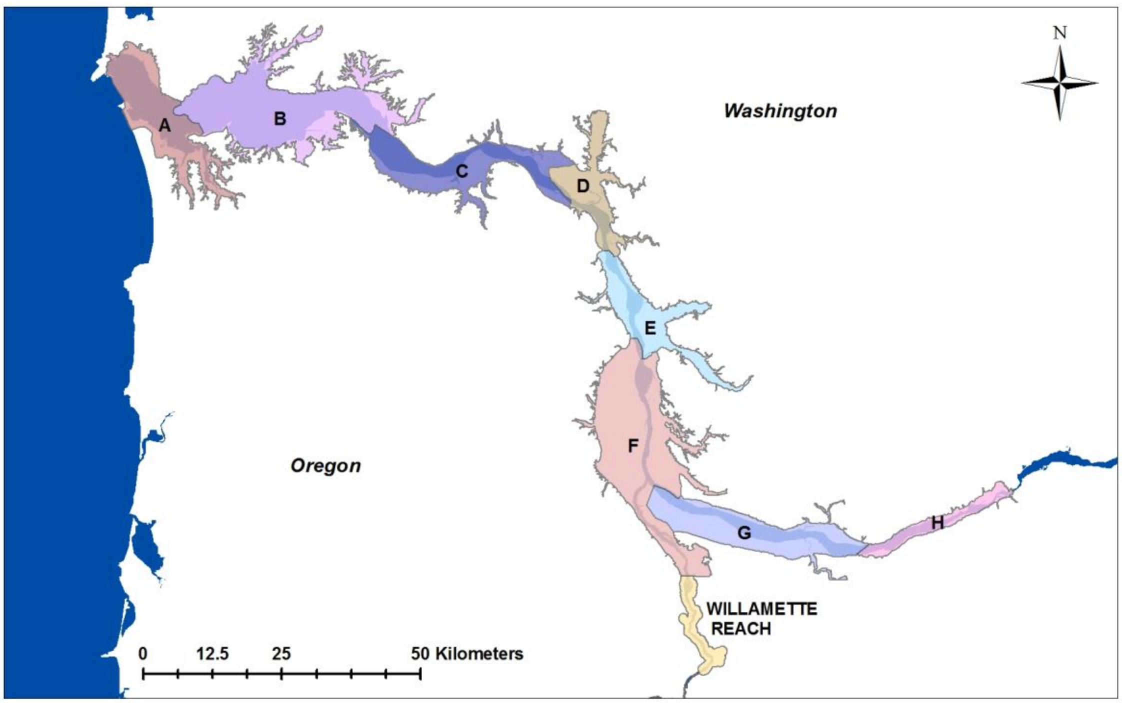

FIGURE 1-2
Lower Columbia River Estuary Reaches
(Adapted from Northwest Power and Conservation Council 2004.)

Figure 1-2 shows these eight reaches, which can be described briefly as follows:

- **Reach A**. This area includes the estuary entrance (Clatsop Spit and Trestle Bay), Bakers Bay, and Youngs Bay. The entrance is dominated by subtidal habitat and has the highest salinity in the estuary. Historically, the estuary entrance was a high-energy area of natural fluvial land forms with a complex of channels, shallow water, and sand bars.

Reach A supports the Columbia River plume, which creates a unique low-salinity, high-productivity environment that extends well into the ocean. The dynamic nature of the entrance area has changed as a result of dredging and the construction of jetties. These activities have limited wave action and the marine supply of sediment.

Historically, ocean currents and wave action made Bakers Bay a high-energy area, but both currents and wave action have been altered by dredging and jetty construction. The migration of mid-channel islands toward the interior of Baker Bay also has sheltered the area from wave action. As a result, tidal marsh habitat has recently started to develop in some areas, although much of the historical tidal marsh and tidal swamp habitat has been lost because of dike construction in the floodplain. Given its proximity to the river mouth, Baker Bay consists primarily of brackish water.

Youngs Bay is characterized by a broad floodplain and historically was abundant in tidal marsh and swamp habitat. Diking and flood control structures have been used to convert floodplain habitat in the area to pasture. The remaining fragmented tidal marsh and tidal swamp habitats in Youngs Bay are thought to be different in structure and vegetative community than historical conditions of these habitats.

- **Reach B**. Reach B generally extends from the Astoria-Meglar Bridge upstream to the westernmost tip of Puget Island. This area includes what has been referred to as the mixing zone (Northwest Power and Conservation Council 2004), along with Grays Bay and Cathlamet Bay. The mixing zone is an area characterized by a network of mid-channel shoals and flats, such as Desdemona and Taylor Sands. It also has the highest variation in salinity within the estuary because of the interactions between tide cycles and river flows. The estuarine turbidity maximum (see p. 3-8), which is created through these interactions, is often located within this area of Reach B. Many islands are found in Reach B, including Tenasillahe, Horseshoe, Marsh, Karlson, Russian, Svensen, Miller Sands, Rice, and Lois islands.

Grays Bay is found on the Washington side of the river in Reach B. Historically, water circulation in this area was a result of interactions between river flow and tidal intrusion. Pile dike fields constructed adjacent to the main Columbia River navigation channel have decreased circulation in Grays Bay. This circulation change is suspected of causing flooding problems in the Grays and Deep River valley bottoms and may have promoted the beneficial development of tidal marsh habitat in the accreting bay. Dike construction, primarily for pasture conversion, has isolated the main channel from its historical floodplain and eliminated much of the historical tidal swamp habitat.

Cathlamet Bay is located on the Oregon side of the river in Reach B. This area is characterized by some of the most intact and productive tidal marsh and swamp habitat remaining in the estuary, and a large portion of Cathlamet Bay is protected by the Lewis and Clark National Wildlife Refuge. The western edge of Cathlamet Bay contains part of the brackish oligohaline zone, which is thought to be important during the transition of juvenile anadromous fish from freshwater to saltwater. Portions of Cathlamet Bay have lost substantial acreage of tidal swamp habitat as a result of dike construction. Conversely, tidal marsh habitat has formed along the fringe of dredge disposal locations.

- **Reach C**. This area, which includes deep channels and steep shorelines on the Washington side of the river, extends from the westernmost tip of Puget Island to the western edge of Longview. Historically, Reach C contained significant acres of tidal swamp dominated by sitka spruce. Dike construction and clearing of vegetation have resulted in a substantial loss of tidal marsh habitat on islands and floodplain in the Oregon portion of Reach C. Lord Walker, Hump Fisher, Crims, Wallace and Puget islands are located within Reach C.
- **Reach D**. This area begins west of Longview and ends north of the city of Kalama. Reach D is distinct from the downstream reaches in its geology, vegetation, and climate. It includes flows from the Cowlitz and Kalama rivers. Extensive diking and filling around Longview and the mouth of the Kalama River have significantly reduced access to the floodplain. Islands and shoreline have been extensively modified through the disposal of dredged material. Sediment loading from eruptions of Mount St. Helens have significantly altered hydrology and channel morphology in and downstream of the Cowlitz and Kalama rivers. Dredging and the disposal of sediment from Mount St. Helens have been extensive. The two primary islands in Reach D are Cottonwood and Howard. High levels of polychlorinated biphenyls (PCBs) have been detected in the Longview and Kalama industrial area.
- **Reach E**. This area includes the Columbia River south of the city of Kalama to the confluence with the Lewis River, adjacent to the city of St. Helens, Oregon. The Lewis River system, including the North Fork and East Fork, flows into the Columbia River in Reach E. Sandy, Goat, Deer, Martin, and Burke islands are included in Reach E. Several of these islands, including Sandy and Goat islands, were created through the placement of dredged materials). Extensive diking has occurred on Deer Island and around the city of Woodland, Washington.
- **Reach F**. This area includes the Columbia River south of the confluence with the Lewis River up to and including the mid-point of Hayden Island. Reach F also extends into the Willamette River, to the downstream tip of Ross Island. Reach F is generally rural in character; however, it is located immediately downstream of the most urban/industrial areas in the entire Columbia River. Reach F contains the largest historical floodplain lakes below Bonneville Dam: Sturgeon Lake, at about 3,600 acres, and Vancouver Lake, which is approximately 2,400 acres. The historical floodplain was very wide in Reach F relative to the narrow and constricted channel through the Columbia River Gorge. Islands included in this reach are Bachelor and Sauvie islands. Sloughs include the 13-mile Lake River system and the more than 20-mile-long Multnomah Channel. Scappoose Bay is relatively undiked; however, Sauvie Island and Bachelor Island have been extensively diked. Reach F also includes Portland Harbor, a heavily industrialized stretch of the Willamette River located north of downtown Portland that was listed as a Superfund site in December 2000. Sediments in the river at this site are contaminated with various toxic compounds, including metals, polycyclic aromatic hydrocarbons (PAHs), PCBs, chlorinated pesticides, and dioxin (Oregon Department of Environmental Quality 2008).
- **Reach G**. This area includes the Columbia River west of Hayden Island and extends to just east of Reed Island. Major tributaries include the Washougal and Sandy rivers. The cities of Portland and Vancouver straddle the Columbia River in this reach. Islands included in this reach are Hayden Island, Government Island, Lady Island, and Reed

Island. Extensive diking has reduced the floodplain throughout the reach. Smith and Bybee lakes represent a large floodplain lake system similar to that of Vancouver and Sturgeon lakes in Reach F. Significant numbers of industrial piers and over-water structures line the Columbia rivers in this reach.

- **Reach H**. This area includes the Columbia River from east of Reed Island to the Bonneville Dam. This reach receives flow from many small tributaries, including Gibbons, Duncan, Hamilton, Hardy, and Multnomah creeks. Notable islands in this reach include Ackerman and Skamania islands. Reach H includes the entrance to the Columbia River Gorge, which is characterized by steep slopes. Little diking has occurred in this area, primarily because the steep adjacent slopes on both side of the river have naturally constrained the floodplain.
- **Lower Willamette Reach**. This reach extends upstream from the northern tip of Ross Island to Willamette Falls at RM 26.6 (RKm 42.6). The Lower Willamette reach is highly urbanized, bisecting the city of Portland and flowing past the cities of Milwaukie, Lake Oswego, Gladstone, and Oregon City. Notable islands in the Lower Willamette reach include Ross and Hardtack, Elk Rock, Hog, Cedar, and Goat islands. The primary tributary entering the Lower Willamette reach is the Clackamas River just downstream of Willamette Falls. Other smaller tributaries include Johnson, Tryon, Kellogg, Miller, and Stephens creeks. The shoreline of the Lower Willamette reach has been highly modified for industry, flood control, and other uses. Twelve transportation bridges cross the Willamette River in this reach.

GIS maps of each of the reaches are presented in Appendix A. The maps show additional information such as the locations of pile dikes and some tide gates, the navigation channel, the historical floodplain, diked areas, and dredged material placement sites.

Columbia River Plume

The Columbia River plume is generally defined by a reduced-salinity contour near the ocean surface of approximately 31 parts per thousand (Fresh et al. 2005). In high flows, the plume front is easily recognized by the sharp contrast between the sediment-laden river water and the clearer ocean (see Figure 1-3). The plume’s location varies seasonally with discharge, prevailing near-shore winds, and ocean currents. In summer, the plume extends far to the south and offshore along the Oregon coast. During the winter, it shifts northward and inshore along the Washington coast. Strong density gradients between ocean and plume waters create stable habitat features where organic matter and organisms are concentrated (Fresh et al. 2005). The Columbia River plume can extend beyond Cape Mendocino, California, and influences salinity in marine waters as far away as San Francisco (Northwest Power and Conservation Council 2000). For the purposes of this estuary recovery plan module, the plume is considered to be off the immediate coasts of both Oregon and Washington and to extend outward to the continental shelf.

Major Land Uses

A variety of land uses are found adjacent to the Columbia River estuary. The area contains multiple cities and political jurisdictions, including Portland, which is Oregon’s largest city, and Vancouver, the fourth largest Washington city. Smaller cities include Astoria, Cathlamet, Longview, Kalama, Woodland, and Camas. Approximately 2.5 million people live in the vicinity of the estuary, and more are coming. Five deep-water ports in the area support a shipping industry that transports 30 million tons of goods annually (Lower Columbia Fish Recovery Board 2004), worth $13 billion each year (Columbia River Channel Improvement Reconsultation Project). Timber harvest occurs throughout the basin—six major pulp mills contribute to the region's economy. Until the early 2000s, aluminum plants along the river produced more than 40 percent of the country's aluminum. Agriculture is widespread throughout the floodplain and includes fruit and vegetable crops along with beef and dairy cattle. Commercial and recreational fishing activity plays an important role in local economies, bringing in millions of dollars of revenue each year. Primary outdoor recreational activities include fishing, wildlife observation, hunting, boating, hiking, and windsurfing.

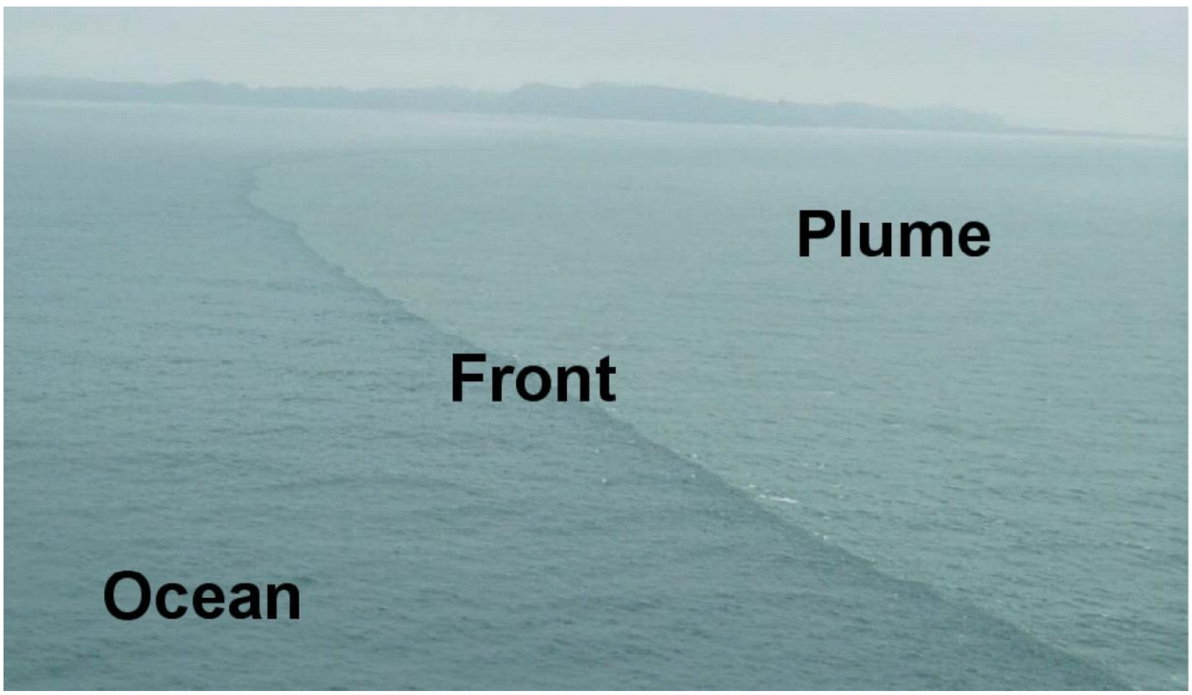

FIGURE 1-3
Plume Front
(Photo courtesy of NMFS.)

Two Centuries of Change

Before Euro-American settlement of the Pacific Northwest, the Columbia River estuary and plume served as a physical and biological engine for salmon. Juveniles from hundreds of populations of steelhead, chum, Chinook, and coho entered the estuary and plume every month of the year, with their timing honed over evolutionary history to make use of habitats rich with food. A beach seine survey during any month of the year would likely have yielded salmon of all species and many populations, with individuals of many sizes. This genetic variation in behavior was an important trait that allowed salmon and steelhead to occupy many habitat niches in time and space. It also guarded populations against catastrophic events such as volcanic eruptions (Bottom et al. 2005).

Today the Columbia River estuary and plume are much different. Notably, the North and South jetties at the mouth of the river restrict the marine flow of nutrients into the estuary. Dikes and levees lining the Washington and Oregon shores prevent access to areas that once were wetlands. New islands have been formed by dredged materials, and pile dike fields reach across the river, redirecting flows. Less visible but arguably equally important are changes in the size, timing, and magnitude of flows that, 200 years ago, regularly allowed the river to top its banks and provide salmon and steelhead with important access to habitats and food sources. Flow factors, along with ocean tides, are key determinants of habitat opportunity and capacity in the estuary and plume.

Salmon have thrived in the Columbia River for up to 1 million years (Lichatowich 1999). In the last 100 years, the entire Columbia River has undergone tremendous change as a direct result of people living and working in the basin. While the threats to salmon persistence are very diverse, at some level it is the increase in human population in the Northwest that underlies every human threat. There are an estimated 5 million people in the Columbia River basin today, and somewhere between 40 million and 100 million people are predicted to be living in the basin by the end of the twenty-first century (National Research Council 2004). If we want healthy salmon runs at the same time that our population is multiplying, our interactions with land and water must pose fewer threats to salmonids than they have in the last 100 years. Before identifying management actions that could do just that, this document discusses which salmonids currently use the Columbia River basin, and how.

CHAPTER 2

Salmonid Use of the Estuary and Plume

The estuary and plume provide salmonids with a food-rich environment where they can undergo the physiological changes needed to make the transition from freshwater to saltwater habitats, and vice versa. Every anadromous salmonid that spawns in the Columbia River basin undergoes such a transformation twice in its lifetime—the first time during its first year of life (or soon after) when migrating out to sea, and the second time 1 to 3 years later, as an adult returning to spawn. The transition zone where juvenile salmonids undergo this transformation is thought to extend from the estuary itself to the near-shore ocean and plume habitats and into rich upwelling areas near the continental shelf (Casillas 1999).

The estuary and plume also serve as rich feeding grounds where juveniles have the opportunity for significant growth as they make the important transition from freshwater to seawater. Studies have shown that juvenile salmon released within the estuary and plume returned as larger adults and in greater numbers than juveniles released outside the transition zone (Emmett and Schiewe 1997 as cited in Casillas 1999). Thus, although juvenile salmonids face risks from a variety of threats in the estuary and plume (see Chapter 4), these environments can be highly beneficial. In the salmon life cycle, successful estuarine and plume residency by juveniles is critical for fast growth and the transition to a saltwater environment.

Clearly, the Columbia River estuary and plume are uniquely important to salmonids, and conditions in the estuary and plume undoubtedly affect salmonid survival. Yet the estuary and plume represent just one in a series of ecosystems that salmon use in their complex life cycle. Exploring the connections among these ecosystems, the habitats they provide, the salmonid species that use them, and the variety of life histories those salmonids display sheds further light on the role of the estuary and plume in the salmonid life cycle.

Salmonid Species in the Columbia River Basin

Before Euro-American settlement, the Columbia River basin was used extensively by six species of the family Salmonidae and the genus *Oncorhynchus*: Chinook, chum, coho, and sockeye salmon plus two trout species: steelhead and sea-run cutthroat (Lichatowich 1999). Within these six species, 13 ESUs,[1] representing more than 150 populations of salmon and steelhead, have been listed as threatened or endangered under the Federal Endangered Species Act (Bottom et al. 2005). All 13 of the ESUs use the estuary and plume as an essential link in their far-reaching life cycles.

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[1] NMFS has revised its species determinations for West Coast steelhead under the Endangered Species Act (ESA), delineating steelhead-only "distinct population segments" (DPSs). The former steelhead ESUs included both anadromous steelhead trout and resident, non-anadromous rainbow trout, but NMFS listed only the anadromous steelhead. The steelhead DPS does not include rainbow trout, which are under the jurisdiction of the U.S. Fish and Wildlife Service. In January 2006, NMFS listed five Columbia River basin steelhead DPSs as threatened (71 FR 834). To avoid confusion, references to ESUs in this estuary recovery plan module imply the steelhead DPSs as well.

It is estimated that historically up to 16 million salmon from perhaps hundreds of distinct populations returned to the Columbia River each year (Lichatowich 1999). This contrasts markedly with recent returns of salmon and steelhead adults, which have averaged about 1.7 million, with 65 to 75 percent of those fish being of hatchery origin.[2] For 2006, scientists from the NMFS Northwest Fisheries Science Center estimated that about 168 million juveniles would enter the estuary (Ferguson 2006b).[3] This suggests that only 1 percent of the juveniles entering the estuary will return as adults and 99 percent are lost as a result of all the limiting factors (human and natural) in the estuary, plume, nearshore, and ocean.

Life History Types and Strategies

In discussing salmonids, fish scientists commonly refer to ocean type and stream type to distinguish two main freshwater rearing strategies. Ocean-type salmonids are characterized by migration to sea early in their first year of life, after spending only a short period in freshwater (Fresh et al. 2005). Ocean types may rear in the estuary for weeks or months, making extensive use of shallow, vegetated habitats such as marshes and swamps, where significant changes in flow and habitat have occurred (Fresh et al. 2005). Conversely, stream-type salmonids are characterized by migration to sea after rearing for more extended periods in freshwater, usually at least 1 year (Fresh et al. 2005). Table 2-1 shows the general characteristics of ocean-type and stream-type ESUs.

TABLE 2-1
Characteristics of Ocean- and Stream-Type Salmonids

Attribute	Ocean-Type Fish: fall Chinook, chum	Stream-Type Fish: coho, spring Chinook, steelhead
Residency time	Short freshwater residence Longer estuarine residence Longer ocean residence	Long freshwater residence (>1 year) Shorter estuarine residence Shorter ocean residence
Size at estuary entry	Smaller	Larger
Primary habitat use	Shallow-water estuarine habitats, especially vegetated ones	Deeper, main-channel estuarine habitats; use plume more extensively

Adapted from Fresh et al. 2005.

In the Columbia River estuary, both ocean- and stream-type salmonids experience significant mortality. However, because the two types typically spend different amounts of time in the estuary and plume environments and use different habitats, they are subject to somewhat different combinations of threats and opportunities.

For ocean-type juveniles, mortality is believed to be related most closely to lack of habitat, changes in food availability, and the presence of contaminants, including persistent, bioaccumulative contaminants present in sediments in the shallow-water habitats where ocean-type juveniles rear in the estuary. Stream types are affected by these same factors, although presumably to a lesser degree because of their shorter residency times in the

[2] This is an informal estimate; determining the ratio of hatchery-origin fish with more certainty would require stock-by-stock run calculations averaged over many years.

[3] 2006 was a normative year and is considered representative.

estuary. However, stream types are particularly vulnerable to bird predation in the estuary because they tend to use the deeper, less turbid channel areas located near habitat preferred by piscivorous birds (Fresh et al. 2005), and they are subject to pinniped predation when they return to the estuary as adults (see Chapter 3). Also, scientists at the NMFS Northwest Fisheries Science Center now hypothesize that larger numbers of stream-type yearling juveniles are susceptible to predation by northern pikeminnow than was previously thought; this predation occurs as the juveniles move into the shallows behind structures such as pilings or pile dikes to forage (Casillas 2007); this and related hypotheses are in the process of being tested through a program initiated by the Federal action agencies (the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and Bonneville Power Administration) and the Lower Columbia River Estuary Partnership. Additionally, stream-type salmonids are thought to use the low-salinity gradients of the plume to achieve growth and gradually acclimate to saltwater. Changes in flow and sediment delivery in the plume may affect stream-type juveniles in a way similar to how estuary conditions affect ocean-type juveniles; however, additional research is needed to determine more precisely how stream types use the plume (Casillas 2006).

Fish scientists also describe salmonids in terms of the life history strategies they employ, meaning a population's unique pattern of preferred spawning substrate, habitat use, migration timing, length of estuarine and marine residency, and so on. For thousands of years, Columbia River salmonids exhibited great diversity in life history strategies, exploiting a wide array of the habitat niches available to them. This rich diversity in life history strategies allowed salmonids to persist as species for millennia even when individual populations were wiped out by disease or natural disturbances such as volcanic eruptions.

Table 2-2 identifies the six basic life history strategies used by salmon and steelhead in the Columbia River and their general attributes.

Changes in Life History Diversity

The 13 listed ESUs in the Columbia River express much less diversity in life history strategies now than they did historically. Formerly, both ocean- and stream-type salmonids entered the estuary and plume throughout the year, at a great variety of sizes, which reflected the various life history strategies in Table 2-2. Today juveniles tend to arrive in pulses and are more uniform in size.

Table 2-3 shows losses in life history diversity in the Columbia River. The table identifies the dominant life history type (ocean vs. stream) and strategies for each ESU, the prevalence of each life history strategy, and whether that prevalence has changed from historical times to the present. The number of life history strategies employed by some ESUs, such as Columbia River chum, have not changed. But for other ESUs—notably the Lower Columbia River coho—several life history strategies that used to exist have been lost. In a research project studying outmigration of juvenile Chinook salmon in the lower Willamette River, results indicated the presence of fry and fingerling juveniles in all months of the year. Although the specific ESUs of these juvenile salmon have not been confirmed, the results indicate more contemporary life history stages present than indicated in Table 2-3 (Friesen et al. 2007).

Losses in life history diversity can also be seen in Figure 2-1, which compares historical and current estuarine life history types for one brood year of Chinook salmon. The figure shows a reduction in the number of strategies available in the contemporary versus historical estimates.

Some of the losses in salmonid life history diversity are attributable to habitat alterations throughout the Columbia River basin that have eliminated entire populations of salmon and steelhead. In other cases, hatcheries and harvest impacts have reduced the health and genetic makeup of species. As a result, many of the populations currently using the estuary and plume are significantly different than the fish that historically used the various habitats available to them, and some existing habitats may not be being used by salmonids at all.

TABLE 2-2
Life History Strategies and Their Attributes

Life History Strategy	Attributes
Early fry	Freshwater rearing: 0 - 60 days Size at estuarine entry: <50 mm Time of estuarine entry: March - April Estuarine residence time: 0 - 40 days
Late fry	Freshwater rearing: 20 - 60 days Size at estuarine entry: <60 mm Time of estuarine entry: May - June, present through Sept. Estuarine residence time: <50 days
Early fingerling	Freshwater rearing: 60 - 120 days Size at estuarine entry: 60 - 100 mm Time of estuarine entry: April - May Estuarine residence time: <50 days
Late fingerling	Freshwater rearing: 50 - 180 days Size at estuarine entry: 60 - 130 mm Time of estuarine entry: June - October, present through winter Estuarine residence time: 0 - 80 days
Subyearling (smolt)	Freshwater rearing: 20 - 180 days Size at estuarine entry: 70 - 130 mm Time of estuarine entry: April - October Estuarine residence time: <20 days
Yearling	Freshwater rearing: >1 year Size at estuarine entry: >100 mm Time of estuarine entry: February - May Estuarine residence time: <20 days

Adapted from Fresh et al. 2005.

TABLE 2-3
Linkage between Salmonid ESU, Dominant Life History Type, and Life History Strategy in the Columbia River Estuary

ESU	Life History Type	Historical and Current Life History Strategies					
		Early Fry	Late Fry	Early Fingerling	Late Fingerling	Sub-yearling	Yearling
Columbia River chum salmon	Ocean	Abundant	Abundant	—	—	—	—
Snake River sockeye salmon	Stream	—	—	—	—	Rare	Abundant
Lower Columbia River coho salmon	Stream	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Upper Columbia River steelhead	Stream	—	—	—	—	Historically rare, currently absent	Abundant
Snake River steelhead	Stream	—	—	—	—	Historically rare, currently absent	Abundant
Lower Columbia River steelhead	Stream	—	—	—	Historically rare, currently absent	Historically medium, currently rare	Abundant
Middle Columbia River steelhead	Stream	—	—	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Abundant
Upper Willamette River steelhead	Stream	—	—	—	—	Historically rare, currently absent	Abundant
Snake River fall Chinook salmon	Ocean	—	—	Historically medium, currently rare	Historically medium, currently rare	Abundant	Historically rare, currently medium
Upper Willamette River Chinook salmon	Ocean	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Historically medium, currently rare	Historically rare, currently medium	Abundant
Lower Columbia River Chinook salmon	Ocean	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently abundant	Rare
Upper Columbia River spring Chinook salmon	Stream	—	—	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Snake River spring/summer Chinook salmon	Stream	—	—	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant

"—" = historically and currently absent.
Adapted from Fresh et al. 2005.

Relationship of the Estuary to the Columbia River Basin

In 2005, scientists working at the NMFS Northwest Fisheries Science Center published a technical memorandum that establishes an ecologically based conceptual framework for understanding the estuary within the larger context of the Columbia River basin. In *Salmon* *at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*, Bottom et al. (2005) hypothesize that Columbia River salmon's resilience to natural environmental variability is embodied in population and life history diversity, which maximizes the ability of populations to exploit available estuarine rearing habitats. Bottom et al.'s conceptual framework is based on Sinclair's (1988) member/vagrant theory, which proposes general principles for understanding marine species with complex life cycles. The member/vagrant theory serves as a useful tool for evaluating salmon's specific needs in estuaries in relation to the entire continuum of their habitat needs throughout their complex life cycles (Bottom et al. 2005).

Bottom et al. (2005) hypothesize that how an individual salmon or steelhead uses the ecosystems it encounters—when juveniles migrate, how big they are, what habitats they use, and how long they stay in a particular habitat—correlates directly to the discrete population of fish that individual is part of. In other words, different populations within ESUs employ different life history strategies. For example, two populations of steelhead within an ESU may produce juveniles of different sizes that enter the estuary at different times, and these juveniles may use distinct habitats that may be available only at that particular time.

Considering that the estuary is just one of three major ecosystems used by salmon and steelhead, the member/vagrant theory implies that how juveniles migrate and use estuarine habitat may depend as much on the status of upriver habitats and corresponding populations as on environmental conditions in the estuary itself (Bottom et al. 2005). In other words, if there is a close relationship between particular geographical features in the estuary and the life history of a discrete salmonid population, use of the estuary may reflect the abundance and life history strategy of the associated population, which is in part a function of upstream conditions. Thus, if salmonid migration and rearing behaviors in the estuary are linked to specific geographic features and those features are reduced or eliminated, mortality in the population that uses those features increases (Bottom et al. 2005). By the same token, if salmonid populations are lost because of other factors (such as blockage by dams), habitats in the estuary may be left unoccupied.

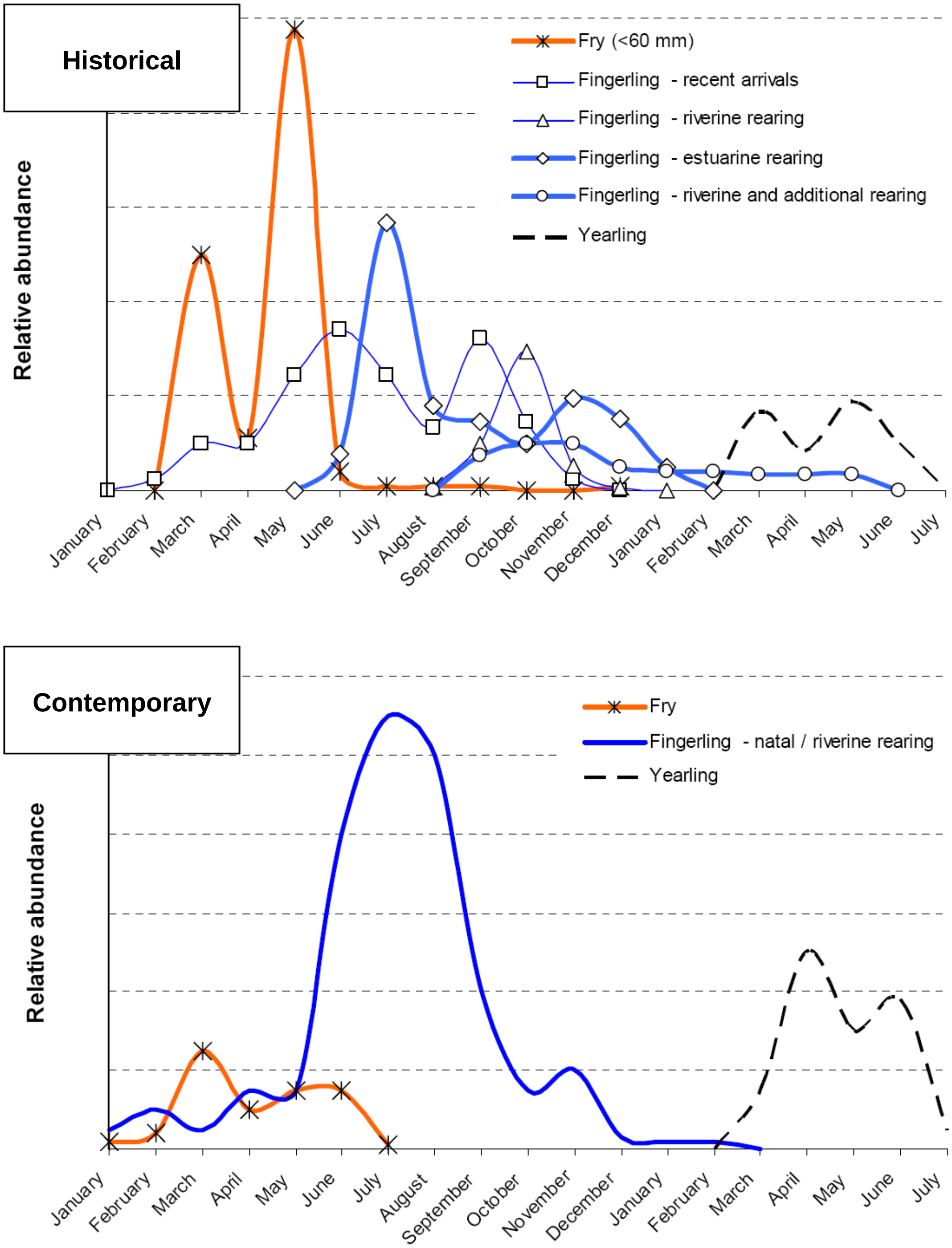

FIGURE 2-1
Historical and Contemporary Early Life History Types of Chinook Salmon in the Columbia River Estuary
(Reprinted from Fresh et al. 2005.)

The implication for salmon recovery in the Columbia River basin is that habitat use by salmonids must be considered from a multi-ecosystem perspective if we are to understand which components of each ecosystem—tributaries, mainstem, estuary, plume, nearshore, and ocean—are limiting the overall performance of salmon.

Summary

Since 1991, 13 Columbia River ESUs have been listed as threatened or endangered under the Federal Endangered Species Act. During their complex life cycles, salmon and steelhead rely on many diverse ecosystems, from tributaries to ocean environments, that span hundreds or thousands of miles. For recovery efforts to be successful, it is necessary to understand salmonids' requirements during all stages of their life cycles. Thus, although the estuary and plume represent important stages in the salmonid life cycle, these ecosystems must be considered within the context of other life cycle stages if management actions are to be effective. Perhaps most central to the recovery of listed ESUs is the importance of conserving biological diversity and the native ecosystems it depends on (Bottom et al. 2005).

CHAPTER 3

Limiting Factors

Chapter 3 identifies and prioritizes the key habitat-related physical, chemical, or biological features that scientific literature and area experts suggest are affecting the viability of ESUs and their component populations in the estuary. These features are referred to as limiting factors.[1] The discussion of limiting factors in this chapter pertains to the estuary and plume; however, upstream limiting factors in some cases have a direct bearing on conditions in the estuary. Discussion of limiting factors in this chapter generally relates to specific factors that limit salmonid productivity; however, it is recognized that the effects of multiple limiting factors may have a compounding effect. The estuary module does not address this compounding effect because of a lack of technical information to address the topic.

Determining Estuary Habitat Limiting Factors

Sources

It would be desirable to know with certainty which factors are responsible for the highest losses of salmon and steelhead in the estuary so that recovery actions could be focused on activities to address those factors. But as described below, researchers have quantified salmonid mortality in the estuary for only a few limiting factors, and additional research on mortality is needed to understand which factor (or factors) is most limiting salmonid viability in the estuary. In the absence of more comprehensive mortality data, the estuary recovery module relies on expert opinion and available information in the literature to identify and prioritize limiting factors.

PC Trask & Associates, Inc., based this chapter on a thorough review and synthesis of pertinent literature, supplemented by input from staff at the NMFS Northwest Fisheries Science Center and Northwest Regional Office, the Lower Columbia River Estuary Partnership, and the Lower Columbia Fish Recovery Board. The following documents, among others, provided consistent guidance:

- *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon* (Bottom et al. 2005)—Technical memorandum by the NMFS Northwest Fisheries Science Center
- *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability* (Fresh et al. 2005)—Technical memorandum by the NMFS Northwest Fisheries Science Center
- "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" and its supplement—Northwest Power and Conservation Council (2004)

These three literature sources, and others, identified and evaluated limiting factors in a similar manner. But it should be noted that the three sources have separate goals, and this

[1] In this module, the term "limiting factors" is used to indicate the full range of factors that are believed to be affecting the viability of salmon and steelhead in the estuary and not to indicate the single factor that is most limiting.

affects each document's structure and content. Thus, the depth and breadth of information were not always consistent across documents. To develop a relatively comprehensive list of factors that are limiting ESUs' viability in the estuary and to weigh the probable effect of each factor, the author had to synthesize information from multiple sources.

Mortality Estimates

Estimates of salmon and steelhead mortality in the estuary and mainstem are not well supported in the literature, especially in the case of indirect mortality. (There are more reliable estimates of direct impacts to salmonids populations than indirect or combined impacts.) However, some modeling efforts have made assumptions about estuary mortality. One example is Ecosystem Diagnosis and Treatment (EDT), a life-cycle model that accounts for the estuarine stage of salmon and steelhead in tributaries of the Columbia River. For lower Columbia River ESUs, EDT assumes 18 to 58 percent mortality for various populations.

In addition, research is under way by NMFS, the U.S. Army Corps of Engineers, and Battelle Laboratories to estimate the survival rate of juvenile salmonids in the lower Columbia River. This research involves technologies for miniaturizing acoustic tags to a size capable of tracking yearling and subyearling juveniles. Current technology developed for the project allows for the tracking of subyearlings of sizes down to approximately 90 mm. Data from 2005 indicated an approximate range of survival of 65 to 75 percent for subyearlings and yearlings during their residency in the estuary (Ferguson 2006a).[2] It is probable that actual survival rates are lower than these estimates suggest because the research did not address mortality among juveniles smaller than 90 mm, mortality occurring in the plume and nearshore, or delayed mortality.

There are reliable mortality estimates for a few limiting factors. For example, Caspian tern predation was estimated to be responsible for the mortality of about 5.5 million smolts in 2007 (Roby et al. 2008)—up to 14.1 percent of in-river migrant steelhead smolts and 7.7 percent of transported steelhead smolts (Roby et al. 2008). Double-crested cormorants appear to be consuming approximately 6 percent of steelhead, 6 percent of subyearling Chinook, 2 percent of yearling Chinook, and 1 percent of sockeye salmon entering the estuary (Fredricks 2010).

Other limiting factors, such as pinnipeds (primarily affecting adult survival), ship wake stranding, and toxic contaminants, have incomplete mortality estimates associated with them. Toxic contaminants, for instance, can have lethal and sublethal impacts to salmonids, resulting in direct and indirect mortality, both of which are difficult to quantify. In most cases it is very difficult to point to a specific limiting factor and then estimate mortality. This is because of the inherent complexity associated with connecting the physical, chemical, and biological features that limit the productivity of salmon and steelhead.

2 The mean yearling survival estimate for the years 2005 to 2009 is 75.8 percent (standard deviation = 5.4 percent), while the mean subyearling survival estimate for the same period is 67.6 percent (standard deviation = 9.0 percent) (Casillas 2010). Because these more current survival estimates are very close to the estimates used when the module was initially drafted, and because local recovery planners in the Washington and Oregon Lower Columbia region incorporated the 2005 estimates into their salmon recovery plans, the module was not updated with the most current numbers. In future revisions of the module and the Lower Columbia tributary plans, needed updates will be made.

Density-Dependent Mortality

In the Columbia River estuary, limiting factors such as off-channel habitat availability, competition with native and exotic fish for food and space, disease, and predation by piscivorous fish and native birds may in part be manifestations of density dependence. Density dependence refers to changes in the size of a population that are themselves a result of the size of the population, such as when a population declines because it has exceeded the amount of resources available to support it. Density-dependent mortality can occur through several mechanisms, such as direct competition for limited food and habitat and changes in the foraging activity of predators. With salmon and steelhead, density-dependent mortality can occur at any stage in the animal's life cycle and may be exacerbated by the introduction of large numbers of hatchery fish released over a relatively short period of time, or by the cumulative effects of such releases on natural-origin salmon.[3]

How much density-dependent mortality is taking place in the estuary compared to in the ocean is unclear. There is some evidence that density-dependent mortality is occurring in the open ocean. For example, during years when salmon are especially numerous in the ocean, their growth rates are reduced (Peterman 1984 as cited in Ford 2007). One study found that, during years when nearshore ocean productivity was low, survival of wild Snake River Chinook decreased as releases of hatchery Chinook increased (Levin et al. 2001 as cited in Ford 2007). However, another study found no connection between ocean conditions and density-dependent mortality, which appeared to be occurring among wild Snake River Chinook as hatchery steelhead were released (Levin and Williams 2002 as cited in Ford 2007). The authors suggested that the apparent density-dependent mortality could be better explained by interactions in the tributaries or estuary than by interactions in the ocean.

There is growing awareness among scientists studying the Columbia River estuary that mechanisms related to density dependence may limit salmon and steelhead while they are using estuary and plume habitats. Scientists studying Skagit River fall Chinook have documented density dependence-related mortality as a result of loss of habitat in the Skagit estuary and believe that such mortality can be attributed to a 75 percent loss of tidal delta estuarine habitat (Beamer et al. 2005). With similar habitat losses in the Columbia River estuary, it is possible that too many fish are competing for limited habitat and associated resources in the estuary at key times, and that the resulting stressors translate into reduced salmonid survival. The NMFS Northwest Fisheries Science Center currently is investigating potential density-dependent mortality in the estuary. The "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" raised the specter of density dependence in the estuary and recommended continued research to analyze conditions there (Northwest Power and Conservation Council 2004). Thus, although the occurrence of density dependence-related mortality in the Columbia River estuary has not been proven, given the dramatic changes in habitat opportunity and capacity in the estuary over the last 200 years, it is likely that some of the mortality associated with the limiting factors described in this chapter is related to increased density of juveniles in the estuary.

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[3] It is also possible that inverse density dependence processes occur in some situations. For example, large numbers of adult salmon could swamp marine mammal predators at Bonneville Dam, and the adult survival rates could be higher than in scenarios with smaller numbers of adult fish.

Consistent with this concern, the NMFS Northwest Region Salmon Recovery Division and Northwest Fisheries Science Center are working to better define and describe the scientific uncertainty associated with ecological interactions between hatchery-origin and natural-origin salmon in freshwater, estuarine, and nearshore ocean habitats. Needs include an assessment of the state of the science to help identify priority research on the ecological interactions between hatchery-origin and natural-origin salmon in these habitats and to better define the ecological risks of such interactions. A conference on ecological interactions between hatchery-origin and natural-origin salmon held in May 2010 in Portland, Oregon, contributed to describing the state of the science on these interactions. Conference proceedings will be published and priority research needs identified. Follow-up workshops will help refine the assessment, develop specific research plans, and identify funding sources.

The estuary recovery plan module assumes that density-dependent mortality that may be occurring in the estuary is manifested in part through limiting factors related to habitat availability, competition for food and space, disease, and predation. Given the uncertainty about the mechanisms and effects of density dependence in the estuary, density dependence itself is not included as a limiting factor in the module. Neither are the effects of hatchery fish. Although it is likely that hatchery fish influence the estuarine survival of naturally produced fish (possibly through mechanisms of competition, predation, and disease transfer), the focus of this estuary recovery plan module is the effects of habitat conditions and processes in the estuary and plume, rather than the effects of hatchery or harvest practices. But the degree of density-dependent mortality occurring in the estuary, the role of large releases of hatchery fish, and the cumulative impact of hatchery releases on density-dependent mechanisms are worth exploring through further research.

Habitat-Related Limiting Factors

Salmonid populations exhibit diverse strategies that guide them through various habitats and ecosystems in specific sequences and patterns. If those sequences and patterns are interrupted, increased mortality may result. Thus, mismatches between the needs of salmonid populations and the availability of habitats to meet those needs can limit salmonid performance in the estuary and plume. The member/vagrant theory discussed in Chapter 2 underscores the need to consider relationships between ESUs' life history strategies and the quality, quantity, and availability of habitats in the estuary and other ecosystems that are interconnected via the salmon and steelhead's complex life cycle.

The habitats that salmonids occupy during their residency in the estuary and plume are formed through the interaction of ocean forces, land, and river flow (Fresh et al. 2005). Flows entering the estuary govern the general availability of habitats, along with sediment transport, salinity gradients, and turbidity, which are themselves aspects of habitat or habitat formation. Over the last 200 years, the magnitude, timing, and frequency of flows have changed significantly, with corresponding effects on the formation and availability of salmonid habitats. Some habitat has been removed, which has reduced the total acreage of the estuary by approximately 15 percent (Fresh et al. 2005). In other cases, particular habitat types have been transformed into other habitat types, and the resulting mosaic of habitats may not be meeting the needs of salmonids as well as the historical pattern of habitats did. For example, approximately 77 percent of historical tidal swamp has been lost (Northwest

Power and Conservation Council 2004), while other shallow-water habitats have increased significantly. The loss of tidal swamps and other forested or vegetated wetlands represents a loss of habitat that ocean-type salmonids use during their estuarine residence. In short, habitat opportunity and capacity have been degraded in the estuary and plume, and alterations in flow have contributed significantly to losses in in-channel, off-channel, and plume habitat. An accurate accounting of specific habitat type changes from pre-European settlement to the present day has not been initiated estuarywide. This measurement of change is important to guiding restoration priorities and represents a significant data gap in the estuary.

An important goal of this estuary recovery module is to describe the various habitats and limiting factors that both ocean- and stream-type juvenile salmonids encounter in the Columbia River estuary and plume. However, current scientific understanding of how stream-type juveniles use the various habitats they encounter in the estuary and plume is less robust than what is known about ocean types' habitat use. To fill this important knowledge gap, the NMFS Northwest Fisheries Science Center and others are exploring how stream-type juveniles expressing all the different possible life history strategies use individual estuarine habitats.

Affected salmonids: Because of their longer estuary residence times and tendency to use shallow-water habitats, ocean-type ESUs are more affected by flow alterations that structure habitat and/or provide access to wetland or floodplain areas than are stream-type ESUs. Stream types have relatively short estuary residence times and use the plume much more extensively than ocean types do. Thus stream-type salmonids are affected by habitat elements such as the shape, behavior, size, and composition of the plume (Fresh et al. 2005).

Reduced In-Channel Habitat Opportunity

In-channel habitat opportunity in the estuary is a function of the size of river flows, the timing of river flows, incoming and outgoing tides, and the amount and patterns of sediment accretion. Together, tidal action, river flow, and sediment movement create a constantly changing mosaic of channel habitats as water levels rise and fall, sands shift, and salinity gradients move in response to tides. To support salmonids, the various habitats in the estuary need to be connected both spatially and in time. With twice-daily tidal fluctuations, areas that are accessible at one point during the day can be inaccessible 6 hours later or can trap salmonids, exposing them to higher water temperatures and lower dissolved oxygen levels that can result in stress or mortality. Changes in both flow and sediment transport have reduced in-channel habitat opportunity.

Limiting Factor: Flow-Related Estuary Habitat Changes. The ability of juvenile salmon to access and benefit from habitat depends greatly on instream flow (Fresh et al. 2005). Changes in the quantity and seasonality of flows in the estuary have a direct bearing on whether key habitats are available to salmonids, when and how long those habitats are available, and whether and how they connect with other key habitats. In addition, juvenile salmonids have physiological or behavioral traits that set the timing for their transformation to saltwater, and changes in flows may interrupt this timing.

Both the quantity and timing of instream flows entering the Columbia River estuary and plume have changed from historical conditions (Fresh et al. 2005). Jay and Naik (2002) reported a 16 percent reduction of annual mean flow from 1878 to the present and a 44 percent reduction in spring freshet flows. Jay and Naik also reported a shift in flow patterns in the Columbia to 14 to 30 days earlier in the year, meaning that spring freshets are occurring earlier in the season.[4] In addition, the interception and use of spring freshets (for irrigation, reservoir storage, etc.) have caused increased flows during other seasons (Fresh et al. 2005). These changes in the volume and timing of Columbia River flow are limiting factors for salmon and steelhead and have affected habitat opportunity and capacity in the estuary and plume. It is likely that global climate change will contribute to further flow-related changes in estuary habitat. However, changes in flow entering the estuary as a result of climate change are expected to be less than those caused by construction of the hydrosystem (Independent Scientific Advisory Board 2007).

Limiting Factor: Sediment/Nutrient-Related Estuary Habitat Changes. The transport of sediment is fundamental to habitat-forming processes in the estuary through sediment deposition and erosion (Fresh et al. 2005). An estuary's form is altered primarily through the deposition of sediment—either sediment that is reworked from other parts of the estuary or sediment that enters the estuary from the watersheds or ocean. Sediment moves among each of the components within the estuary, allowing the estuary as a whole to continually be adjusting toward some long-term equilibrium form in response to changes in physical or geomorphic processes (Philip Williams & Associates and Farber 2004). Sediment from the estuary and upstream sources also affects the formation of nearshore ocean habitats north and south of the Columbia River entrance.

Since the late nineteenth century, sediment transport from the interior basin to the Columbia River estuary has decreased about 60 percent and total sediment transport has decreased about 70 percent (Jay and Kukulka 2003). This reduction in the amount of sediment transport in the Columbia River has affected habitat-forming processes in the estuary and plume (Bottom et al. 2005) and is presumed to be a limiting factor for salmon and steelhead because it limits the accretion of sediment and thus the formation of shallow-water habitats. Although the consequences of the reduced transport of sediment through the estuary and plume are not fully understood, the magnitude of change is very large compared to historical benchmarks (Fresh et al. 2005).

Sediment also provides important nutrients that support food production in the estuary and plume. Microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically. Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004).

Reduced Off-Channel Habitat Opportunity

Columbia River access to its historical floodplain is an important factor for rearing ocean-type juvenile salmonids. Stream-type juvenile salmonids also are believed to benefit from access to off-channel habitats, which support less dominant stream-type life histories and provide food resources for stream types during downstream migration (Bottom et al. 2005).

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4 These analysis were calculated by comparing observed flow (data from a gauge), estimated adjusted flow (observed flow corrected for reservoir manipulations), and estimated virgin flow (estimate of river flow without human alteration).

Historically, flows that topped the river's bank provided juvenile salmonids with access to low-velocity areas in the lower river and estuary that juveniles used as refugia and for rearing; many of these areas were dominated by Sitka spruce tidal swamps, which were an integral component of the estuarine ecosystem. Overbank flows contributed key food web inputs to the ecosystem and influenced wood recruitment, predation, and competition in the estuary (Fresh et al. 2005).

Today, mainstem habitat in the Columbia and Willamette rivers has, in many cases, been reduced to a single channel (Northwest Power and Conservation Council 2004), and channelization of the estuary has eliminated access to an estimated 77 percent of historical tidal swamps (Fresh et al. 2005). In fact, over the past 200 years the surface area of the estuary has decreased by approximately 20 percent (Fresh et al. 2005).

The near elimination of overbank flooding is a function of both reductions in peak freshet flows (as a result of flow regulation for electricity generation, storage for irrigation and municipal use, and flood control) and increases in the bankfull level of the Columbia River (as a result of dikes and levees), among other factors.

Figure 3-1 shows diked areas from the estuary mouth to Bonneville dam. This map was generated from a GIS database developed by the University of Washington, U.S. Geological Survey, and Lower Columbia River Estuary Partnership that provides statistics and maps depicting the historical floodplain, diked areas, dredged material disposal sites, over-water structures, contaminant monitoring sites, and other key features in the estuary. Some of these features are shown in GIS-based reach maps presented in Appendix A.

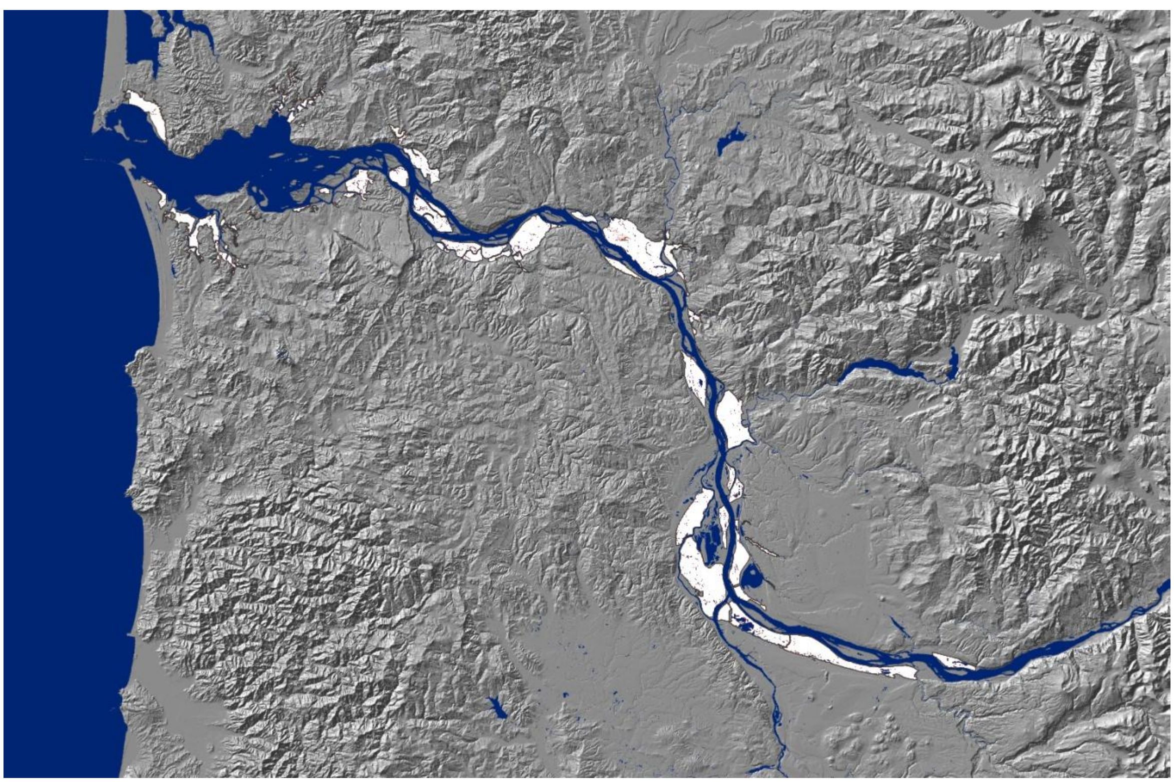

FIGURE 3-1
Diked Areas in the Columbia River Estuary
(Source: Lower Columbia River Estuary Partnership 2005.)

Limiting Factor: Flow-Related Changes in Access to Off-Channel Habitat. Reduced access to off-channel habitats is a limiting factor for salmon and steelhead because of impacts on food webs and the reduced availability of habitats preferred by fry and fingerlings. Typically, overbank flows were driven by spring freshets, which occurred at the time of year when there was the greatest variety of juvenile salmon and steelhead using the estuary (Fresh et al. 2005). Overbank flows occur much less frequently now than they did historically, in part because climate changes and human alterations have reduced the number of high flows in the Columbia (Jay and Kukulka 2003).

Limiting Factor: Bankfull Elevation Changes. The construction of levees also has reduced the frequency of overbank flows because more river water is needed to cause overbank flow. Historically the bankfull level was 18,000 $m^3 s^{-1}$, while today it is 24,000 $m^3 s^{-1}$—fully one-third more. Only five overbank events have occurred since 1948 (Jay and Kukulka 2003). The reduction in overbank events is a limiting factor because it reduces the availability of food and refugia for ocean-type juveniles rearing in the estuary. Less dominant stream-type juveniles are affected in the same manner.

Reduced Plume Habitat Opportunity

Evidence suggests that the plume supports ocean productivity by increasing primary plant production during the spring freshet period, distributing juvenile salmonids in the coastal environment, concentrating food sources such as icthyoplankton (megalopae, for example) and zooplankton, and providing refugia from predators in the more turbid, low-salinity plume waters (Fresh et al. 2005). Changes in the volume and timing of Columbia River flow have altered both the size and structure of the plume during the spring and summer months (Northwest Power and Conservation Council 2000).

Limiting Factor: Flow-Related Plume Changes. For juvenile salmonids preparing for ocean life, the plume is believed to function as habitat, as a transitional saltwater area, and as refugia. As mentioned earlier, stream-type ESUs in particular are affected by the size, shape, behavior, and composition of the plume (Fresh et al. 2005).

Over the past 200 years characteristics of the plume have been altered, and conditions caused by reductions in spring freshets and associated sediment transport processes may now be suboptimal for juvenile salmonids (Casillas 1999). Plume attributes affected by changes in flow include surface areas of the plume, the volume of the plume waters, the extent and intensity of frontal features, and the extent and distance offshore of plume waters (Fresh et al. 2005).

Limiting Factor: Sediment/Nutrient-Related Plume Changes. It is believed that the sediment and nutrients transported in the plume fuel salmon productivity in the ocean and provide relief from predation (Casillas 1999). This is particularly true for stream-type ESUs, who use the plume more extensively than ocean types do and thus are more affected when the amount of plume habitat is reduced.

Limiting Factor: Water Temperature

Higher water temperatures have reduced habitat quality for salmonids that use the estuary during summer months. Since 1938, average summer water temperatures at Bonneville Dam have increased 4° F (2.2° C) (Lower Columbia Fish Recovery Board 2004). Among-year variability in temperature has been reduced by 63 percent since 1970 (Lower Columbia Fish Recovery Board 2004). As shown in Figure 3-2, temperatures entering the estuary (as measured at Bonneville Dam) have increased steadily since 1938. Temperatures also exceed 20° C (68° F) earlier during the year and more frequently than they did historically (National Research Council 2004).

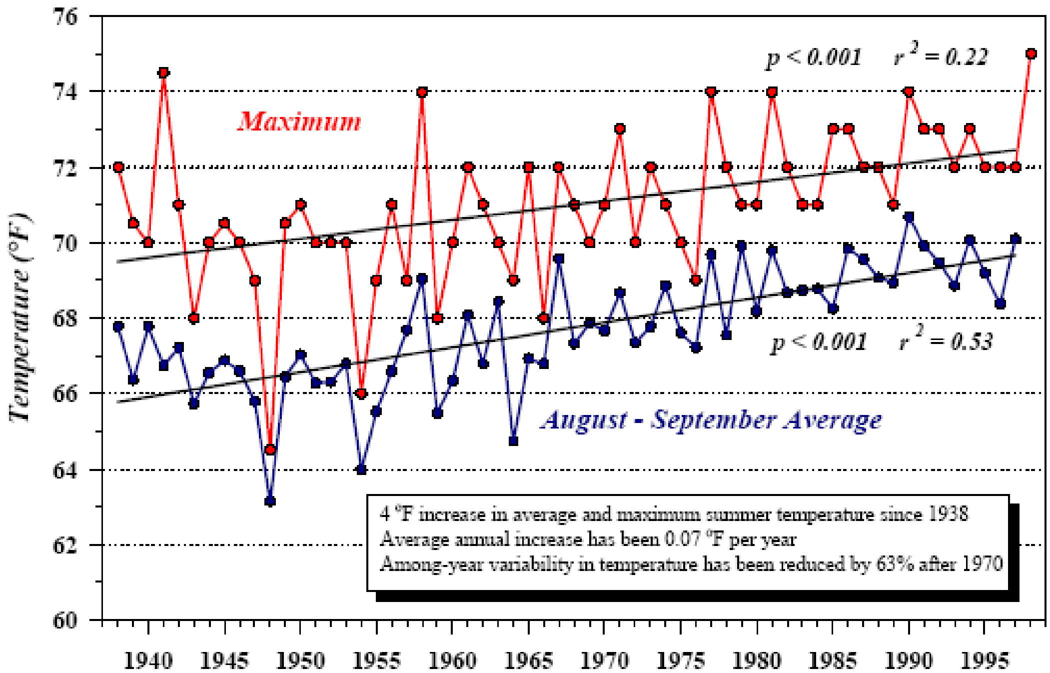

FIGURE 3-2
Temperatures of Water Entering the Estuary
(Reprinted from Lower Columbia Fish Recovery Board 2004.)

(Water temperatures of 20° C (68° F) are considered the upper thermal tolerance limit for cold-water species such as salmonids (National Research Council 2004). Pacific salmon can suffer adverse physiological and behavioral effects as a result of persistent, intermittent, or cumulative exposure to high water temperatures, or from increased daily variation in water temperature (McCullough 1999). Temperatures above 18° C (64.4° F) can impair the metabolism, growth, and disease resistance of salmonids, as well as alter the timing of adult migrations, fry emergence, and smoltification (McCullough et al. 2001, Sauter et al. 2001). Other effects of high water temperatures include adult mortality, reduced pre-spawning survival of eggs and sperm, difficulty competing with non-salmonid fish, prevention or reversal of smoltification, and harmful interactions with certain other habitat stressors (Marine 2004, McCullough 1999, Dunham et al. 2001, Materna 2001, McCullough et al. 2001, and Sauter et al. 2001). For example, the toxicity of some contaminants increases at high water temperatures, and levels of dissolved oxygen go down. Adult sockeye have been known to suffer stress and disease as they are exposed to warm water in estuaries, waiting for cool runoff conditions in their natal stream (Independent Scientific Advisory Board 2007). Warmer temperatures may also enhance conditions for warm-water fish that prey on or compete with juvenile salmonids (Independent Scientific Advisory Board 2007) and cause other changes in the estuarine food web.

During the next century, it is likely that global climate change will contribute to continued water temperature rises in the Columbia River basin as precipitation increasingly falls as rain rather than snow, snow pack diminishes, peak flows increase, and late-summer/early-fall flows are reduced (Independent Scientific Advisory Board 2007). (See Chapter 4 for more on the expected effects of global climate change in the Columbia River basin and estuary.)

Limiting Factor: Stranding

In the estuary, large ships passing through the navigational channel produce bow waves that crash against shorelines in Oregon and Washington. Small ocean-type fry and fingerlings rear within inches of shore and may become stranded as waves intersect the bank and recede (Ackerman 2002), although the extent of this problem is unclear. A 1977 study by Washington Department of Fisheries (WDF) observed 2,397 juvenile salmonids—mostly Chinook—stranded as a result of passage of 216 deep draft vessels (Bauersfeld 1977).

A NOAA technical memorandum (Hinton and Emmett 1994) published in 1994 concluded that the problem was not as significant as documented in the WDF report. Hinton and Emmett found only five juvenile salmonids stranded after observing 145 vessels. A third study, conducted for the U.S. Army Corps of Engineers, observed 21 juvenile Chinook salmon stranded at two sites (Ackerman 2002). In one occurrence, 10 juveniles were stranded by one vessel. As part of the channel deepening project being conducted by the U.S. Army Corps of Engineers, a two-part study of stranding was initiated by the University of Washington and the Portland District of the Corps. The study is designed to measure differences in stranding events before and after channel deepening activities. The first study was published in February 2006 (Pearson et al. 2006). In general, the report documents mortality attributed to stranding events for three test sites; it also builds on other work to determine the conditions that increase the likelihood of stranding events.

Early in 2008, the Port of Vancouver enlisted Entrix, Inc., to perform a spatial analysis of beach susceptibility for the stranding of juvenile salmonids by ship wakes (Pearson 2008). The study examined wave characteristics and the geomorphology of the lower river but did not examine nearshore fish density. The purpose of the study was to estimate the number of miles of shoreline that exhibit traits expected to potentially cause stranding. The study concluded that approximately 33 miles of shoreline between the mouth of the river and the city of Vancouver have shoreline characteristics consistent with stranding (Pearson 2008).

Food Web-Related Limiting Factors

Energy released from the Columbia River and the ocean converges in the estuarine and plume environments where, combined with the biological energy of primary plant production, it forms the basis for life in the estuarine ecosystem. Ultimately, energy that is transferred through the estuarine food web begins with sunlight; sunlight, minerals, and nutrients lead to plant growth in primary production; plants are eaten by animals and animals are preyed upon by other animals in secondary production; and dead plants, animals, and their material are broken down and re-integrated into the base of the food web. Salmon and other native species have evolved together in response to the basic inputs of energy and their circulation through the ecosystem. The result has been the development of an intricately structured food web in the estuary that encompasses food sources, food availability, and inter- and intra-species relationships. Alterations in any one of the elements of the food web, such as food sources or availability, can ripple throughout the ecosystem, reducing habitat capacity and having potentially far-reaching effects on salmonids and other species.

As part of the food web, decomposing materials known as detritus are consumed by juvenile salmonids, either directly or indirectly through other organisms that feed on the detritus (Northwest Power and Conservation Council 2004). There is evidence that a shift in the food base of the estuary—from macrodetrital to microdetrital—has significantly changed the food web and that complex inter- and intra-species relationships have been permanently altered (Northwest Power and Conservation Council 2004). Microdetrital sources favor production of planktonic copepods and other deep-water organisms that are not typically consumed by juvenile salmon (Bottom et al. 2005). Juvenile salmon that rear extensively in the estuary preferentially consume invertebrates from shallow-water and vegetated habitats, where decomposing plant tissue from emergent plants in estuarine wetlands creates macrodetritus (Bottom et al. 2005). Reductions of wetland and foraging habitat, simplification of habitats, and altered sediment inputs have contributed to the changes in detrital sources in the estuary. By disrupting the food web, these conditions have increased competition and predation (Bottom et al. 2005).

Most studies of prey preferences of juvenile salmon using the estuary focus on stream-type fish, which are less likely than ocean types to rear in estuarine habitats for extended periods. Studies that focus on ocean-type salmonids demonstrate that juvenile salmon appear to feed selectively within particular regions of the estuary (Bottom et al. 2005). In freshwater and brackish habitats, juvenile salmon feed extensively on emergent insects such as chironomids (midges) and epibenthic crustaceans such as mysid shrimp and gammarid amphipods (Macneale et al. 2009 and Miller and Simenstad 1997). Farther downstream in higher salinity portions of the estuary, salmon consume epibenthic crustaceans such as gammarid amphipods and harpaticoid copepods (Bottom et al. 2005). According to a University of Washington master’s thesis that demonstrated the importance of midge insects in the diet of juvenile Chinook salmon occupying shallow-water habitats in the Columbia River estuary, emerging chironomids were the dominant prey for Chinook of all sizes (Lott 2004). Additionally, the Oregon Department of Fish and Wildlife found migrating yearling Chinook actively feeding on daphnia. The same study found subyearling Chinook and coho feeding on daphnia year-round in the lower Willamette River (Friesen 2005).

Affected salmonids: Ocean-type ESUs are more likely than stream-type juveniles to be affected by food web alterations because of their use of estuary habitats and their longer residency times. Stream-type ESUs are more influenced in the plume environment because of reduced fine-sediment inputs leaving the estuary.

Food Source Changes

As described below, changes in the detrital sources that form the base of the estuarine food web have been significant and represent a limiting factor for salmonids. Figure 3-3 shows a conceptual model of the estuary food web developed by the U.S. Army Corps of Engineers. The historical tidal marsh macrodetritus-based food web is displayed at the top of Figure 3-3, while the current food web, which is based on imported microdetritus, is shown at the bottom.

Limiting Factor: Reduced Macrodetrital Inputs. The estuarine food web formerly was supported by macrodetrital inputs that originated from emergent, forested, and other wetland rearing areas in the estuary (Northwest Power and Conservation Council 2004). Today, detrital sources from emergent wetlands in the estuary are approximately 84 percent less than they were historically (Bottom et al. 2005). The reduction of macrodetritus in the estuary reduces the food sources for juvenile salmonids. As a result, juveniles may have reduced growth, lipid content, and fitness prior to ocean migration or may need to reside longer in the estuary.

Macrodetrital plant production has declined as a result of the construction of revetments along the estuary shorelines, the disposal of dredged material in what formerly were shallow or wetland areas where plant materials or insects could drop into the water, simplification of habitat through the removal of large wood, and reductions in flow. Flow reductions affect detrital sources by limiting the amount and availability of wetlands—areas that normally would be contributing macrodetritus to the food web—and cutting the number of overbank flows. Historically, much of the detrital inputs occurred during overbank events, which provided additional shallow-water habitat for juvenile salmonids and resulted in significant detrital inputs to the estuary. As mentioned earlier, overbank events occur much less frequently today than they did historically.

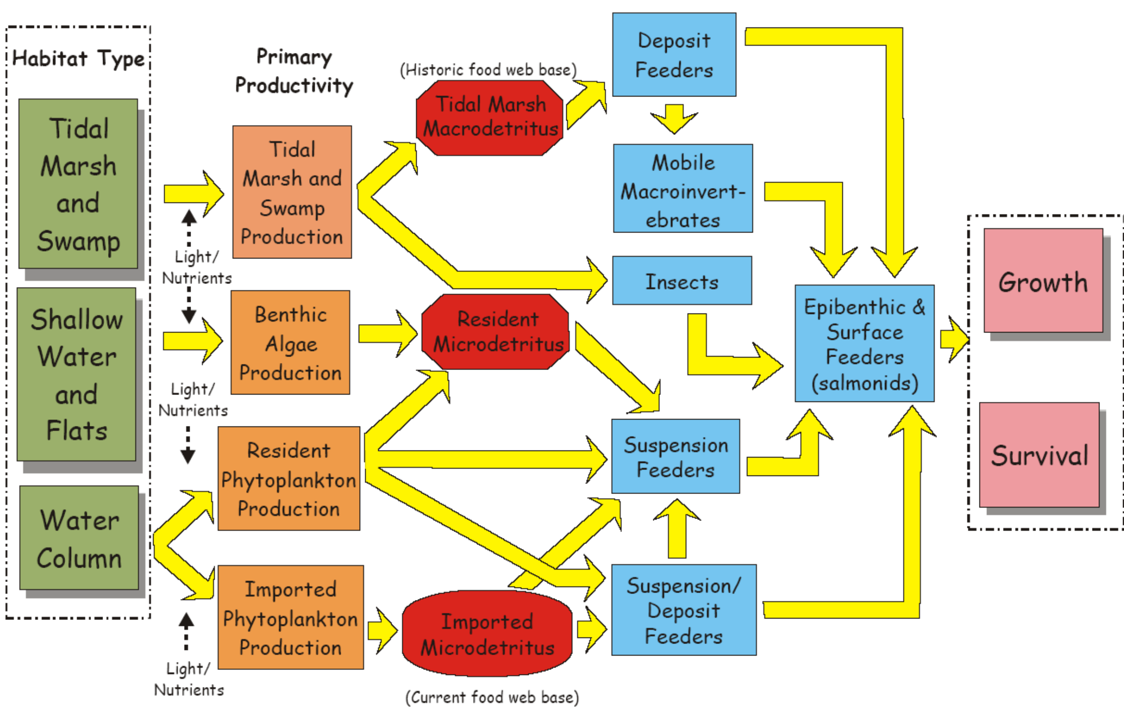

FIGURE 3-3
Conceptual Model of the Columbia River Estuary Food Web

Limiting Factor: Increased Microdetrital Inputs. The current food web is based on decaying phytoplankton delivered from upstream reservoirs and nutrient inputs from urban, industrial, and agricultural development. The amount of this microdetritus has increased dramatically (Bottom et al. 2005). The switch in the estuarine food web from a macrodetritus-based source to a microdetritus-based source has altered the productivity of the estuary (Bottom et al. 2005).

The substitution of detrital sources in the estuary also has contributed to changes in the spatial distribution of the food web (Bottom et al. 2005). Historically the macrodetritus-based food web was distributed evenly throughout the estuary, including in the many shallow-water habitats favored by ocean-type salmonids. But the contemporary microdetrital food web is concentrated within the estuarine turbidity maximum in the middle region of the estuary (Bottom et al. 2005). This location is less accessible to ocean-type ESUs that use peripheral habitats and more accessible to species such as American shad that feed in deep-water areas.

Pelagic fish such as shad may also benefit from the fact that the estuarine turbidity maximum traps particles and delays their transport to the ocean up to 4 weeks, compared to normal transport of around 2 days (Northwest Power and Conservation Council 2004). The estuarine turbidity maximum is thought to contain bacteria that attach to detritus. Together these represent the primary food source in the estuary today (Northwest Power and Conservation Council 2004).

Competition and Predation

Predation and competition for habitat and prey resources limit the success of juvenile salmonids entering the estuary and plume. Both spatial and energetic losses can involve either density-dependent or density-independent processes (Bottom et al. 2005). Spatial and temporal losses of habitat and large pulses of hatchery juveniles may, under some conditions, result in density-dependent salmonid mortality (Bottom et al. 2005).

Competition among salmonids and between salmonids and other fish may be occurring in the estuary (Lower Columbia Fish Recovery Board 2004), with the estuary possibly becoming overgrazed when large numbers of ocean-type salmonids enter the area. Food availability may be reduced as a result of the temporal and spatial overlap of juveniles from different locations (Bisbal and McConnaha 1998 as cited in Lower Columbia Fish Recovery Board 2004).

Ecosystem-scale changes in the estuary have altered the relationships between salmonids and other fish, birds, and mammal species, both native and exotic. Some native species' abundance levels have decreased from historical levels—perhaps to the point of extinction—while others have increased to levels far exceeding those in recorded history, with associated changes in predation of salmon and steelhead juveniles.

The presence of non-indigenous fish, invertebrates, and plants in species assemblages indicates major changes in aquatic ecosystems (Northwest Power and Conservation Council 2004). Globally the introduction of such species is increasing, a fact that is attributable to the increased speed and range of world trade, which facilitates the transport and release—whether intentional or not—of non-indigenous species (Northwest Power and Conservation Council 2004). In the estuary, the introduction of exotic species has altered the ecosystem through competition, predation, disease, parasitization, and alterations in the food web.

Non-native species affect ocean-type ESUs more than they do stream-type ESUs because of the ocean types' longer juvenile estuary residency times and use of shallow-water habitats.

Limiting Factor: Native Fish. The northern pikeminnow is a native piscivorous fish that preys on juvenile salmonids in the estuary. Although pikeminnows have always been a significant source of mortality for juvenile salmonids in the Columbia River, changes in physical habitats may have created more favorable conditions for predation (Northwest Power and Conservation Council 2004). These changes include reduced flows and favorable micro-habitats formed by pilings, pile dikes, and other over-water structures. The diet of pikeminnows varies with age, with the largest adults representing the biggest risk to juvenile salmonids. Both ocean-type ESUs and stream-type ESUs are affected, but for different reasons. Ocean-type juveniles are susceptible because of their longer estuary residency times and use of shallow-water habitats. Stream-type juveniles are susceptible because they are leaving faster, deeper water to forage for food in shallow areas that are frequented by pikeminnow.

Limiting Factor: Native Birds. As a result of estuary habitat modifications, the number and/or predation effectiveness of Caspian terns, double-crested cormorants, and a variety of gull species has increased (Fresh et al. 2005). In 1997 it was estimated that avian predators consumed 10 to 30 percent of the total estuarine salmonid smolt production in that year (Northwest Power and Conservation Council 2004). The 2007 season summary of *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River* (Roby et al. 2008) estimates that 5.5 million juvenile salmonids were consumed by terns in 2007. Stream-type juvenile salmonids are most vulnerable to avian predation by Caspian terns because the juveniles use deep-water habitat channels that have relatively low turbidity and are close to island tern habitats (Roby et al. 2008). Double-crested cormorants are estimated to have consumed an average of 7 million juvenile salmonids annually over the years 2001 to 2009. Cormorant predation has increased in the past several years and has been as high as 11 million, in 2009 (Fredricks 2010).

Limiting Factor: Native Pinnipeds. The abundance of native pinnipeds has steadily increased since passage of the Marine Mammal Protection Act in 1972. Harbor seals, Steller sea lions, and California sea lions all prey on salmon and steelhead in the estuary (Northwest Power and Conservation Council 2004). Diet studies indicate that pinnipeds consume both juvenile and adult salmonids. U.S. Army Corps of Engineers' annual estimates of adult mortality that occurs at Bonneville Dam because of pinnipeds (primarily California sea lions) ranged from 0.4 percent (2002) to 4.2 percent (2007) during the study period ending in 2010 (U.S. Army Corps of Engineers 2010).[5] Other, radio telemetry-based studies suggest that annual pinniped predation on spring Chinook and winter steelhead at Bonneville Dam may be as high as 8.5 percent and 20 percent, respectively (NMFS 2008b, Appendix G). These estimates do not account for pinniped mortality occurring downstream of Bonneville Dam. There are no official estimates of downstream mortality on adult spring Chinook and winter steelhead (both of which are stream-type salmonids); however, unsubstantiated estimates are as high as 10 percent.

Limiting Factor: Exotic Fish. At least 37 exotic fish species are now found in the Columbia River estuary (Northwest Power and Conservation Council 2004). American shad were introduced into the Columbia River in the 1880s, and adult returns now exceed 4 million in

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[5] Estimated consumption of adult salmonids ranged from a low of 1,010 in 2002 to a high of 6,081 in 2010; the percent of run consumed varied among reporting years because of changes in run size.

a single year (Northwest Power and Conservation Council 2004). While shad do not eat salmonids, they exert tremendous pressure on the estuary food web given the sheer weight of their biomass. Some evidence suggests that planktivorous American shad have an impact on the abundance and size of *Daphnia* in Columbia River mainstem reservoirs (Haskell et al. 2006 in Independent Scientific Advisory Board 2008), thereby reducing this important food source for subyearling fall Chinook. Other exotic fish in the estuary, such as smallmouth bass, walleye, and catfish, are piscivorous; however, their abundance levels are relatively small.

Limiting Factor: Introduced Invertebrates. Twenty-seven non-native invertebrate species have been observed in the estuary and documented by the Lower Columbia River Aquatic Non-indigenous Species Survey (Sytsma et al. 2004). Surveys have documented that the estuarine copepod community has changed from a system dominated by a single introduced species, *Pseduodiaptomis inopinus*, to a system dominated by two newly introduced Asian copepods: *Pseudodiaptomis forbesi* and *Sinoclaanus doerri* (Santen 2004). In some cases, the abundance of non-native invertebrates can alter food webs through their wide distribution and key role in the food chain (Northwest Power and Conservation Council 2004).

Limiting Factor: Exotic Plants. The introduction of non-indigenous plant species also has altered the estuary ecosystem. Exotic plant species often out-compete native plants, which results in altered habitats and food webs (Northwest Power and Conservation Council 2004). About 18 aquatic plants have been introduced into the estuary since the 1880s (Sytsma et al. 2004). Examples of non-indigenous plant species include purple loosestrife, Eurasian milfoil, parrot feather, and Brazilian elodea. In addition to out-competing native plants, introduced plant species can contribute to poor water quality and create dense, monospecific stands that represent poor habitat for native species (Northwest Power and Conservation Council 2004). In turn, these new plant communities may alter insect and detritus production in and around vegetated wetlands.

Toxic Contaminants

The quality of habitats and the food web in the Columbia River estuary is degraded as a result of past and current releases of toxic contaminants (Fresh et al. 2005, Lower Columbia River Estuary Partnership 2007), from both estuary and upstream sources. Historically, levels of contaminants in the Columbia River were low, except for some metals and naturally occurring substances (Fresh et al. 2005). Today, contaminant levels in the estuary are much higher, as the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from agricultural and urban sources (Fuhrer et al. 1996). With the cities of Portland, Vancouver, Longview, and Astoria on its banks, the Columbia River below Bonneville Dam is the most urbanized section of the river. In 2000, Portland Harbor was placed on the National Priorities List, which designates Superfund sites. Sediments in the river at Portland Harbor are contaminated with various toxic compounds, including metals, PAHs, PCBs, chlorinated pesticides, and dioxin (Oregon Department of Environmental Quality 2008). Work in recent decades has detected contaminants in aquatic insects, resident fish species, salmonids, river mammals, and osprey, reinforcing that contaminants are widespread throughout the estuary's food web (Tetra Tech 1996, Fuhrer et al . 1996, Lower Columbia River Estuary Partnership 2007).

Depending on concentration, exposure to toxic contaminants can kill aquatic organisms outright or have sublethal effects that compromise their health and behavior. Sublethal concentrations of contaminants affect the survival of aquatic species by increasing stress, decreasing fitness, predisposing organisms to disease, delaying development, and disrupting physiological processes such as reproduction and smoltification.

Acute lethal effects of toxic contaminants, such as fish kills in response to accidental discharges or spills, have been reported but are generally rare. However, research by the NMFS Northwest Fisheries Science Center has revealed some notable exceptions in which toxic contaminants may lead to the direct mortality of salmonids, such as the following situations:

- Coho pre-spawn mortality. For the past several years, NMFS has been documenting the recurrent die-offs of adult coho salmon returning to spawn in restored lowland urban streams in the Puget Sound Basin, at rates ranging from 30 to 90 percent of local coho runs (McCarthy et al. 2008). The weight of evidence to date suggests that pollutants in runoff from urban landscapes are causing the fish kills, and the phenomenon is correlated with high densities of roads and vehicle traffic. Based on findings from Puget Sound, coho spawners are likely at risk in urbanizing watersheds in the greater Columbia Basin (particularly the lower Columbia River).

- Synergistic toxicity of pesticide mixtures. A study by NMFS, in collaboration with Washington State University, has shown that common current-use pesticides (organophosphate and carbamate insecticides) produce unexpectedly synergistic toxicity and death in juvenile salmon following short-term exposure (Laetz et al. 2007). These agricultural pesticides are used in most of the major subbasins, and they reach rearing and migration habitats for salmon via spray drift, surface runoff, and irrigation return flows. In a 10-year study by the U.S. Geological Survey, Gilliom (2007) found that mixtures of pesticide compounds are prevalent in streams in watersheds that are dominated by agricultural, urban, or mixed land use.

- Salmon egg mortality. Increased mortality has been observed in salmon eggs exposed to PAHs in oil, such as at sites in Alaska following the Exxon Valdez oil spill (Heintz et al. 1999, Carls et al. 2005). An unpublished study by NMFS suggests that salmon embryos incubated in urban stream water also show relatively high rates of developmental defects and mortality when compared to embryos raised in the same water passed though an in situ streamside filtration system. At this time, the contaminants in the urban stream water are unidentified contaminants that are toxic to salmon embryos and likely pose an important early life stage threat to salmon in urbanizing watersheds.

Although the lethal effects described above are of concern, sublethal effects of contaminants are probably the greatest threat to juvenile salmon in the Columbia River. In juvenile salmonids, contaminant exposure can result in decreased immune function and generally reduced fitness (Northwest Power and Conservation Council 2004, Arkoosh and Collier 2002). Exposure can also impair growth, development, and reproduction and disrupt olfaction; salmonids depend on olfaction for migration, imprinting on natal streams, homing, and detecting predators, prey, potential mates, and spawning cues. These sublethal effects of contaminant exposure may indirectly increase mortality from other factors like infectious disease, parasites, predation, exhaustion, and starvation by suppressing salmonid immune systems and impairing necessary behaviors such as swimming, feeding, responding to stimuli, and avoiding predators (Lower Columbia River Estuary Partnership 2007). Contaminants that affect growth can have significant effects. Juvenile growth is necessary for ocean survival (Zabel and Williams 2002 as cited in Lower Columbia River Estuary Partnership 2007), and adult fish size has been correlated to reproductive success and egg size (Healey and Heard 1983, Beacham and Murray 1987). Low lipid content, which has been observed in outmigrating juvenile Chinook salmon in the Columbia River estuary (Johnson et al. 2007b, Lower Columbia River Estuary Partnership 2007), is another sign of poor growth that is correlated with an increased risk of juvenile mortality (Biro et al. 2004). Thus, toxic contaminants that impair salmonid growth can reduce juvenile survival, adult returns, and individual reproduction. Although many effects of contaminants require an exposure period of weeks to months, some impacts, especially those on behavior, can occur very quickly. For example, effects of pesticides and copper on the salmon olfaction system can be seen after exposure periods of only a few hours (Sandahl et al. 2004 and 2007, Hecht et al. 2007).

Toxic contaminants can also indirectly affect salmon via the food web, especially prey such as aquatic and terrestrial insects. Insect bodies accumulate contaminants, which salmon in turn ingest when they consume insects. Additionally, many toxic contaminants are specifically designed to kill insects and plants, reducing the availability of insect prey or modifying the surrounding vegetation and habitats. The availability of prey species is one of the primary determinants of salmonid growth, and reductions in the prey base can affect salmonid survival and productivity (Chapman 1966 and Mundie 1974 as cited in Lower Columbia River Estuary Partnership 2007). Changes in vegetative habitat can shift the composition of biological communities; create favorable conditions for invasive, pollution-tolerant plants and animals; and further shift the food web from macrodetrital to microdetrital sources.

A study by Loge et al. (2005) in the Columbia River will likely bring more attention to the effects of contaminants on salmonids in the estuary. The study documents infectious disease in outmigrating juvenile salmonids attributed to abiotic stressors, such as chemicals, that influence host susceptibility to infection. The study estimates disease-induced mortalities in Chinook salmon related to exposure to contaminants at 1.5 percent and 9 percent for estuary residence times of 30 to 120 days, respectively (Loge et al. 2005).

Other contaminants, including endocrine-disrupting substances such as synthetic hormones, are beginning to be characterized in the estuary, and these contaminants could have substantial effects on salmon and steelhead (Fresh et al. 2005). A study by the Lower Columbia River Estuary Partnership, aided by NMFS and the U.S. Geological Survey, found emerging contaminants such as caffeine, acetaminophen, and human and veterinary antibiotics in the water column of the estuary and evidence of exposure to estrogenic compounds in the blood of juvenile Chinook salmon (Lower Columbia River Estuary Partnership 2007). Several suspected hormone disruptors were detected in the water column, including bisphenol A (a plasticizer), HHCB (a synthetic musk), and polybrominated diphenyl ethers (PBDEs, which are synthetic flame retardants used in everyday products like plastic, cushions, and fabrics). Although some forms of PBDEs have been banned, PBDE concentrations in the environment have increased exponentially during recent decades. In the Columbia River estuary, they have been found in the water column, on suspended sediment, and in the tissue and stomach contents of juvenile Chinook salmon, which indicates that salmon prey also are contaminated (Lower Columbia River Estuary Partnership 2007). PBDEs are similar to PCBs in their chemical structure and sublethal effects, such as neurotoxicity and hormone disruption.

Affected salmonids: Contaminant exposure by stream-type and ocean-type salmon likely reflects contaminants present in rearing habitats. Stream-type salmon are apt to have contaminant loads that reflect conditions in the upper Columbia River and its tributaries, while ocean-type salmon are apt to have loads that reflect conditions in the lower river and estuary (Leary et al. 2006, Johnson et al. in prep, Dietrich et al in prep a). It is likely that both stream-type and ocean-type juvenile salmonids are affected by short-term exposure to waterborne contaminants such as organophosphate pesticides and dissolved metals that can have acute effects on salmon olfactory function and behavior (Fresh et al. 2005, Johnson et al. in prep a), and both types could be affected by bioaccumulative legacy pesticides, such as DDTs, that are present throughout the Columbia Basin. Additionally, ocean-type juveniles likely experience adverse effects and possibly mortality from urban and industrial bioaccumulative toxics such as PCBs and PBDEs that are present in the Columbia River estuary and are absorbed during longer estuarine residence times (Fresh et al. 2005). Both life history types could be affected by contaminant impacts on prey resources (Johnson et al. in prep). Preliminary data tend to support the hypothesis that contaminant body burdens are generally higher in ocean-type stocks than in stream-type stocks (Johnson et al. 2007a) and higher in outmigrating subyearling Columbia River Chinook than in yearlings, especially for industrial contaminants such PCBs and PBDEs that are present at higher concentrations in the Columbia River estuary (Lower Columbia River Estuary Partnership 2007, Dietrich et al. 2008). However, more work is needed on contaminant uptake and impacts on salmon of different stocks and life history types.

Limiting Factor: Bioaccumulation Toxicity. Bioaccumulative and potentially toxic waterborne contaminants, trace metals, and chlorinated compounds have been observed in the estuary (Fuhrer et al. 1996, Fresh et al. 2005, Lower Columbia River Estuary Partnership 2007). DDT and PCBs have been detected in juvenile salmon from the estuary at concentrations above threshold levels for health effects, and in salmon stomach contents and water quality samples from sites throughout the estuary (Lower Columbia River Estuary Partnership 2007). DDT, PCBs, and trace metals such as copper all bioaccumulate and concentrate in animals near the top of the food chain.

Loge et al. (2005) estimated disease-induced, contaminant-related mortalities at 1.5 percent and 9 percent for juvenile Chinook residing in the Columbia River estuary for 30 to 120 days, respectively (Loge et al. 2005). Figures 3-4 and 3-5 show concentrations of PCBs and DDTs found in the stomach contents of subyearling fall Chinook in several locations of the Columbia River estuary, other Pacific Northwest sites, and hatcheries.

Limiting Factor: Non-Bioaccumulative Toxicity. A variety of organochlorines (including trichlorobenzene, the insecticides aldrin and dieldrin, and PAHs) in the estuary are above state and Federal guidance levels (Northwest Power and Conservation Council 2004). These contaminants tend not to bioaccumulate in salmon and steelhead (although PAHs do bioaccumulate in invertebrates), but they are readily absorbed and can have sublethal effects. Copper also was detected in juvenile salmon, at concentrations that can impair olfaction (Lower Columbia River Estuary Partnership 2007). In addition, copper can interact with other toxic contaminants—mercury, aluminum, iron, and certain pesticides—to cause synergistic effects, such that the combined toxicity is greater than the toxicity predicted based on the sum of the contaminants present (Eisler 1998 as cited in Lower Columbia River Estuary Partnership 2007).

As mentioned above, sublethal concentrations of contaminants can affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes (Northwest Power and Conservation Council 2004). Exposure to PAHs may be a particular problem for salmon in the urbanized portions of the estuary, as these contaminants are very common in stormwater as well as in industrial discharges. Although salmonids can break down PAHs, the metabolites of PAHs can be mutagenic and carcinogenic, especially in cases of chronic exposure. PAHs also can contribute to immune dysfunction in juvenile salmon (Arkoosh and Collier 2002, Bravo et al. 2008) and cause alterations in growth and metabolism that could increase the risk of mortality (Meador et al. 2006 and 2008). Figure 3-6 shows concentrations of PAHs in the stomach contents of subyearling fall Chinook in various locations of the Columbia River estuary, other Pacific Northwest sites, and hatcheries.

One study detected numerous currently used pesticides present in water quality samples from sites throughout the estuary, with the most frequently detected pesticides being the suspected hormone disruptors atrazine, simazine, and metolachlor (Lower Columbia River Estuary Partnership 2007). Exposure to individual pesticides has sublethal effects on salmon behavior, interfering with predator avoidance, altering homing and migration, and reducing egg fertilization. Health effects include reduced olfactory function, impaired growth, and immune suppression. Pesticides also can be toxic to salmon prey.

Although the concentrations of the individual pesticides detected in the study were lower than threshold levels for health effects in juvenile salmonids, pesticides often were found in combination (Lower Columbia River Estuary Partnership 2007). This is of concern because some pesticides are known to have additive effects. For example, when common pesticides such as diazinon, chlorpyrifos, and carbaryl occur together, even if each is at a relatively low concentration, their combined concentration can have toxic effects on fish and wildlife (Scholz et al. 2006 as cited in Lower Columbia River Estuary Partnership 2007). Among salmonids, carbamate and organophosphate pesticides can have additive effects on olfactory function (Scholz et al. 2006 as cited in Lower Columbia River Estuary Partnership 2007). Some studies suggest that synergistic effects may also be occurring when current-use pesticides occur together in the environment (Anderson and Zhu 2004 and Denton et al. 2003 as cited in Lower Columbia River Estuary Partnership 2007). This is a reminder that the effects of toxic contaminants in the estuary may not be directly proportional to measured concentrations.

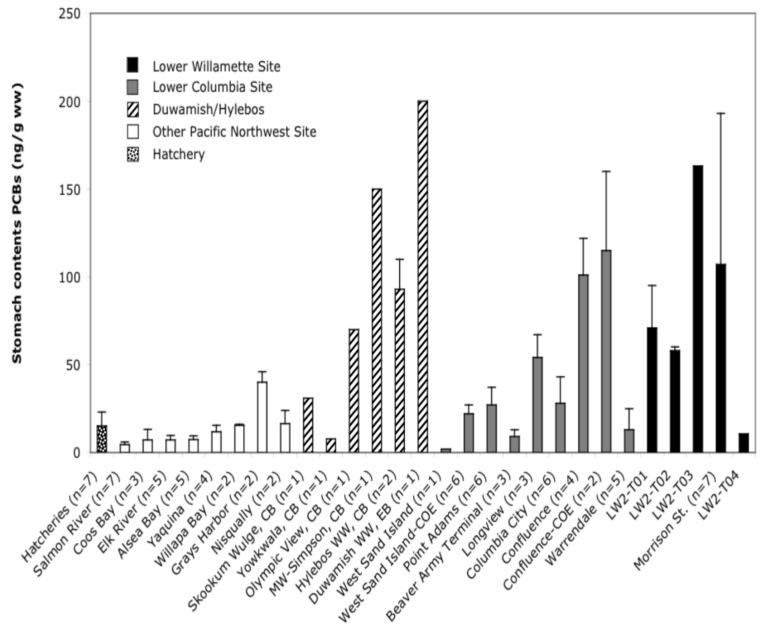

FIGURE 3-4

Concentrations of PCBs in the Stomach Contents of Subyearling Fall Chinook

(From Johnson et al. 2007a and 2007b, Lower Columbia River Estuary Partnership, Olson et al. 2008, Stehr et al. 2000, and Lower Willamette Group 2007)

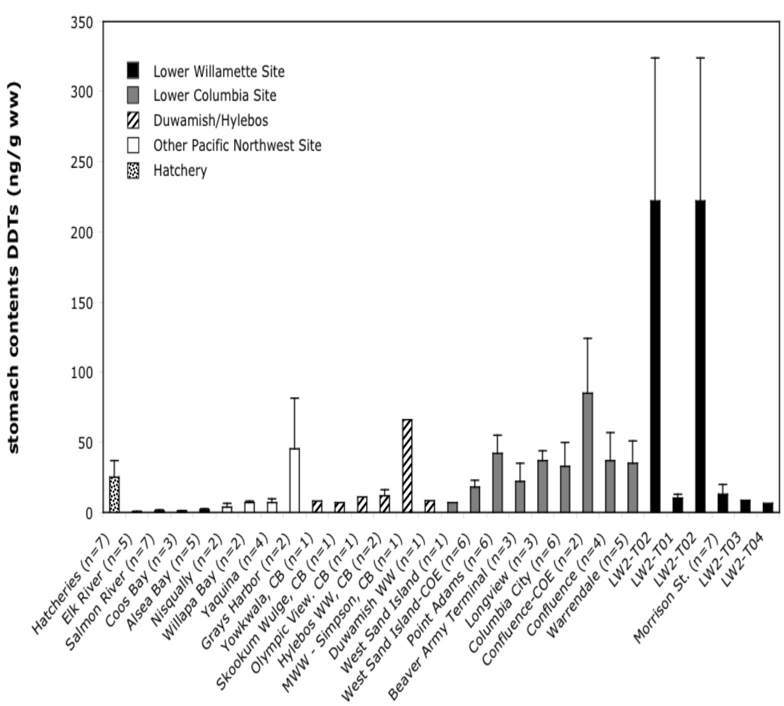

FIGURE 3-5

Concentrations of DDTs in the Stomach Contents of Subyearling Fall Chinook

(From Johnson et al. 2007a and 2007b, Lower Columbia River Estuary Partnership, Olson et al. 2008, Stehr et al. 2000, and Lower Willamette Group 2007)

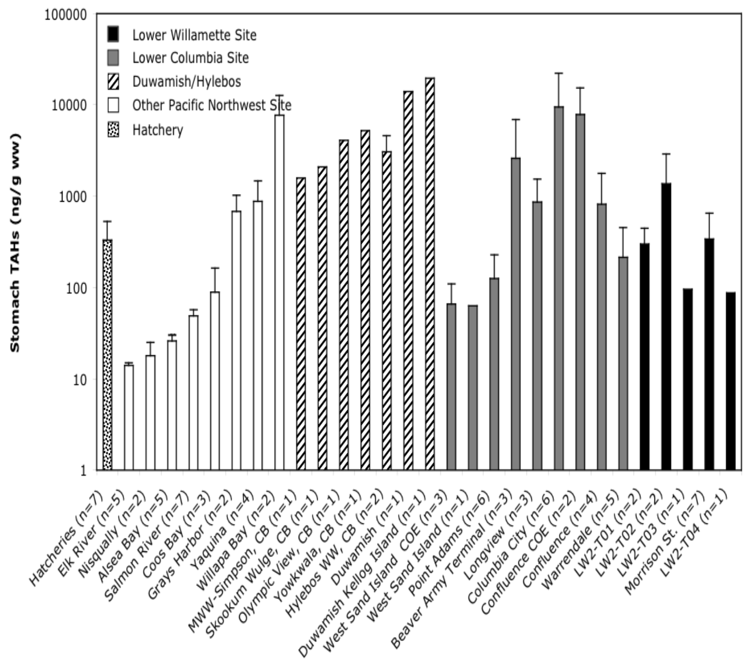

FIGURE 3-6
Concentrations of Total Aromatic Hydrocarbons (PAHs) in the Stomach Contents of Subyearling Fall Chinook

(From Johnson et al. 2007a and 2007b, Lower Columbia River Estuary Partnership, Olson et al. 2008, Stehr et al. 2000, and Lower Willamette Group 2007)

Habitat Opportunity, Habitat Quality, and Synergistic Effects

A lack of habitat opportunity and reduced habitat quality both play a role in limiting the viability of salmon and steelhead in the Columbia River estuary. In terms of habitat opportunity, changes in the timing and volume of Columbia River flows, combined with higher bankfull elevations, have reduced the amount and accessibility of in-channel, off-channel, and plume habitat. Overbank flooding that normally would aid juveniles in accessing off-channel refugia and food resources has been virtually eliminated, and sediment transport processes that structure habitat have been impaired.

Meanwhile, the quality of the habitat available to salmon and steelhead in the estuary has been compromised. Water temperatures are relatively high for cold-water species such as salmon and steelhead and are expected to continue to climb. Researchers have found a variety of toxic contaminants in water, sediments, and salmon tissue in the estuary. With changes in vegetation and flow, juvenile salmonids' traditional macrodetrital food sources have become scarcer and the food base has switched to a microdetritus-based source, thus altering the productivity of the estuary. Predation by northern pikeminnow, pinnipeds, Caspian terns, and cormorants has increased, and it is likely that the presence of native and exotic fish, introduced invertebrates, and invasive plant species is further altering food web dynamics. These and other changes in habitat quality make the estuary a very different place for salmon and steelhead than it was historically.

Habitat quality often is influenced by features that this analysis considers aspects of habitat opportunity, such as river flow and sediment processes. As one example, alterations in flow have eliminated much of the vegetated wetlands that ordinarily would supply insect prey for juvenile salmonids and macrodetrital inputs to the estuarine food web. In some cases it may not be not be possible to improve habitat quality without reducing limiting factors related to habitat opportunity. Likewise, it may be necessary to address habitat quality issues, such as toxic contaminants, before increasing access to habitat that could be contaminated.

This type of interplay between habitat opportunity and habitat quality is a reminder of how connected limiting factors in the estuary are, even though this chapter describes them discretely. It is possible that some of the limiting factors have synergistic effects, in which the cumulative negative impact of two or more limiting factors is greater than the sum of the impacts of the individual limiting factors. This likely is the case with flow reductions and increases in bankfull elevation, which combine to limit juveniles' access to off-channel habitats. Although synergistic effects are difficult to identify and quantify, the estuary recovery plan module assumes that they exist and that they can be taken advantage of to enhance the beneficial impacts of management actions in the estuary. Chapter 7 addresses the implications of potential synergistic effects more directly.

Prioritization of Limiting Factors

This estuary recovery module uses a 1-to-5 rating system to prioritize limiting factors by ocean- and stream-type salmon and steelhead, at the estuary scale. PC Trask & Associates, Inc., performed an initial prioritization, based on a synthesis of the three main literature sources (Bottom et al. 2005, Fresh et al. 2005, and Northwest Power and Conservation Council 2004), supplemented by additional literature. (See the discussion of each limiting factors for specific source material.) Staff from the Lower Columbia River Estuary Partnership, NMFS Northwest Fisheries Science Center, NMFS Northwest Regional Office, and Lower Columbia Fish Recovery Board reviewed and provided input on the prioritization.

All three of the main literature sources used in this estuary recovery module identify flow, sediment, water quality, and food web alterations as limiting factors. *Salmon at River's End* (Bottom et al. 2005) analyzes each of the limiting factor categories in the context of habitat opportunity and capacity and how the limiting factor fits within the member/vagrant conceptual framework. The Fresh technical memorandum evaluates selected limiting factors (tern predation, toxics, habitat, and flow) for their impacts on ocean- and stream-type ESUs (Fresh et al. 2005). Finally, the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" and its supplement (Northwest Power and Conservation Council 2004) evaluate limiting factors for their impacts to salmonids and the level of certainty that the factor is limiting. Of the limiting factors identified in this module, the only one not identified in at least one of the three main documents is stranding, which the author researched at the suggestion of Washington Department of Fish and Wildlife staff.

In prioritizing limiting factors, the author considered the following: (1) how the three main literature sources evaluated and/or prioritized limiting factors, (2) the magnitude or severity of limiting factors as described in the source documents, (3) estimates of mortality caused by a limiting factor, which were available only for predation-related limiting factors, and (4) the frequency with which a limiting factor was identified in the source documents.

Limiting factors were prioritized individually, without trying to account for potential negative synergistic effects, which are difficult to evaluate.

Table 3-1 shows the results of the limiting factor rating process. Each limiting factor received two scores—one for ocean-type salmonids and one for stream-type salmonids. One simplifying assumption in scoring is that both ocean- and stream-type salmonids express a diversity of life history strategies within ESUs and their constituent populations. Relative scores between ocean- and stream-type salmonids generally reflect the dominant life history stage by providing extra weight to the dominant life history strategy; however, less dominant strategies are considered. For example, reduced off-channel habitat is primarily a limiting factor for ocean-type juveniles because the dominant life history strategy is subyearlings that use shallow-water habitats extensively to feed and rear. However, some ocean-type populations and subpopulations also express a yearling strategy as part of the overall genetic makeup of the population. As a result, both ocean- and stream-type salmonids received scores (albeit lower) for other less dominant life history strategies. The far right-hand column of the table is the total score, which adds ocean- and stream-type impact scores into a single composite score. The assumption that within healthy ESUs there is expression of less-dominant life history strategies is central to *Salmon at River's End* (Bottom et al. 2005) and the Fresh technical memorandum.

Table 3-2 organizes limiting factors into groups based on total score. Top-priority limiting factors are those that have the greatest impact on both ocean- and stream-type ESUs, while lowest priority limiting factors have the least combined impact to ocean- and stream-type ESUs. An important assumption in the rating system is that all limiting factors had an effect on one or both ESU types.

The prioritization of limiting factors in this module should be considered a working hypothesis to be tested and refined through research and evaluation (including a formal expert opinion, or "Delphi," process). Future planning efforts would also be enhanced by a limiting factors analysis at the reach or sub-reach scale, although information is generally not available at this time to consistently identify limiting factors at these finer scales. (In Chapter 5, priority reaches are identified for the 23 management actions.)

Summary

The identification of limiting factors in the Columbia River estuary is well supported in a variety of literature sources, although additional research is needed to understand the relative impacts of the limiting factors and their interactions. Source documents take different approaches to lumping limiting factors together or splitting them apart for the purposes of evaluation, but all of the documents generally agree that channel confinement and alterations to flows and sediment have significantly degraded the estuary ecosystem in far-reaching ways. Water quality and food web limiting factors also are well documented.

The interconnectedness of these limiting factors suggests the use of ecosystem-based analysis to understand more exactly their effects on salmonids; however, at this point modeling efforts cannot fully explain the complex relationships among limiting factors.

The next chapter examines human actions and natural events that cause or contribute to the limiting factors described in Chapter 3.

TABLE 3-1
Impact of Limiting Factors on Ocean- and Stream-Type Salmonids

Limiting Factor	Level of Impact		
	Ocean Type*	Stream Type*	Total Score
Habitat-Related Limiting Factors			
Reduced in-channel habitat opportunity			
Flow-related estuary habitat changes	5	3	8
Sediment/nutrient-related estuary habitat changes	4	3	7
Reduced off-channel habitat opportunity			
Flow-related changes in access to off-channel habitat	5	3	8
Bankfull elevation changes	5	2	7
Reduced plume habitat opportunity			
Flow-related plume changes	3	5	8
Sediment/nutrient-related plume changes	2	3	5
Water temperature	5	3	8
Stranding	3	2	5
Food Web-Related Limiting Factors			
Food Source Changes			
Reduced macrodetrital inputs	5	3	8
Increased microdetrital inputs	3	2	5
Competition and Predation			
Native fish	3	3	6
Native birds	2	5	7
Native pinnipeds	2	5	7
Exotic fish	2	2	4
Introduced invertebrates	2	2	4
Exotic plants	2	2	4
Toxic Contaminants			
Bioaccumulation toxicity	4	2	6
Non-bioaccumulative toxicity	4	3	7

*Significance of limiting factor to life history strategy:
1 = No likely effects.
2 = Minor effects on populations.
3 = Moderate effects on populations.
4 = Significant effects on populations.
5 = Major effects on populations.

TABLE 3-2
Limiting Factor Prioritization

Limiting Factor	Limiting Factor Score[a]	Limiting Factor Priority[b]
Flow-related estuary habitat changes	8	Top
Flow-related changes in access to off-channel habitat	8	
Flow-related plume changes	8	
Water temperature	8	
Reduced macrodetrital inputs	8	
Sediment/nutrient-related estuary habitat changes	7	High
Bankfull elevation changes	7	
Native birds	7	
Native pinnipeds	7	
Non-bioaccumulative toxicity	7	
Native fish	6	Medium
Bioaccumulation toxicity	6	
Sediment/nutrient-related plume changes	5	Low
Stranding	5	
Increased microdetrital inputs	5	
Exotic fish	4	Lowest
Introduced invertebrates	4	
Exotic plants	4	

[a]From Table 3-1.
[b]Limiting factors have been prioritized in groups, rather than individually, to avoid a false sense of precision in this qualitative analysis.

CHAPTER 4

Threats to Salmonids

Chapter 4 identifies and prioritizes threats to ESUs in the Columbia River basin. Threats are the human actions or natural events, such as volcanic eruptions or floodplain development, that cause or contribute to limiting factors (Gaar 2005). Threats may be caused by past, present, or future actions or events.

PC Trask & Associates, Inc., identified and prioritized threats using the same process and sources used to identify and prioritize limiting factors—that is, a thorough review and synthesis of pertinent literature (particularly Bottom et al. 2005, Fresh et al. 2005, and Northwest Power and Conservation Council 2004), supplemented with input from staff at the NMFS Northwest Fisheries Science Center and Northwest Regional Office, Lower Columbia River Estuary Partnership, and Lower Columbia Fish Recovery Board. The module's three key source documents and a number of other sources document both limiting factors and threats. In most cases the literature addresses limiting factors and threats together, and it required substantial effort to separate them for the purposes of this estuary recovery plan module.

The one threat presented in this chapter that the three main source documents do not mention is ship wakes, which can cause stranding of juvenile salmonids. Although the topic of stranding was first raised in a 1977 report (Bauersfeld 1977), the extent of stranding remains unclear. Washington Department of Fish & Wildlife staff suggested that the topic be addressed in this recovery plan module.

The relationship between limiting factors and threats is not necessarily one-to-one. A single threat can contribute to several limiting factors, and in many cases a limiting factor exists because of the effects of multiple and varied threats. (Table 4-1, which is presented later in this chapter, shows the linkages between the limiting factors in Chapter 3 and the threats described in Chapter 4.) For ease of understanding, this chapter organizes threats to salmonids into the following groupings: flow, sediment, structures such as dikes and jetties, ship wakes, food web (including species relationships), and water quality in the estuary. The presentation of threats as discrete activities or phenomena is an oversimplification of complex physical and biological relationships that affect salmon survival. The threats related to flow, sediment transport, and food webs are particularly difficult to tease apart and discuss discretely. Thus the reader should bear in mind that describing threats individually does not fully capture the dynamic interplay of forces that are currently putting salmonids in the estuary at risk. The complexity of these forces is illustrated in Figure 4-1, which is a representation of a conceptual model of the Columbia River estuary developed by the U.S. Army Corps of Engineers (Diefenderfer et al. 2005). The model provides in-depth detail on the relationships between limiting factors and threats.

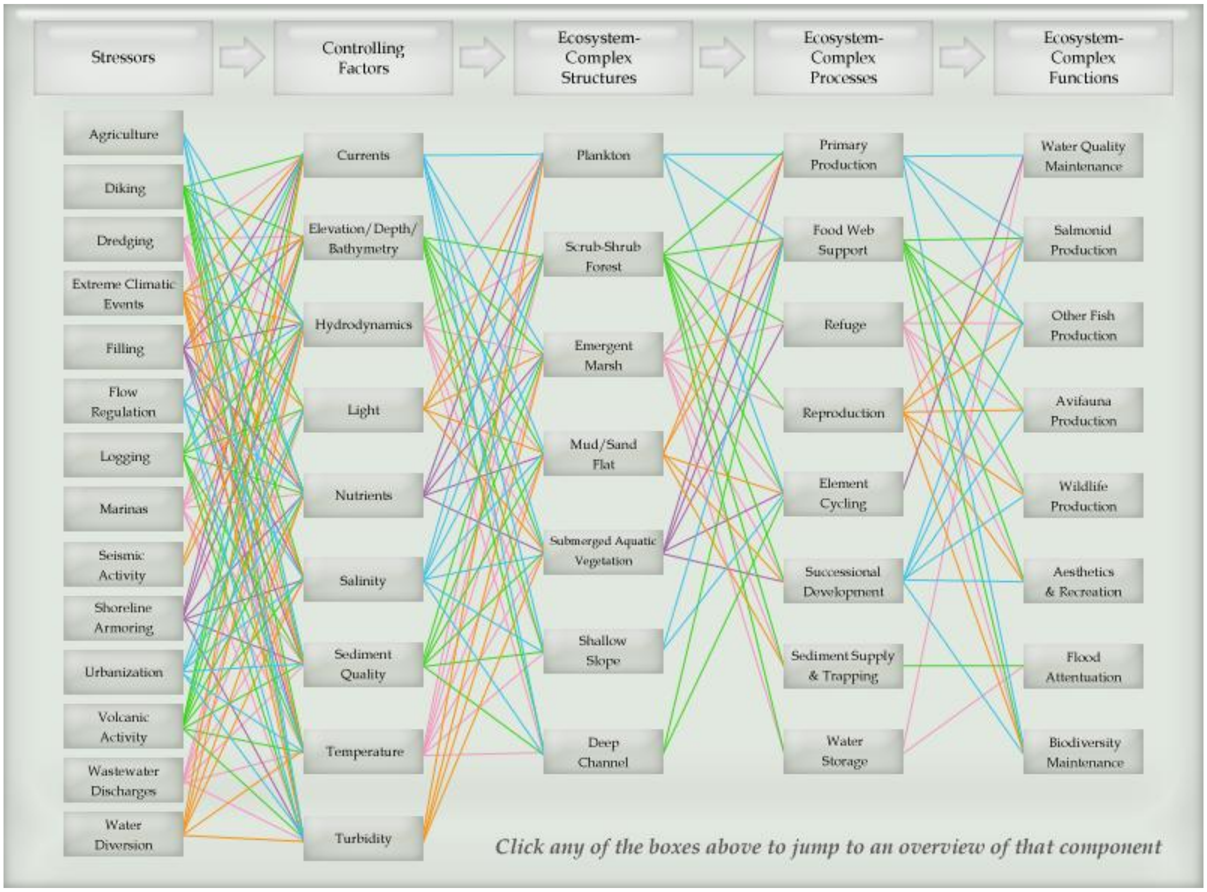

FIGURE 4-1
Conceptual Model of the Columbia River Estuary
(Note: "Stressors" are equivalent to threats as defined in this module.)
(Figure provided courtesy of the U.S. Army Corps of Engineers.)

Most of the human threats described in this chapter are the result of the cumulative impacts of European Americans living in the Northwest. From an ecological perspective these impacts have taken place relatively quickly. Consider that in 1770, when American Robert Gray first crossed the Columbia River bar, about 100,000 Native Americans lived in the Columbia River basin (Oregon State University 1998). Today the population of the Columbia Basin is approximately 5 million (National Research Council 2004). In the early years of Euro-American settlement, the area's abundant natural resources supported farming, mining, logging, fishing, and other activities that modified the landscape into productive uses for people. Later, the availability of cheap hydroelectric power helped fuel expanded agriculture, manufacturing, and development and the rise of urban centers such as Portland. The impacts of these activities on salmonids in the estuary have been substantial.

Flow-Related Threats

Over the last 4,000 years, salmon thrived in the Columbia River by adapting to habitats created by characteristics of the land and water flow (Fresh et al. 2005). Key attributes of flow include magnitude and timing, both of which have changed significantly in the

Columbia River over the last two centuries. Today the mean flow to the estuary is about 16 percent less than it was in the latter part of the nineteenth century (Jay and Kukulka 2003), and spring freshet peak flows have declined about 44 percent in that same time period (Jay and Kukulka 2003). In addition, the timing of peak flows occurs about 14 to 30 days earlier than it did historically (Jay and Kukulka 2003). Reductions in the spring freshet flows are shown in Figure 4-2, which presents simulated mean monthly discharge at Bonneville Dam before development of the hydrosystem and under current hydrosystem configurations and operations.

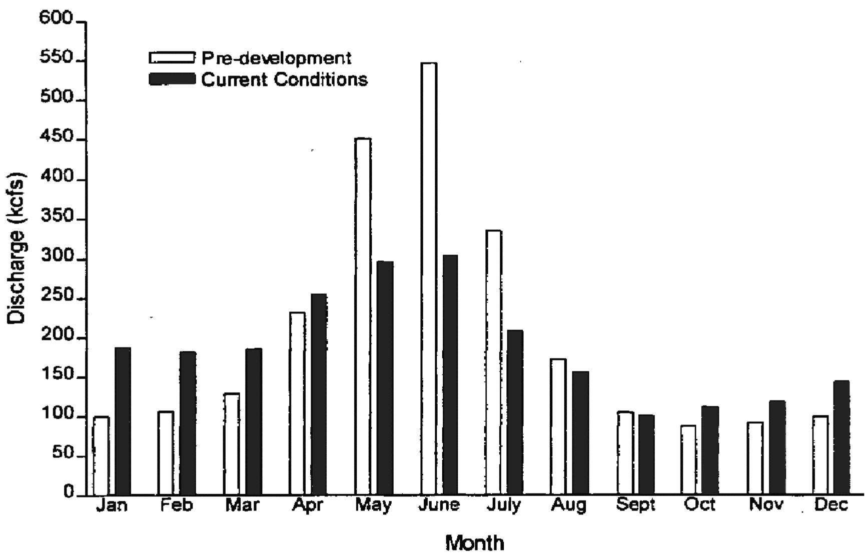

FIGURE 4-2
Changes in the Annual Columbia River Flow
(Adapted from National Marine Fisheries Service 2000.)

Flow alterations, in connection with other factors, can increase or decrease salmonids' ability to access habitats and the capacity of habitats to sustain salmonids (Bottom et al. 2005). In the case of the Columbia River, alterations in the timing, magnitude, and duration of flows are responsible for dramatic changes in habitat opportunity and capacity in the estuary, including effects on groundwater recharge, cold-water upwelling, flooding, off-channel habitat quality and quantity, and water quality. Climate fluctuations, the withdrawal of water, and regulation of river flow have altered the amount and timing of instream flows entering the estuary and plume.

Affected salmonids: Alterations in the magnitude and timing of Columbia River flows affect both ocean- and stream-type juvenile salmonids. Ocean-type juveniles spend more time in the estuary, where they rely on shallow vegetated marsh habitats and upland swamp habitats (Northwest Power and Conservation Council 2004). Chum salmon (ocean-type) also spawn in the mainstem and are affected by low flows during the spawning and egg incubation life stages. In extreme cases, redds may have been dewatered; however, a minimum flow now has been administratively set from November through April to reduce the potential for dewatering of chum redds located immediately below Bonneville Dam. Ocean-type salmonids also rely on seasonal overbank flows to access habitats and preferred food sources.

Stream-type juveniles do not spend much time in the estuary, but research indicates that they may use the Columbia River plume habitat as they adjust to saltwater conditions (Fresh et al. 2005). Columbia River flows have a direct effect on the plume's surface area, volume, frontal features, and extent offshore (Fresh et al. 2005). Flow alterations also affect sediment transport processes and water quality.

Threat: Climate Cycles and Global Climate Change

Natural variations in Columbia River flow as a result of long- and short-term climate fluctuations have occurred throughout history. The Pacific Decadal Oscillation (PDO) alternates between cold and warm phases approximately every 30 years (Fresh et al. 2005). The cold, rainy phase is typical of the Northwest and increases flows, while the warm phase is drier and decreases flows (Fresh et al. 2005). The El Niño/Southern Oscillation (ENSO) is a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that may magnify or reduce the effects of the PDO.

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Since 1878, climatic changes have reduced Columbia River flows by 9 percent (Jay and Kukulka 2003). The NMFS Northwest Fisheries Science Center has observed changes in PDO and ENSO indicators that suggest that changes in ecosystem structure can be expected that are unfavorable for salmon and steelhead (Varanasi 2005). These changes may continue over the next several years.

Scientists believe that the release of high levels of carbon dioxide as a result of human activities is contributing to global climate change. The source of these releases includes the use of fossil fuels to run cars, heat homes and offices, and power factories. Over the past century, global climate change has caused sea levels to rise about 4 to 5 inches (10 to 13 centimeters), worldwide precipitation to increase by about 1 percent, and the frequency of extreme rainfall events to increase in much of the United States (U.S. Environmental Protection Agency 2005). Sea level rise is predicted to accelerate worldwide in the coming decades as a result of global climate change (Intergovernmental Panel on Climate Change 2007). The Intergovernmental Panel on Climate Change has observed that sea levels rose at an average rate of 1.8 millimeters per year from 1961 to 2003 and may be 0.18 to 0.59 meter (0.6 to 1.9 feet) higher at the end of the 21st century than they were during the baseline period of 1980 to 1999 (Intergovernmental Panel on Climate Change 2007).

The Independent Scientific Advisory Board for the Northwest Power and Conservation Council (2007) reports that the Pacific Northwest has warmed about 1° C (1.8° F) since 1900 (this is about 50 percent more than the global average for the same time period) and is projected to warm at a rate of 0.1 to 0.6° C (0.18 to 1.1° F) per decade during the next century. Over the long term, winter precipitation is expected to increase, and summer precipitation is expected to decrease. Within the Columbia River basin, expected effects of rising temperatures include more precipitation falling as rain rather than snow, diminished snow pack, associated reductions in late-summer/early-fall flow, altered timing of flows, increased peak flows, and continued rises in water temperatures. In the estuary, these factors could lead to changes in flooding and ecosystem processes and conditions that already are considered limiting factors for salmon and steelhead—namely, flow-related habitat changes, sediment transport, food web dynamics, populations of non-native species, and water temperature (Independent Scientific Advisory Board 2007). Increasingly, water temperatures in the estuary are approaching the upper thermal limit for salmonids that use the estuary during summer months (National Research Council 2004). Further increases in water temperature could render some current estuarine habitat unsuitable for salmonids, enhance conditions for warm-water fish that prey on or compete with juvenile salmonids, and alter physiological processes such as growth and metabolism among juveniles (Independent Scientific Advisory Board 2007). Some evidence suggests that salmonid response to climate change varies among populations (Crozier and Zabel 2006 as cited in Independent Scientific Advisory Board 2007). Other potential impacts of global climate change in the estuary may include continued rises in sea level and associated effects on intertidal habitat formation and maintenance.

Study of the impacts of global climate change is an evolving field, and additional research is needed to understand the phenomenon's likely effects on estuarine habitats and processes with specificity. Although the estuary recovery plan module does not consider global climate change separately from other climate-related impacts in the estuary, the topic should receive increasing attention for its potential to affect fish management in the Columbia River basin as a whole. As additional scientific information on global climate change becomes available, it will be incorporated into any updates of the estuary recovery plan module and implementation of associated management actions.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, water temperature, and reduced macrodetrital inputs.

Threat: Water Withdrawal

Reduction in the amount of instream flow in a river system is an important measure of alterations to the system (Fresh et al. 2005). Water withdrawals affect both the magnitude and timing of flows entering the estuary and plume.

Historically, flow conditions in the estuary were determined by seasonal climate effects (such as precipitation) and hydrology. Since the early 1900s and to a larger degree since the 1960s, irrigation practices have reduced flows in the Columbia River. Water withdrawals as a result of agricultural irrigation and other water uses are estimated to have reduced flows of the Columbia River by 7 percent since the latter part of the nineteenth century (Jay and Kukulka 2003).

Other human activities that reduce flows are the result of upstream use of surface water and groundwater for commercial, industrial, municipal, domestic, and other purposes (National Research Council 2004).

Irrigation withdrawals of surface water account for approximately 96 percent of total water used, while municipal and other uses account for only 4 percent (National Research Council 2004). On the other hand, about 75 percent of all groundwater withdrawals support irrigation and the remaining 25 percent are used for other purposes (National Research Council 2004).

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Threat: Flow Regulation

The timing and magnitude of spring freshets have been drastically altered by management of the Columbia River hydrosystem (Fresh et al. 2005). Jay and Kukulka (2003) estimate that 26 percent of the overall reduction of freshet season flow since the late nineteenth century is attributable to flow regulation. Together with irrigation storage and withdrawal, flow regulation has increased fall and winter flows (winter flows have increased because of pre-release before the freshet season), and much of the seasonal timing of flows in the estuary can be attributed to flood control and hydroelectric operations.

Flow regulation is a function of the hydrosystem in the United States and Canada. The first hydroelectric facility in the lower Columbia Basin—the T.W. Sullivan Dam in Oregon City—was constructed in 1888. Since then, more than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). These dams supply British Columbia with 50 percent of its electricity, while the American Northwest relies on hydropower for about two-thirds of its electricity (Columbia Basin Trust). Columbia River dams also provide flood control, enhance irrigation, and improve navigation.

The total active storage of water in the Columbia River Basin is 42 million acre-feet (Northwest Power and Conservation Council 2001), with dams in Canada accounting for about half of the total storage (Northwest Power and Conservation Council 2001). Major Canadian dams include the Duncan, Arrow, and Mica dams. Major U.S. hydroelectric facilities with significant storage include the Grand Coulee, Dworshak, Hungry Horse, and Libby dams. In addition, the U.S. Bureau of Reclamation owns and operates dozens of water storage dams in the Snake and Yakima rivers. The U.S. Army Corps of Engineers also operates many large flood control projects in the Willamette River.

Several recent changes in hydrosystem operations have been implemented to benefit salmonids throughout the basin. These include increasing flows by minimizing winter flood control drafts and reducing the amount of water needed to refill projects during the spring—measures that benefit spring juvenile salmonid migration in the mainstem Snake and Columbia rivers. Also, summer flows have been augmented to cool Snake River temperatures and assist migration of Snake River salmon and steelhead. Finally, a minimum flow has been administratively set from November through April to reduce the potential for dewatering of chum redds, primarily in Reach G in the estuary.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, increased microdetrital inputs, and reduced macrodetrital inputs.

Sediment-Related Threats

Changes to seasonal flows, dredging, and the entrapment of sediment in reservoirs have altered those habitat-forming processes in the Columbia River estuary and plume that relate to sediment.

As described in Chapter 3, the transport of sediment is fundamental to habitat-forming processes in the estuary. Sediment helps create and maintain and promote wetlands, which are important to carbon cycling in the estuary and provide habitat for juvenile salmonids. Sediment also provides important minerals and nutrients that support food production in the estuary and plume. And suspended sediments contribute to turbidity, which is important to salmonids because of the protection it provides from predators. Although the effects of impaired sediment processes on salmonids in the estuary are not fully understood, the magnitude of change and the key role that sediments play in habitat- and food-related processes are significant.

Entrapment of sediment in reservoirs, reduced downstream transport of sediment as a result of altered spring freshets, and dredging are the primary sediment-related threats to salmonids in the estuary. Ocean-type juvenile salmonids are affected by sediment-related changes in habitat in the estuary and by reduced turbidity (which can increase predation). Stream-type juveniles are affected by reduced turbidity in deeper waters in the estuary and plume.

Threat: Entrapment of Fine Sediment in Reservoirs

Reduction in water velocity as a result of upstream reservoirs has altered the transport of organic matter associated with fine sediments such as silt and clay. Fine sediments entering the estuary originate in the upper watersheds of the Snake River (Northwest Power and Conservation Council 2004). Reduced velocities behind upstream reservoirs cause reservoirs to act as a sink to fine sediments and likely reduce amounts delivered to the estuary (Northwest Power and Conservation Council 2004). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004). Additionally, reductions in the quantity of fine sediments can increase water clarity and thus contribute to increased predation by piscivorous fish and birds.

Limiting factors this threat contributes to: Flow-related plume changes, sediment/nutrient-related estuary habitat changes, native birds, native fish, and exotic fish.

Threat: Impaired Transport of Coarse Sediment

Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly ocean types. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2003). It is likely that the magnitude of change in sand transport affects habitat-forming processes and reduces turbidity, which results in increased predation in the estuary and plume environments.

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Dredging

Dredging and the disposal of sand have been a major cause of estuarine habitat loss over the last century (Northwest Power and Conservation Council 2004). Currently, three times more sand is dredged from the estuary than is replenished by upstream sources (Northwest Power and Conservation Council 2004). In addition to causing habitat loss, dredging may have impaired sediment circulation in nearshore ocean areas and resulted in impacts to benthic organisms through disturbance. Still other impacts include the entrainment of crab, juvenile salmonids, sturgeon, and other fish and wildlife species.

Additional losses of vegetated wetlands in the Columbia River estuary are attributable to filling activities, with deposition of dredged materials accounting for most of the filling activities in the estuary (Fresh et al. 2005). Most dredged materials result from maintenance of the shipping channel. Dredged materials are disposed of in-water, along shorelines, or on upland sites; some dredged material disposal sites are shown in the reach maps in Appendix A. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year (Northwest Power and Conservation Council 2004). Significantly more dredged material has resulted from the U.S. Army Corps of Engineers' 43-foot channel deepening project. Dredge fill and diking activities have significantly reduced the availability of wetlands to the river, while placement of dredged material in several areas has increased nesting habitat for Caspian terns and cormorants.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and native birds.

Structural Threats

The development of instream and over-water structures has altered circulation patterns, sediment deposition, sediment erosion, and the formation of habitats in the estuary. Examples of instream and over-water structures include jetties, pile dikes, tide gates, docks, breakwaters, bulkheads, revetments, seawalls, groins, and ramps (Williams and Thom 2001). Such structures create favorable conditions for predators such as northern pikeminnow and walleye, and they can reduce circulation in areas outside of the channel. Instream and over-water structures are found in all reaches of the estuary (for locations, see the reach maps presented in Appendix A).

Another structural threat is reservoirs associated with the hundreds of dams in the Columbia River basin. The construction and operation of these reservoirs has contributed to changes in the temperature of water entering the estuary.

Affected salmonids: Structural threats primarily affect ocean-type juvenile salmonids because of their longer residency time in the estuary and their wider use of off-channel habitats; however, scientists are now hypothesizing that stream-type juveniles forage outside of deeper channels in shallow-water habitats, where they may fall victim to predators that congregate near instream and over-water structures.

Threat: Pilings and Pile Dike Structures

Construction of the North and South jetties has altered sediment accretion and erosion processes near the mouth of the Columbia River. Sediment accretion in the marine littoral areas adjacent to the mouth has decreased the inflow of marine sediments into the estuary (Northwest Power and Conservation Council 2004), while the extensive use of pilings, pile dikes, and other structures to maintain the shipping channel has affected natural flow and sedimentation patterns. Pile dikes maintain the navigation channel by reducing the cross section of the river, increasing the velocity of the river within the channel, and at times slowing velocities immediately downstream of the dike. Development of the navigation channel has reduced flow to side channels and peripheral bays (Northwest Power and Conservation Council 2004). In addition, pile dikes and similar structures may create conditions that increase predation on juvenile salmonids by northern pikeminnow and other piscivorous fish.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and exotic fish.

Threat: Dikes and Filling

Dikes and filling activities have significantly altered the size and function of the Columbia River estuary. Since the early 1900s, dikes have been built to allow agricultural and residential uses (Fresh et al. 2005). Dikes are thought to have caused more habitat conversion in the estuary than any other human or natural factor (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). The effects of diking on estuarine habitats are directly proportional to elevation, with the greatest impacts on the highest elevation estuarine habitats: forested wetlands, followed by tidal swamps and tidal wetlands. Diking-related impacts to these habitats have reduced their availability to juvenile salmon and steelhead (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). Figure 4-3 shows the various zones found in typical estuaries. The emergent vegetation, diked marsh, shrub wetlands, and forested wetlands are the zones most affected by dike and filling practices (reprinted from Thom 2001). Diked areas and the historical floodplain in the Columbia River estuary are shown in the reach maps presented in Appendix A.

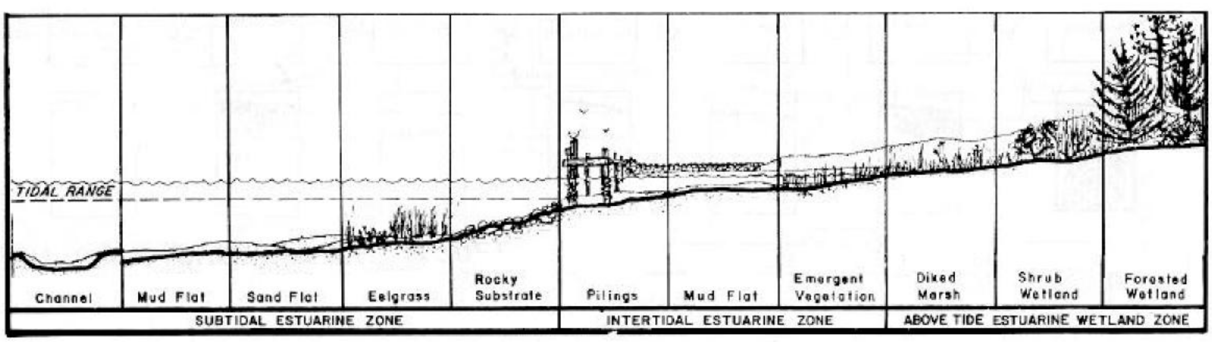

FIGURE 4-3
Subtidal, Intertidal, and Above-Tidal Estuarine Wetland Zones

Before development of the Columbia River hydrosystem and diking and filling, the estuary was dominated by macrodetrital inputs that originated from vegetated wetlands within the estuary. As a result of diking and filling practices and flow alterations (such as changes in the number and timing of spring freshets), emergent plant production in the estuary has decreased by 82 percent and macroalgae production has decreased by 15 percent (Northwest Power and Conservation Council 2004). The availability of insect prey for ocean-type salmonids has been reduced as vegetation has been removed via diking and filling activities and associated dike vegetation maintenance.

Limiting factors this threat contributes to: Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat and plume changes, bankfull elevation increases, and exotic plants.

Threat: Reservoir-Related Temperature Changes

More than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). The associated impoundment of water in upstream reservoirs increases the surface area of the Columbia River, allowing more solar heating of river water than occurs in free-flowing river stretches. This solar heating, combined with the reduced flows from upstream impoundments, has contributed to increased water temperatures in the Columbia River. Measurements at Bonneville Dam indicate that periods of increased temperatures are lasting longer than they did historically (National Research Council 2004). Currently, during summer months, average and maximum values of Columbia River water temperatures are often above 20° C (68°F), which approaches the upper limits of thermal tolerance for cold-water fishes such as salmon (National Research Council 2004). (For additional information on increases in water temperature in the lower Columbia River, see Figure 3-2 and the text that precedes the figure.)

The dynamics of reservoir-related temperature changes in the estuary are complicated and are affected by factors such as thermal inertia, which, among other things, contributes to delayed fall cooling and spring warming of downstream waters. Additional study is needed to better understand reservoir-related temperature changes and their effects on salmonids rearing in the estuary.

Limiting factors this threat contributes to: Water temperature.

Threat: Over-Water Structures

Over-water structures refer to docks, piers, transient moorage, log rafts, and other structures. These structures block sunlight, reduce flow, and trap sediments downstream of pilings (Kahler, Grassley, and Beauchamp 2000; Nightingale and Simenstad 2001). They also change circulation patterns and reduce edge habitats for ocean-type salmonids. Over-water structures contribute to predation on salmonids by altering habitat, creating microhabitats and favorable conditions for predators, especially the northern pikeminnow and non-native species such as small-mouth bass (Kahler, Grassley, and Beauchamp 2000; Nightingale and Simenstad 2001).

Although the actual square footage of over-water structures in the Columbia River estuary has never been inventoried, the structures themselves number in the thousands. Some research has occurred on the effects of breakwaters and over-water structures in the context of marinas. Salmon fry tend to concentrate in higher densities around these structures, thus increasing the risk of predation (Williams and Thom 2001).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, and exotic fish.

Food Web-Related Threats

As described in Chapter 3, changes in the estuarine food web can ripple through the ecosystem, altering energy pathways, feeding patterns, predator/prey relationships, and competition within and among species. As a result of increased nutrients, elevated water temperatures, slower passage of water through reservoirs, and entrapment of organic matter in reservoirs, concentrations of phytoplankton at the base of the food web in the estuary are higher than they were historically. The introduction of exotic species such as shad may have accelerated the pace of ecological change in the estuary by permanently altering food webs. Food webs also have been altered by sediment transport, in that microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically.

Affected salmonids: Both stream- and ocean-type salmonids are affected by energy-related threats—stream types primarily through increased predation in deep-water habitats and ocean types primarily through food web changes in the estuary. Ocean-type juveniles also are affected by reduced availability of insect prey as a result of the construction and maintenance of dikes.

Threat: Increased Phytoplankton Production

A reduction in macrodetrital inputs has shifted the food base in the estuary to phytoplankton produced in and imported from upstream reservoirs (Northwest Power and Conservation Council 2004), or produced as a result of augmented levels of nutrients from urban, industrial, and agricultural development. Phytoplankton support a food web that is less accessible to ocean-type salmonids occupying shallow edge habitats than the historical food web (Northwest Power and Conservation Council 2004). A shift from a generally animal-based salmonid diet to a generally plant-based diet may impair caloric inputs (Garman 1991; Cloe and Garman 1996; Nakano, Miyasaka, and Kuhara, 1999; Henschel, Mahsberg, and Stumpf 2001), and thus the fitness of salmonids that rely on estuarine rearing habitats to grow and prepare for ocean migration. The shift in food sources from a macrodetrital base to a microdetrital base provides different food sources than salmonids historically were accustomed to, in different places within the estuary, and this may favor different species. Because this area of study is immature in the estuary, it is difficult to establish which species benefit more than others.

Limiting factors this threat contributes to: Increased microdetrital inputs.

Threat: Altered Predator/Prey Relationships

Although predation has always occurred in the estuary ecosystem, the cumulative effect of altered flows, changes in sediment transport processes and food sources, introduced species, hatcheries, upstream habitat impacts, hydroelectric impacts, and contaminants have recast estuary and plume environments such that predator/prey relationships have changed significantly. As a result, significant numbers of salmon are lost to fish, avian, and marine mammal predators during migration and residency in the estuary (Northwest Power and Conservation Council 2004). Fish predators include northern pikeminnow, walleye, smallmouth bass, and catfish; avian predators include Caspian terns, double-crested cormorants, and gull species; and marine mammal predators include Steller and California sea lions and harbor seals.

Degraded conditions (loss of habitat and altered food web) in the Columbia River estuary and the timing of large hatchery releases have increased the likelihood that mortality from competition may occur under some circumstances (Northwest Power and Conservation Council 2004). Mortality from intra-species competition has been documented in the Skagit River estuary (Beamer et al. 2005), and there is speculation that it may be a factor in the Columbia River as well (Northwest Power and Conservation Council 2004). If inter-species competition is occurring, it is likely to have the greatest impact on ocean-type salmonids because of their longer residence time in the estuary (Northwest Power and Conservation Council 2004). If density dependence is affecting stream-type juveniles, it likely happens in the plume.

As the result of human alterations of the estuary environment, native species such as Caspian terns and double-crested cormorants have significantly increased in number, with measurable impacts on stream-type salmonids (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). These increases in population in the Columbia River estuary are attributed to the deposition of dredged materials in the estuary that represent high-quality habitat for the birds (Bottom et al. 2005) and predation opportunities for cormorants created through the placement of pilings, pile dikes, and other structures. The loss of habitat elsewhere has contributed to terns and cormorants effectively relocating to the Columbia River estuary, with the populations there now representing the largest nesting colonies in the world.

Similarly, the new microdetritus-based food web in the estuary has benefited zooplanktivores, including American shad (an introduced species) (Northwest Power and Conservation Council 2004). Although shad do not appear to be in direct competition with salmonids, their biomass alone—more than 4 million returning adults a year—represents a threat to trophic relationships in the Columbia River. Future increases in water temperatures as a result of climate change may improve conditions for shad in the Columbia River Basin and lead to their continued expansion (Independent Scientific Advisory Board 2008). Other exotic fish species such as introduced walleye and catfish also have been able to capitalize on degraded conditions in the upper reaches of the estuary and altered food web dynamics through predation and competition for food resources (Northwest Power and Conservation Council 2004).

Pinniped predation on adult spring Chinook and winter steelhead continues to increase. On the West Coast the total abundance of California sea lions is approximately 250,000; Stellar sea lions total about 31,000, and Pacific harbor seals total about 25,000 (Griffin 2006). Each spring about 1,000 Stellar sea lions, 3,000 Pacific harbor seals, and 800 California sea lions take up residence in the lower estuary (Griffin 2006). About 1,000 sea lions and harbor seals enter the freshwater portion of the estuary; of these, approximately 80 animals (primarily California sea lions) congregate at Bonneville Dam. The U.S. Army Corps of Engineers' estimates that annual adult mortality at Bonneville Dam because of pinnipeds (primarily California sea lions) ranged from 0.4 percent (2002) to 4.2 percent (2007) during the study period ending in 2010 (U.S. Army Corps of Engineers 2010).[1] Other, radio telemetry-based studies suggest that annual pinniped predation on spring Chinook and winter steelhead at Bonneville Dam may be as high as 8.5 percent and 20 percent, respectively (NMFS 2008b, Appendix G). There is a need for better estimates of the mortality caused by pinnipeds throughout the estuary and plume. Unsubstantiated estimates suggest a mortality rate of 10 percent of the entire adult spring Chinook and steelhead runs in a given year.

Non-native plant species have altered habitat and food webs in the Columbia River estuary. The rate of intentional and unintentional introductions has been increasing over the past 100

[1] Estimated consumption of adult salmonids ranged from a low of 1,010 in 2002 to a high of 6,081 in 2010; the percent of run consumed varied among reporting years in part because of changes in run size.

years, mostly as a result of horticultural practices and the increase in travel and commerce in the Columbia River. Four of those species—purple loosestrife, Eurasian water milfoil, parrot feather, and Brazilian elodea—are of particular concern. Each of these species, in its own way, alters habitat and food webs in the estuary. Purple loosestrife, for example, adapts easily to environmental changes and expands its ranges quickly. The primary ecological effect of purple loosestrife is that it disrupts wetland ecosystems by displacing native plants. Eventually, animals that rely on native flora for food, nesting, or cover also are displaced (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Native birds, native fish, native pinnipeds, introduced invertebrates, exotic fish, and exotic plants.

Threat: Ship Ballast Practices

Ship ballast practices have been responsible for the introduction of at least 21 exotic species in the Columbia River estuary (Sytsma et al. 2004). When ships release ballast water, non-indigenous species can enter receiving waters. Most of the non-indigenous species in the estuary have originated from Asia (Sytsma et al. 2004). Populations of non-native copepods have established themselves in Reaches A and B (Youngs Bay, Cathlamet Bay, and Grays Bay), and the New Zealand mudsnail has colonized other estuary reaches. The Asian bivalve *Corbicula fluminea* has expanded its range in the estuary, with densities of 10,000 per m^2 being recorded in Cathlamet Bay; however, densities of 100 to 3,000 m^2 are more common (Northwest Power and Conservation Council 2004). These and other non-indigenous invaders disrupt food webs and out-compete juvenile salmonids' native food sources.

An emerging source of concern regarding ship ballast practices is the potential entrainment of juvenile salmonids when large ships take on ballast water as they leave ports unloaded. This issue is being evaluated in relevant Endangered Species Act (ESA) Section 7 consultations (Tortorici 2008).

Limiting factors this threat contributes to: Introduced invertebrates.

Water Quality-Related Threats

The release of toxic contaminants, nutrient loading, and reduced dissolved oxygen have altered the quality of salmonid habitats in the Columbia River estuary. Currently the estuary receives toxic contaminants or nutrients from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from urban and agricultural areas (Fuhrer et al. 1996 as referenced in Fresh et al. 2005). In most areas, nonpoint sources such as agricultural, urban, industrial, and timber harvest practices contribute greater nutrient loads than point sources do (Wise et al. 2007). The Snake, Yakima, Deschutes, and Willamette rivers contribute most of the nutrient loads discharged to the Columbia River. Nutrient yields (loads normalized for basin size) are generally greater in basins west of the Cascade Range and are correlated with precipitation and point-source loads (Wise et al. 2007).

Threat: Agricultural Practices

The health of an aquatic ecosystem is substantially affected by agricultural, urban, and industrial practices and wastewater discharge (National Research Council 2004). Specific threats include increased nutrients (nitrogen and phosphorus), sediment, and organic and trace metals (National Research Council 2004). For example, Wise et al. (2007) found a significant correlation between total nitrogen yields in basins west of the Cascades and fertilizer and manure loads. Increased nutrient loads from anthropogenic sources can lead to increased phytoplankton concentrations, decreased water clarity, and depressed dissolved oxygen levels, especially in areas with longer residence times and warmer water temperatures. DDT, other banned pesticides that have persisted in the environment, and pesticides in current use are entering the estuary from agricultural runoff, some of which originates outside the lower Columbia River basin. The middle and upper Columbia are primary sources of DDT and other organochlorine pesticides in the estuary, as are tributaries such as the Yakima and Willamette rivers (Clark et al. 1998, Williamson et al. 1998, Hinck et al. 2006, Johnson and Norton 2005, McCarthy and Gale 2001 as cited in Lower Columbia River Estuary Partnership 2007). A 2007 study confirmed the presence of the pesticides atrazine, simazine, metolachlor, EPTC, DCPA, and diuron at sites throughout the estuary, often in combination (Lower Columbia River Estuary Partnership 2007). The timing of detections suggests that precipitation events play an important role in transporting pesticides to the Willamette River, which is a primary contributor of both agricultural and urban/industrial contaminants to the Columbia River estuary.

The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) program also reports detection of a wide range of commonly used pesticides at sampling sites near Bonneville Dam and at the confluence of the Willamette and Columbia rivers (Fresh et al. 2005). Detected pesticides include simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl. Arsenic and trace metals such as copper, iron, and manganese also have been detected. Although trace metals occur naturally, they also are introduced through human activities, such as the use of lead arsenate as an insecticide for apples (Fresh et al. 2005). Water-soluble contaminants, trace metals, and chlorinated compounds have been detected in the estuary (Fresh et al. 2005), and DDT, PCBs, dioxins, and metals have been detected at elevated levels in tissue from fish in the estuary (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Non-bioaccumulative toxicity, bioaccumulation toxicity, and increased microdetrital inputs.

Threat: Urban and Industrial Practices

The Columbia River downstream of Bonneville Dam is the most urbanized stretch in the entire basin. The area has more than 100 point sources that are known to discharge directly into the Columbia River estuary; these include chemical plants, pulp and paper mills, hydroelectric facilities, municipal wastewater treatment plants, and seafood processors (Fuhrer et al. 1996 as cited in Lower Columbia River Estuary Partnership 2007). Potential nonpoint sources include hazardous waste sites, landfills, marinas and moorages, and overland surface runoff that transports nutrients, sediment, PAHs, metals, and pesticides from streets, yards, and industries.

The largest sources of effluent in this area are the Portland and Vancouver sewage treatment plants (Fresh et al. 2005), with Portland's wastewater treatment facility being the largest point-source discharger in the Columbia Basin (Wise et al. 2007). The annual nutrient loads from this facility equal approximately 2 to 3 percent of the annual in-stream nutrient loads at the Beaver Army Terminal water quality sampling site, downstream of Longview, Washington (Wise et al 2007). Contaminants also are transported to the estuary from areas above Bonneville Dam, such as the Deschutes, Yakima, and Snake rivers. These rivers, together with the Willamette, contribute most of the nutrient loads discharged to the Columbia River (Wise et al. 2007).

An intensive study of sediments in Portland Harbor (the stretch of the Willamette River from Sauvie Island to Swan Island) has uncovered pesticides, PCBs, and other toxic chemicals. In general, studies have shown that PCB and PAH concentrations in salmon and their prey in the estuary are comparable to those in organisms in other moderately to highly urbanized areas (Fresh et al. 2005, Lower Columbia River Estuary Partnership 2007, Johnson et al. 2007b). Industrial contaminants such as PAHs have been detected in sediments from the lower Willamette River in Portland at levels that exceed state or Federal sediment quality guidelines. The U.S. Environmental Protection Agency identified PCB and DDT hot spots within the estuary, including near Longview, West Sand Island, the Astoria Bridge, and Vancouver (Fresh et al. 2005). Studies in the 1990s found that sediment contamination was highest near urban and industrial areas, with concentrations in excess of levels of concern for DDE (a breakdown product of DDT), PCBs, dioxins and furans, and PAHs (Tetra Tech 1996). Current studies find higher levels of flame retardants (PBDEs), PCBs, and DDT on bed sediment collected near Portland than in sediment collected from other sites in the estuary (Jones et al. 2008).

In addition, emerging contaminants associated with urban development are beginning to be detected in the Columbia River estuary. These include PBDE flame retardants, which have been found in juvenile salmon tissue, their stomach contents, the water column, and on suspended sediment at sites throughout the estuary (Lower Columbia River Estuary Partnership 2007). Caffeine, human and veterinary antibiotics, synthetic musk, and the plasticizer bisphenol A have also been detected in the water of the estuary (Lower Columbia River Estuary Partnership 2007). Although the effects of these compounds are not yet well understood, some of them are suspected hormone disruptors, and juvenile salmon collected from the estuary show evidence of exposure to estrogenic compounds (Lower Columbia River Estuary Partnership 2007). This could be the result of emerging contaminants or more familiar toxic contaminants in the estuary, such as certain pesticides.

Limiting factors this threat contributes to: Non-bioaccumulative toxicity, bioaccumulation toxicity, and increased microdetrital inputs.

Other Threats

Threat: Riparian Practices

Riparian practices along the estuary mainstem and in tributaries throughout the Columbia River basin have contributed to increases in water temperature in the estuary by changing hydrology and removing riparian habitats (National Research Council 2004) that—among other ecological functions—provide insects and macrodetrital inputs to the food web.

Problematic practices include shoreline modifications, timber harvest, certain agricultural activities within riparian zones, and residential, commercial, and industrial land uses. These activities increase water temperatures, alter hydrology and macrodetrital inputs, and in some cases modify shoreline habitats used by salmonids, especially ocean types (Lower Columbia Fish Recovery Board 2004).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, reduced macrodetrital inputs, water temperature, and exotic plants.

Threat: Ship Wakes

Ships traveling through the Columbia River estuary produce waves and an uprush which, under certain circumstances, causes juvenile salmonids and other fish to become stranded on shore (Bauersfeld 1977). Although Bauersfeld concluded that ship wake stranding was a significant cause of mortality in ocean-type Chinook salmon and other species, other studies have not confirmed the magnitude of this threat. As a part of the U.S. Army Corps of Engineers' channel deepening project, a study is under way that may help characterize the magnitude of ship wake stranding. The purpose of the study is to document ship wake stranding before and after channel deepening. The first half of the study, published in February 2006, documented stranding events at three test sites. The second part of the study will begin after dredging is completed (Pearson et al. 2006). These results should be useful as partial basis for Light Detection and Ranging (LIDAR) analysis and extrapolation of test site mortality throughout the estuary for similar habitat types. Early in 2008, the Port of Vancouver enlisted Entrix, Inc., to perform a spatial analysis of beach susceptibility for the stranding of juvenile salmonids by ship wakes (Pearson 2008). The study examined wave characteristics and the geomorphology of the lower river but did not examine nearshore fish density. The purpose of the study was to estimate the number of miles of shoreline that exhibit traits expected to potentially cause stranding. The study concluded that approximately 33 miles of shoreline between the mouth of the river and the city of Vancouver have shoreline characteristics consistent with stranding (Pearson 2008).

Limiting factors this threat contributes to: Stranding.

Prioritization of Threats

This estuary recovery module establishes priorities for threats by linking them to pertinent limiting factors and estimating their relative contribution to those limiting factors. The threats identified above are well supported in a wide variety of literature sources, including Fresh et al. (2005), Bottom et al. (2005), the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" (Northwest Power and Conservation Council 2004), and a variety of more topic-specific primary literature sources.[2] The prioritization of threats, though, is not nearly as well supported, partly because of the limited understanding of how threats contribute to limiting factors and to what degree salmon and steelhead are affected by a given limiting factor. While it is attractive to assume that additional study will fully answer these questions, the biological response to environmental conditions will always be difficult to model because of the tremendous complexities of the physical, biological, and

[2] As with the limiting factors, most of the threats identified in this chapter are not supported by data at the reach or sub-reach scale.

ecological interplay that occurs in the environment. On the other hand, new interest in the estuary and its role in the recovery of listed species in the Columbia River has generated better understanding, and it is likely that uncertainty surrounding threats and limiting factors will continue to lessen.

Table 4-1 demonstrates the relationship between limiting factors and threats by showing which threats are causing which limiting factors and estimating the contribution of each threat to each limiting factor. The presumed relative contribution of a threat to each limiting factor is indicated by the primary, secondary, or tertiary designation. The contribution of each threat to its associated limiting factor(s) is multiplied by the relative importance of that limiting factor to salmonids to yield the threat index score. This score expresses the relative priority of the threat in question. (The relative importance of limiting factors is taken from Table 3-2.)

PC Trask & Associates, Inc., developed the initial threat contribution scores for Table 4-1 by reviewing the extent to which the three main literature sources—and other sources—described relationships between limiting factors and threats or evaluated the contribution of multiple threats to a single limiting factor. Although literature sources were useful in making connections between threats and limiting factors, in many cases the literature did not separate limiting factors from threats or did not attempt to identify and rank the full scope of threats that might be contributing to a particular limiting factor. In nearly all cases, authors discussed cause-and-effect relationships in qualitative language. In some cases, authors described quantitative relationships, as in the relationship between flow regulation and sediment transport. Only a handful of sources estimated priorities for threats.

To supplement information gleaned from the literature, the author talked with regional experts (see Acknowledgements) to identify potential threat contributions not described in the literature. The author also refined the initial scores based on review and input by NMFS Northwest Fisheries Science Center, NMFS Northwest Regional office, Lower Columbia River Estuary Partnership, and Lower Columbia Fish Recovery Board staff. The author, in consultation with staff from the Lower Columbia River Estuary Partnership and NMFS, also made minor adjustments to the scores in response to comments received during the public review period.

TABLE 4-1
Linkages Between Limiting Factors and Threats to Ocean- and Stream-Type Salmonids

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
Flow-related estuary habitat changes	Climate cycles and global climate change	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related changes in access to off-channel habitat	Climate cycles and global climate change	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related plume changes	Climate cycles and global climate change	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
	Impaired transport of coarse sediment	Top (5)	Secondary (2)	10
	Entrapment of fine sediment in reservoirs	Top (5)	Tertiary (1)	5
Water temperature	Climate cycles and global climate change	Top (5)	Secondary (2)	10
	Reservoir-related temperature changes	Top (5)	Secondary (2)	10
	Riparian practices	Top (5)	Secondary (2)	10
Reduced macrodetrital inputs	Climate cycles and global climate change	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Riparian practices	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Dikes and filling	Top (5)	Primary (3)	15
Sediment/nutrient-related estuary habitat changes	Impaired transport of coarse sediment	High (4)	Primary (3)	12
	Entrapment of fine sediment in reservoirs	High (4)	Secondary (2)	8
	Dredging	High (4)	Secondary (2)	8
	Pilings and pile dike structures	High (4)	Primary (3)	12
	Dikes and filling	High (4)	Primary (3)	12
	Over-water structures	High (4)	Tertiary (1)	4
	Riparian practices	High (4)	Tertiary (1)	4
Bankfull elevation changes	Dikes and filling	High (4)	Primary (3)	12
Native birds	Entrapment of fine sediment in reservoirs	High (4)	Tertiary (1)	4
	Dredging	High (4)	Secondary (2)	8
	Altered predator/prey relationships	High (4)	Primary (3)	12
Native pinnipeds	Altered predator/prey relationships	High (4)	Primary (3)	12
Non-bioaccumulative toxicity	Agricultural practices	High (4)	Primary (3)	12
	Urban and industrial practices	High (4)	Primary (3)	12
Native fish	Entrapment of fine sediment in reservoirs	Medium (3)	Tertiary (1)	3
	Altered predator/prey relationships	Medium (3)	Primary (3)	9
Bioaccumulation toxicity	Agricultural practices	Medium (3)	Primary (3)	9
	Urban and industrial practices	Medium (3)	Primary (3)	9
Sediment/nutrient-related plume changes	Dredging	Low (2)	Primary (3)	6
	Pilings and pile dike structures	Low (2)	Secondary (2)	4
	Dikes and filling	Low (2)	Secondary (2)	4
Stranding	Ship wakes	Low (2)	Primary (3)	6
Increased microdetrital inputs	Agricultural Practices	Low (2)	Secondary (2)	4
	Urban and industrial practices	Low (2)	Secondary (2)	4
	Increased phytoplankton production	Low (2)	Primary (3)	6
	Flow regulation	Low (2)	Tertiary (1)	2

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
Exotic fish	Entrapment of fine sediment in reservoirs	Lowest (1)	Tertiary (1)	1
	Over-water structures	Lowest (1)	Secondary (2)	2
	Pilings and pile dike structures	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3
Introduced invertebrates	Altered predator/prey relationships	Lowest (1)	Tertiary (1)	1
	Ship ballast practices	Lowest (1)	Primary (3)	3
Exotic plants	Dikes and filling	Lowest (1)	Primary (3)	3
	Riparian practices	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3

[a] From Table 3-2.
[b] Indicates how important the threat is in perpetuating the limiting factor:

3 = Threat is a primary cause of the limiting factor. Addressing this threat would significantly improve salmonid performance.

2 = Threat is a secondary cause of the limiting factor. Addressing this threat would improve performance.

1 = Threat is a tertiary cause of the limiting factor. Addressing this threat would benefit performance, but by itself would result in only minor improvement.

[c] Product of the numerical scores for the limiting factor priority and the threat's contribution to the limiting factor. A high threat index score means that the threat is a major contributor to one or more significant limiting factors. A low threat index score means the threat is a small contributor to a minor limiting factor.

Table 4-2 organizes threats by their threat index score, in descending order. However, the state of the science is such that the differentiation of threat priorities in Tables 4-1 and 4-2 should be viewed as reasonable guidance and a set of working hypotheses to be tested and refined through research and evaluation. Given uncertainties about estuarine ecosystems and how they function, some threats that are ranked relatively low in Table 4-2 may eventually prove to have large impacts to the estuary. For example, it is difficult to dispute the importance of flow regulation compared to ship ballast practices. But it is possible that the effects of exotic invertebrates introduced to the estuary through ship ballast practices will significantly degrade the overall health of the estuary ecosystem over time and that this threat will move up in the priority ranking. As another consideration, Tables 4-1 and 4-2 reflect the prioritization of threats across the entire estuary; within each reach, threats could be prioritized differently. A reach-scale analysis of limiting factors and threats was beyond the scope of this document and, in some cases, beyond the limits of currently available science. But such an analysis would be useful as additional scientific information becomes available.

TABLE 4-2
Prioritization of Threats to Ocean- and Stream-Type Salmonids

Threat	Threat Index*	Threat Priority
Flow regulation	15	HIGH
Dikes and filling	15	
Altered predator/prey relationships	12	
Urban and industrial practices	12	
Agricultural practices	12	↑
Impaired transport of coarse sediment	12	
Pilings and pile dike structures	12	
Reservoir-related temperature changes	10	
Riparian practices	10	
Climate cycles and global climate change	10	
Water withdrawal	10	
Dredging	8	
Entrapment of fine sediment in reservoirs	8	
Ship wakes	6	↓
Increased phytoplankton production	6	LOW
Over-water structures	4	
Ship ballast practices	3	

* From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

Summary

Chapter 4 provides information on the underlying causes of the factors that influence the viability of ocean- and stream-type ESUs during their residency and migration in the estuary. Analysis of threats is challenging because a single threat often contributes to multiple limiting factors and may originate miles upstream from the estuary. In Chapter 4, threats were identified, described, linked to limiting factors, and prioritized. Chapter 5 turns to management actions, identifying actions that will address threats and thus help reduce risks to the 13 ESA-listed ESUs using the Columbia River estuary.

CHAPTER 5

Management Actions

Chapters 3 and 4 of this recovery plan module identify factors that currently limit salmonids' biological performance in the estuary and the threats that contribute to those limiting factors. Chapter 5 presents 23 management actions that, together, address the range of threats salmonids in the estuary face, from altered habitat-forming processes to physical structures in the estuary, changes in the food web, and poor water quality. If implemented, the actions presented in this chapter would reduce the impacts of threats to salmonids during their migration and residency in the estuary and plume.

In addition to identifying the management actions, Chapter 5 evaluates them in terms of constraints to implementation, potential improvement in salmonid survival, and cost. More specifically, the chapter discusses each management action's potential benefits and implementation constraints, hypothesizes how benefits could translate into increased survival of salmonids, breaks each action into component projects, and estimates the cost of each project, and thus of each action. Also included is a list of actions that would address threats to salmonids in the estuary but that would need to be implemented outside the estuary, either in estuary tributaries or in upstream areas of the Columbia River basin.

As in other chapters of this recovery plan module, the analysis in Chapter 5 does not fully capture the subtleties of the ecological interactions that influence salmonid survival. Despite continuing research, many aspects of the salmonid life cycle are poorly understood, in part because of the sheer complexity of the ecosystems that salmonids transition into and out of during their lives. The actual relationships among threats and management actions are far more intricate than what is described here. Additionally, given the limits in scientific understanding, there is a degree of uncertainty at each step of the analysis in this chapter. Yet the categories, ratings, and associations presented here are useful tools for discussing complex ecological relationships and comparing possible outcomes of different management actions.

Identification of Management Actions

For the purposes of this recovery plan module, a management action is any action that has the potential to reduce the impact of human-caused or naturally occurring threats to salmonids while they migrate or rear in the estuary and plume. PC Trask & Associates, Inc., identified management actions using available literature and input from area experts (see Acknowledgements). Key documents used to identify management actions are the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" (Northwest Power and Conservation Council 2004) and its supplement; *Role of the Estuary in the Recovery of Columbia River Salmon and Steelhead (*Fresh et al. 2005); *Salmon at River*'s *End* (Bottom et al. 2005); and the *2004 FCRPS Biological Opinion on Remand* (National Marine Fisheries Service 2004). Table 5-1 lists threats to salmonids in the estuary and plume and management actions that would address those threats; this information is organized by topic and does not reflect the priority of either threats or management actions.

TABLE 5-1
Management Actions to Address Threats

	Threat	Management Action
Flow-related threats	Climate cycles and global climate change[2]	**CRE[1]-1:** Protect intact riparian areas in the estuary and restore riparian areas that are degraded.[2] **CRE-2:** Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.[2] **CRE-3:** Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.[2]
	Water withdrawal	***CRE-3:*** *Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries*
	Flow regulation	**CRE-4**: Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume. ***CRE-3:*** *Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.*
Sediment-related threats	Entrapment of fine sediment in reservoirs	**CRE-5:** Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.
	Impaired transport of coarse sediment	**CRE-6:** Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially. **CRE-8:** Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health. ***CRE-4:*** *Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.*
	Dredging	**CRE-7:** Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.
Structural threats	Pilings and pile dike structures	***CRE-8:*** *Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health.*
	Dikes and filling	**CRE-9:** Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat. **CRE-10:** Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.
	Reservoir-related temperature changes	***CRE-2:*** *Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.*
	Over-water structures	**CRE-11:** Reduce the square footage of over-water structures in the estuary.

	Threat	Management Action
Food web-related threats	Increased phytoplankton production	***CRE-10:*** *Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.*
	Altered predator/prey relationships	**CRE-13:** Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids. **CRE-14:** Identify and implement actions to reduce salmonid predation by pinnipeds. **CRE-15:** Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants. **CRE-16:** Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island. **CRE-17:** Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations. **CRE-18:** Reduce the abundance of shad in the estuary. ***CRE-8:*** *Remove or modify pilings and pile dikes with low economic value when removal or modification would benefit juvenile salmonids and improve ecosystem health.*
	Ship ballast practices	**CRE-19:** Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations ***CRE-7:*** *Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.*
Water quality-related threats	Agricultural practices	**CRE-20:** Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.[3] ***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.* ***CRE-9:*** *Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.*
	Urban and industrial practices	**CRE-21:** Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants. **CRE-22:** Restore or mitigate contaminated sites. **CRE-23:** Implement stormwater best management practices in cities and towns.[3] ***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.* ***CRE-9:*** *Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.*
Other threats	Riparian practices	***CRE-1:*** *Protect intact riparian areas in the estuary and restore riparian areas that are degraded.*
	Ship wakes	**CRE-12:** Reduce the effects of vessel wake stranding in the estuary.

[1] CRE = Columbia River estuary.

[2] Study of the impacts of global climate change is an evolving field, and additional research is needed to understand the phenomenon's likely effects on estuarine habitats and processes with specificity. At this time, the Independent Scientific Advisory Board of the Northwest Power and Conservation Council expects that the regional effects of global climate change in the next century will include more precipitation falling as rain rather than snow, reduced snow pack, and late-summer/early-fall stream flows, and associated rises in stream temperature (Independent Scientific Advisory Board 2007). The climate-related management actions in Table 5-1 reflect these expected impacts. Although the management actions clearly would not change the threat of global climate change itself, they have the potential to lessen its impact on salmonids in the estuary. Even if climate cycles and global climate change have effects different from those assumed in this document, the management actions that Table 5-1 associates with climate would provide benefits to salmonids by addressing other threats, such as water withdrawal, urban and industrial practices, and reservoir heating. All three of the management actions associated with climate in Table 5-1 are associated with other threats listed in Table 5-1.

[3] Unless otherwise noted, the term *best management practices* is used in this document to indicate general methods or techniques found to be most effective in achieving an objective. NMFS envisions that in implementation, specific best management practices would be developed or recommended.

Note: Italics indicate an action's second occurrence in the table, in connection with a different threat.

Given the complexity of the riverine, estuarine, and marine ecosystems that salmon use during their lives, the actual relationships among threats and management actions are more complicated than Table 5-1 suggests. For example, several of the management actions in Table 5-1 are associated with more than one threat (italics indicate an action's second occurrence in the table). This illustrates the complex interplay of ecological processes in the estuary, particularly processes related to flow, sediment, the food web, and water quality, all of which influence salmon survival. Later in this chapter actions are described and analyzed discretely. Some actions are interrelated, both in the problems they attempt to solve and their probable effects. As an example, CRE-2 through CRE-5 (reducing the effects of reservoir heating, protecting/enhancing instream flows influenced by withdrawals and other water management actions in tributaries, adjusting flow timing and magnitude, and addressing entrapment of fine sediments in reservoir) all deal with reservoir and hydrosystem operations. If implemented together, these actions could act in concert to significantly improve water temperature and sediment delivery in the estuary, potentially providing greater benefits through synergistic action than if they were implemented singly. The potential for synergistic effects of management actions is discussed in more detail in Chapter 7.

The estuary recovery module also identifies specific monitoring, research, and evaluation activities appropriate to the 23 management actions. These activities will provide crucial information on the effectiveness of actions that are implemented in the estuary, associated changes in the ecology of the estuary, and scientific uncertainties that affect implementation of the actions. Monitoring, research, and evaluation activities are presented in Chapter 6. Some of these activities are part of the *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program* (Johnson et al. 2008), while others are specific to the management actions in this recovery plan module.

Other Recommended Management Actions

In many ways, conditions in the estuary are the sum of ecological stressors that exist throughout the Columbia River basin. Although some threats to salmonids in the estuary originate exclusively in the estuary itself (Caspian tern predation is one example), others are the result of activities in estuary tributaries or in upstream areas; examples of such threats are riparian practices and upstream water withdrawals that reduce stream flow in the estuary. Still other threats, such as land use practices that contribute contaminants to the river, originate in all three areas—estuary, estuary tributaries, and upstream. Because of the geographic scope of these threats, fully addressing them will require effort not just in the estuary but throughout the basin.

When it comes to management actions, though, the geographic scope of this estuary recovery plan module is limited. For the most part the module focuses on management actions that can be implemented within the estuary itself and that will address threats that either originate exclusively within the estuary itself or have a significant in-estuary component. The assumption is that threats originating from outside the estuary are affecting local conditions in tributary and upstream areas and that actions to address these threats will be included in recovery plans being developed for upstream salmonid populations.

Even so, the analysis in Chapters 3 and 4 of this recovery plan module and a review of contemporary literature yielded six management actions that would directly affect threats to salmonids in the estuary yet would need to be implemented almost exclusively outside of the estuary or are otherwise beyond the scope of this document:

- Implement hatchery actions as appropriate throughout the Columbia River basin to reduce the threat of density-dependent mortality as a direct result of ecological interactions (disease, predation, or competition for food or space) between hatchery and wild salmonid juveniles using reduced and/or impaired lower river habitats. The magnitude of the ecological interactions as a function of the cumulative effects of large hatchery releases on natural-origin salmonids, both spatially and temporally, is currently an important scientific uncertainty.
- Upgrade up-river irrigation structures to reduce evaporation and conveyance losses and improve estuary instream flows.
- Implement public and private best management and water system conservation practices to maximize the quantity and quality of instream flows entering the estuary.
- Incorporate water availability analysis in land use planning activities to ensure efficient use of water, improve tributary flows, and reduce stream temperatures.
- Protect and restore riparian areas in tributaries to provide shade and future wood sources.
- Reduce inputs of toxic contaminants originating from upstream tributary and mainstem sources.

Because these six actions are outside the geographic scope of the estuary recovery plan module, they are not analyzed in this chapter. Nevertheless, implementation of these six out-of-estuary actions is important to improving the survival of salmonids in the estuary, so it is recommended that the actions be included in recovery plans being developed for upstream areas of the Columbia River basin.

One factor that is beyond the geographic scope of the estuary recovery plan module but is addressed in the module in a limited manner is hydrosystem operations, which affect water temperature, sediment transport, and various other habitat-forming processes and conditions in the estuary. Although actual operation of the hydrosystem occurs outside the estuary, the system's effects are considered in the module because they are such significant determinants of habitat conditions for juvenile salmonids in the estuary. Also, unlike the recommended out-of-estuary actions listed above, hydrosystem operations that affect estuarine habitat are unlikely to be addressed in recovery plans being developed for upstream areas of the Columbia River basin. For these reasons, the estuary recovery plan module includes two management actions (CRE-2 and CRE-4) that focus specifically on hydrosystem operations.

The recommendation of out-of-estuary actions to improve survival in the estuary is another reflection of the interconnectedness of the various ecosystems salmonids use during their life cycles, the power of the river as a connector, and how the effects of problematic upstream activities are manifested—and sometimes magnified—in the estuary.

Evaluation of Management Actions: Constraints to Implementation

Constraints to implementation are a key factor in evaluating management actions and their likely impacts on salmonids. No management action can benefit salmonids if it cannot be implemented, and in many cases the degree of benefit corresponds to the degree of implementation. For this reason, the 23 management actions identified above are evaluated in terms of the constraints to their implementation, which yields information about the actions' likely outcomes and starts to provide a basis for comparing the probable effectiveness of different actions.

PC Trask & Associates, Inc., performed an initial rating of management action constraints by qualitatively estimating the degree of difficulty in implementing each action, taking into account social, political, and technical factors, including the probable cost of implementation. Staff at the Lower Columbia River Estuary Partnership, NMFS Northwest Fisheries Science Center, NMFS Northwest Regional Office, and Lower Columbia Fish Recovery Board provided input into this process. PC Trask & Associates, Inc., and NMFS also revised some constraint scores in response to the *Federal Register* public comment process. Because the scientific literature generally falls short of prescribing discrete actions to address threats and is even less robust when it comes to evaluating constraints to implementation, the reader should view specific ratings as a qualitative estimate only, but one that is useful in comparing relative implementation constraints across the 23 management actions.

For each management action, Table 5-2 summarizes the primary threat and limiting factors that the action addresses and expresses the significance of those threats and limiting factors in terms of a threat index. (The threat index indicates whether the threat is a major contributor to a significant limiting factor or a minor contributor to a minor limiting factor. The index is useful in distinguishing those actions that, even if they were successful, would affect a relatively small number of fish from those actions that, even if they were only partially implemented or partially successful, would have more profound benefits because they would affect a larger number of fish.) Table 5-2 also provides a score for the potential benefit to salmonids in the estuary if implementation of the action were completely unconstrained, plus a brief rationale for the score.

Assigning a score for potential benefit with unconstrained implementation is just the first step in evaluating management actions. In fact, decisions about management actions will be made within a complex social and political context that includes a wide variety of interests, and it is likely that many of the actions will not be able to be implemented fully because of various technical, financial, political, or social obstacles. To address this issue, Table 5-2 assigns an implementation constraints score to each management action and briefly explains how implementation of the action could be constrained by various factors. It then gives a score that represents the potential benefits of the action if implementation of the action is constrained. By design, the estuary recovery module takes a relatively optimistic view about what is possible in terms of reducing the constraints to implementation of management actions. This means that even the score in Table 5-2 for constrained implementation of an action may represent a higher degree of implementation than is likely to actually occur. However, some constraints may be reduced over time, such as through technology advances or changes in economic sectors; as a result, some actions may have greater potential for implementation than is represented in this recovery plan module.

The table concludes with a score for potential benefit of each action assuming that implementation of the action is constrained. This score is an attempt to identify more realistically what the results of an action would be given the social, political, and financial climate in which management actions will be decided on, but it also assumes that considerable effort is made to reduce constraints to implementation. Also, the difference in Table 5-2 between potential benefit with unconstrained implementation of an action and potential benefit with constrained implementation is helpful in identifying where it might be worthwhile to expend effort to reduce constraints because the benefits would be great. This topic is discussed more fully in Chapter 7.

The threat index and scoring in Table 5-2 are for the estuary as a whole, instead of by reach, because in most cases the assessment information needed to do a reach-scale analysis currently is lacking. However, the severity of individual threats and limiting factors varies from reach to reach in the estuary, as do the potential benefits of the management actions. It is assumed that implementation of the management actions will involve dialogue and additional evaluation at the reach scale to aid in prioritizing actions and focusing them in the geographical areas where they would be most beneficial.

TABLE 5-2
Constraints to Implementation of Management Actions

Management Action CRE-1:

Protect intact riparian areas in the estuary and restore riparian areas that are degraded.

Primary threat this action would address		**Riparian Practices.** Riparian areas provide key ecological functions that affect water temperature, the availability of insects, and macrodetrital inputs to the ecosystem. Riparian areas in the lower Columbia River have been degraded by a number of factors, including shoreline modifications, diking and dike maintenance practices, and activities related to the disposal of dredged material.
Associated limiting factors		Water temperature, reduced macrodetrital inputs, and exotic plants.
Threat index[1]	10	This threat is a secondary contributor to two top-priority limiting factors (water temperature and reduced macrodetrital inputs) and a tertiary contributor to one additional limiting factor.
Potential benefits with unconstrained implementation of action[2]	4	Protecting intact riparian areas and restoring degraded riparian areas in priority reaches would provide significant benefits to salmonids by reducing water temperatures and increasing macrodetrital inputs to the system.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	Levels of protection vary across the lower Columbia region. In some cases, riparian areas in cities and counties are protected through regulatory mechanisms such as growth management or shoreline rules. Regulatory tools such as buffer zones along streams can be effective but require broad public support over time. Restoration projects are expensive and can take decades to provide their full benefit to tributaries directly entering the estuary.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-2:

Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.

Primary threat this action would address		**Reservoir-related temperature changes.** Low-velocity flows and broad surface area exposure in reservoirs increase the temperature of flows in the estuary. Salmonids are cool-water fish that need stream temperatures of 20º C or lower for normal metabolism, growth, disease resistance, and timing of important life functions such as smoltification and adult migration. Salmonids in the estuary are experiencing water temperatures at the upper limit of their tolerance for longer periods and more frequently than they did historically.
Associated limiting factors		Water temperature.
Threat index[1]	10	This threat is a secondary contributor to a top-priority limiting factor.
Potential benefits with unconstrained implementation of action [2]	3	Given that at many times during the year water temperatures in the estuary are at or above the upper limits of salmonids' thermal tolerance, any lowering of water temperature could provide significant survival benefits. Water temperatures of below 20º C throughout the year would aid salmonids in carrying out essential physiological processes and life functions.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	5	Elevated temperatures that result from reservoir heating are difficult to reduce. Temperatures may be influenced by the volume and speed of flows through the hydrosystem and the source of those flows (some impoundments have cooler water than others do). International treaties, conflicting fish management objectives systemwide, the need for flood control, power management, and other factors constrain management of the hydrosystem to allow cooler flows to enter the estuary.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-3:

Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.

Primary threats this action would address		**Water withdrawal and impaired transport of coarse sediment.** Instream flows in the estuary are important for salmonids because they maintain habitat-forming processes and conditions in the estuary and plume. Transport of sand and gravel from upstream and estuary sources during high flows helps establish and maintain salmonid habitats, contributes to turbidity that shelters salmonids from predation, and influences food sources in the plume. Some instream flows have been established in Columbia River basin tributaries, but others are needed, especially with human population growth in the basin. This action focuses on water withdrawals in tributaries and the mainstem and other tributary flow issues, including tributary hydropower. It complements CRE-4, which focuses on mainstem hydrosystem flow-related issues, such as hydrosystem regulation, to establish incremental flow improvements in the estuary within the context of power generation and flood control.
Associated limiting factors		Flow-related estuary habitat changes, flow-related changes in access to off-channel habitat, flow-related plume changes, and reduced macrodetrital inputs.
Threat index[1]	12	This threat is a secondary contributor to four top-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	2	This action contributes incremental instream flow improvements that protect/enhance the flow regime in the estuary and plume and support associated habitat-forming processes.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings); stream-type salmonids in the plume.
Implementation constraints[3]	5	Implementation of this action would require the involvement of multiple stakeholders, including irrigation, commercial, industrial, hydrosystem, tribal, Federal, state, and local interests, plus significant public involvement. Establishing protected instream flows is challenging because of competing interests and often takes years.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-4:

Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.

Primary threats this action would address		**Flow regulation and impaired transport of coarse sediment.** The magnitude, frequency, and timing of flows are an important determinant of habitat opportunity for salmonids in the estuary. Salmonids have adapted to historical flows and depend on them to complete their life cycles. The transport of sand and gravel from upstream and estuary sources helps maintain salmonid habitats, contributes to turbidity that shelters salmonids from predation, and influences food sources in the plume. Spring freshets are important habitat-shaping events for the estuary and plume. Improved flow regimes would help ecological processes (and salmonids) by making nutrients and other food sources, such as insects, available in the food web.
Associated limiting factors		Flow-related estuary habitat changes, flow-related changes in access to off-channel habitat, flow-related plume changes, reduced macrodetrital inputs in the estuary, and sediment/nutrient-related estuary habitat changes.
Threat index[1]	15	This threat is a primary contributor to several top-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	5	Return to a more natural flow regime would have significant ecosystem benefits and would affect all facets of salmonid life histories expressed in the estuary and plume. Adjustments to the timing, magnitude, and frequency of hydrosystem flows entering the estuary would be likely to have synergistic effects that would increase the benefit of many of the other actions.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies; stream-type juveniles rearing in the plume.
Implementation constraints[3]	5	Constraints on hydrosystem operations prevent the return to a natural flow regime in the estuary. Implementation of this action would be limited by international treaties, the need for flood control, fish management objectives systemwide, and power production. However, even slight modifications in the flow regime have the potential to provide significant ecosystem benefits.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-5:

Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.

Primary threat this action would address		**Entrapment of fine sediment in reservoirs.** Fine sediments originating from upstream sources are trapped in low-velocity impoundments in the Columbia River, and their movement into the estuary and plume has been reduced. This alters processes that form shallow-water habitats, affects food sources, and reduces turbidity that otherwise would shelter salmonids from predation.
Associated limiting factors		Flow-related plume changes and sediment/nutrient-related estuary habitat changes.
Threat index[1]	8	This threat is a secondary contributor to several high-priority limiting factors.
Potential benefits with unconstrained implementation of action[2]	2	Fine sediment transport processes are important determinants of estuary and plume habitats. Effective mitigation of this threat would reduce predation of salmonids in the main channel and plume and strengthen habitat-forming processes.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[3]	5	There are no apparent technical solutions to this threat at this time. Mitigation is recommended, but research is needed to identify the magnitude of the threat and potential solutions or mitigation measures.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = Current constraints to implementation are significant.

Management Action CRE-6:

Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.

Primary threat this action would address		**Impaired transport of coarse sediment.** The transport of sand and gravel from upstream and estuary sources is a primary force that influences the creation, maintenance, and distribution of salmonid habitats in the estuary. While there are many potential beneficial uses of dredged materials—including enhanced nourishment of the littoral cell, land creation, property stabilization, and out-of-stream uses—there is also an important ecological need to retain coarse sediments in the estuary for habitat creation and maintenance.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes and flow-related plume changes.
Threat index[1]	12	Although impaired transport of coarse sediment is a primary contributor to a top-priority limiting factor (flow-related plume changes), this management action is likely to have its greatest effect in addressing sediment/nutrient-related estuary habitat changes, a high-priority limiting factor; thus it has a threat index of 12.
Potential benefits with unconstrained implementation of action [2]	2	The beneficial use of sand resulting from dredge activities could play an important role in restoring habitat capacity and habitat opportunity in the estuary and plume. The beneficial use of dredged materials to provide sand nourishment could reduce the effects of ship wake stranding, improve habitat for *Americorphium* (a food source for salmonids), and be beneficial in the development of intertidal swamps and marshes and other salmonid habitat features. Sand entering the littoral cell could also have important ecological benefits.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings). This particularly applies to ocean-type juveniles because of their significant use of shallow-water habitats and the nearshore environment.
Implementation constraints[3]	3	Beneficial uses of dredged materials, such as through littoral cell sand nourishment and direct beach nourishment, are currently receiving significant attention, The most obvious constraint to implementation is identifying funding sources to pay for activities beyond the minimum required by law.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-7:

Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.

Primary threat this action would address		**Dredging**. Annual dredge operations maintain a navigational channel that concentrates flows, alters tidal influences, reduces circulation patterns around the estuary, and releases toxic contaminants from substrates. Dredging activities can result in deposited contaminants being disturbed and redistributed throughout the estuary. Dredging activities also result in the entrainment of juvenile salmonids and benthic organisms through the physical removal of sand via pipeline or clamshell dredging. Ship ballast intake may also result in the entrainment of juveniles as ships take on ballast water when exiting port facilities.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes, native birds, and sediment/nutrient-related plume changes.
Threat index[1]	8	As it relates to this action, dredging is a secondary contributor to a high-priority limiting factor (sediment/nutrient-related estuary habitat changes) and thus has a threat index of 8.
Potential benefits with unconstrained implementation of action [2]	2	Continued dredge operations represent a physical change to the Columbia River estuary. However, reducing or mitigating the effects of dredging would improve habitat-forming processes that would benefit salmonids. Reduction of entrainment through new technologies or management practices for both dredging and ship ballast intake would reduce mortality of juveniles.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Dredging activities have been occurring since the 1870s to provide sufficient draft for ships entering the Columbia River and will continue into the foreseeable future. Ongoing maintenance is needed to keep the channel to specifications for ships, and additional dredging will be conducted in the estuary as part of the channel deepening process. Maintaining the navigation channel requires dredging and disposal of large volumes of material (4 to 5 million cubic yards) each year. Changing dredging equipment, ballast water intake screens, and practices to reduce entrainment and habitat effects would be expensive.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.

1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.

1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-8:

Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.

Primary threat this action would address		**Pilings and pile dike structures**. Extensive use of pilings and pile dikes has altered sediment accretion and erosion processes and reduced flow circulation through shallow-water habitats in the estuary. Pile structures also have created favorable conditions for predators of salmonids and can reduce physical access to low-velocity juvenile salmonid habitats. In some cases, treated pilings may release toxic contaminants, including PAHs, and it can be beneficial to remove these structures. In other cases, pile structures may protect riparian areas from erosion and wave energy, collect large wood to form complex habitat, and stimulate sediment accretion in the creation of habitat. In these cases, maintenance or modification of existing structures may be beneficial.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes, sediment/nutrient-related plume changes, exotic fish, native birds, and bioaccumulation toxicity.
Threat index[1]	12	This threat is a primary contributor to a high-priority limiting factor (altered predator/prey relationships), a secondary contributor to a high-priority limiting factor (sediment/nutrient-related estuary habitat changes) and two low-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	4	Removing many instream structures would improve circulation in shallow-water habitats and eliminate some salmonid predator habitats.
Affected salmonids		Ocean-type salmonids; stream-type salmonids (yearlings) leaving the heavier flows to forage in shallow waters downstream of pilings and pile dikes; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings);
Implementation constraints[3]	2	Only some of the thousands of pilings, pile dikes, and similar structures in the Columbia River estuary are necessary to maintain the shipping channel, protect property, or serve their intended economic use. Removal of superfluous structures generally is restricted only by cost and would be unlikely to affect property rights or the shipping industry. In cases where pile dikes that do aide in navigation are removed, constraints to implementation would include the cost for additional dredging to maintain the channel.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-9:

Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.

Primary threat this action would address		**Dikes and filling.** High-quality off-channel habitat provides crucial feeding, rearing, and refuge opportunities for juvenile salmonids and supplies macrodetrital inputs to the estuarine food web. Reduced floodplain inundation has limited juvenile salmonids' access to historical wetland and swamp habitat, much of which has been converted to other land uses. Protecting remaining intact and accessible off-channel habitats and restoring accessible but degraded off-channel areas are critical to maintaining key habitats and food sources for juvenile salmonids.
Associated limiting factors		Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants.
Threat index [1]	15	This threat is a primary contributor to both top-priority and high-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	5	Protecting high-quality off-channel areas would help maintain important wetland habitats and supply macrodetrital inputs to the food web and insect food sources for juvenile salmonids—a main component of their diet. Restoring or enhancing accessible but degraded off-channel areas in the estuary represents a largely untapped strategy that could provide similar benefits. Benefits from this strategy likely would be realized more quickly than from the passive restoration associated with CRE-10.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints [3]	3	Regulatory programs often do not effectively protect floodplains from conversion to other uses. The acquisition of land for habitat protection remains controversial in the estuary. Rural county governments see land disappearing off tax rolls and also listen to citizen disapproval of public ownership of land. Land acquisition is expensive and depends on the willingness of landowners to sell. Restoring accessible off-channel habitat also depends on willing landowners .The fact that many habitats already have been converted to other land uses limits opportunities to protect high-quality off-channel habitat.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-10:

Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.

Primary threat this action would address		**Dikes and filling.** Many juvenile salmonids rely on off-channel habitats for feeding and refuge opportunities. Historically, insects and macrodetritus from these habitats were important inputs to the estuarine food web. Dikes, levees, tide gates, and filling have limited the amount and accessibility of key off-channel habitats by reducing floodplain inundation and allowing conversion of land to agricultural, residential, and industrial uses. This action would allow juvenile salmonids access to habitats and food sources that currently are unavailable to them and support improved habitat conditions over time.
Associated limiting factors		Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants.
Threat index[1]	15	This threat is a primary contributor to both top-priority and high-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	5	Establishing or improving access to off-channel areas via dike breaching and similar activities would reclaim habitat that is important to salmonids. Over time, improved hydrology would support reestablishment of wetland vegetation and salmonid food sources in off-channel areas, through passive restoration. In most cases, project benefits would accrue over relatively long periods of time.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	Opportunities to establish or improve access to off-channel habitats are limited because many such habitats already have been filled with dredged materials. Breaching, lowering, or relocating dikes and levees or removing tide gates often requires the cooperation of multiple landowners and may fundamentally alter land uses. The associated habitat restoration is expensive.
Potential benefits with constrained implementation of action	4	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-11:

Reduce the square footage of over-water structures in the estuary.

Primary threat this action would address		**Over-water structures.** Over-water structures may provide habitats for predators and affect instream and shoreline plant communities. However, the total surface area of over-water structures in the estuary has not been quantified and the structures' case-by-case functions have not been analyzed.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes and exotic fish.
Threat index[1]	4	This threat is a tertiary contributor to a high-priority limiting factor (habitat changes) and a secondary contributor to one of the lowest priority limiting factors (exotic fish).
Potential benefits with unconstrained implementation of action [2]	3	Given the uncertainty about how much of a threat over-water structures actually pose to salmonids, the potential improvement in survival must be considered low pending additional research and analysis.
Affected salmonids		Ocean-type salmonids (because of their preference for the shallow-water habitats where most structures are located); stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	It is assumed that some over-water structures are more important than others and that removing superfluous or less useful structures would not have deleterious effects on adjacent land uses. Removal of over-water structures that are in currently use would likely require compensation. In some cases, structures such as log rafts could be relocated.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-12:

Reduce the effects of vessel wake stranding in the estuary.

Primary threat this action would address		**Ship wakes.** Wakes from deep-draft vessels traveling through the estuary wash subyearling salmonids onto shore, leaving them stranded. Factors that affect stranding include beach slope and time of day as well as vessel draft, speed, and hull design.
Associated limiting factors		Stranding.
Threat index[1]	6	This threat is a primary contributor to a low-priority limiting factor.
Potential benefits with unconstrained implementation of action [2]	2	The extent of mortality caused by ship wake stranding is unknown. Studies in 1977 and 1994 (Bauersfeld 1977, Hinton and Emmett 1994) reached different conclusions, using different approaches. A soon-to-be-released study by the University of Washington and U.S. Army Corps of Engineers may provide further clarification of the issue.
Affected salmonids		Ocean-type salmonids (because of their longer estuarine residency times, their relatively small size, and the habitats they prefer); stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	Options for reducing the effects of vessel wake stranding are limited, primarily because of the lost revenues that would result from slower ship travel. Ship traffic through the estuary will continue, ship hull design is unlikely to change, and the speed of ships traveling the estuary may be difficult to alter. Modification of some habitats may be necessary to reduce this threat and would likely be expensive.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-13:

Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.

Primary threat this action would address		**Altered predator/prey relationships.** Pikeminnows have always been a significant source of mortality for juvenile salmonids in the Columbia River, but changes in physical habitat, such as the addition of in-water structures, have created more favorable conditions for predation by pikeminnow. Introduced species such as smallmouth bass, walleye, and channel catfish also prey on juvenile salmonids, primarily in the freshwater reaches.
Associated limiting factors		Native fish and exotic fish.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action addresses only the native and exotic fish limiting factors, which have threat indexes of 12 and 3, respectively.
Potential benefits with unconstrained implementation of action [2]	4	Ecosystem alterations in the estuary as a result of pikeminnow, smallmouth bass, walleye, and channel catfish are uncertain. Scientists speculate that pikeminnow may be preying on both ocean- and stream-type juveniles. Stream-type juveniles may be affected significantly more than previously thought because evidence suggests that they forage in shallow areas downstream of piling structures.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Because of their abundance, pikeminnow appear to be a far greater threat to juvenile salmonids than bass, walleye, and channel catfish, at least at this time. Implementation activities to reduce pikeminnow predation are constrained by the challenge of reducing their preferred slack-water habitats. Bounty programs can be effective at removing older pikeminnow, which represent the largest threat to salmonids. Although the introduction of exotic fish to the estuary may be irreversible, there are viable tools for managing smallmouth bass, walleye, and channel catfish; these include habitat management and less restricted harvest management. It is likely that warm-water fishers would actively support maintaining the abundance of these species at current—rather than reduced—levels.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-14:

Identify and implement actions to reduce salmonid predation by pinnipeds.

Primary threat this action would address		**Altered predator/prey relationships.** Pinniped predation on adult salmonids at Bonneville Dam has been estimated at between 0.4 percent (2002) and 4.2 percent (2007) of the spring Chinook and winter steelhead runs, or possibly as high as 8.5 percent and 20 percent, respectively (based on radio-telemetry studies). The extent of predation needs further study and documentation.
Associated limiting factors		Native pinnipeds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to native pinnipeds.
Potential benefits with unconstrained implementation of action [2]	3	Actions to reduce predation by pinnipeds would have moderate impacts on salmonid survival, depending on how many adults are actually being consumed by pinnipeds—a question that remains uncertain.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[3]	4	Methods for reducing salmonid predation by pinnipeds are limited because pinnipeds are protected under the Marine Mammal Protection Act (MMPA). It could take years to amend the act to allow additional pinniped management tools. Non-lethal methods have been only minimally successful, although it is possible that additional testing would identify effective non-lethal methods. In 2008, NMFS granted Washington, Oregon, and Idaho authority to use and evaluate lethal methods of control under Section 120 of the MMPA.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-15:

Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.

Primary threat this action would address		**Altered predator/prey relationships.** Exotic plants in the estuary often out-compete native plants and change the structure of plant communities. The resulting habitat frequently does not provide the same food or shelter that other species, including salmonids, have adapted to over time.
Associated limiting factors		Exotic plants.
Threat index[1]	3	This threat contributes to many limiting factors, although the management action relates only to exotic plants, one of the lowest priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	2	Preventing and controlling invasive plants would help maintain the estuarine food web and habitats that juvenile salmonids rely on.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	4	Controlling existing infestations of certain species is functionally impossible once the species are established. Although landowners are the most important agents in preventing and controlling exotic plant infestations, landowner education is a significant task that requires a large effort.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-16:

Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.

Primary threat this action would address		**Altered predator/prey relationships.** Caspian tern predation represents a significant source of mortality for stream-type juveniles migrating to saltwater. Stream-type salmonids are particularly vulnerable because of the timing of their out-migration (during tern nesting season) and their preference for deep-channel habitats near tern nesting sites.
Associated limiting factors		Native birds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to Caspian terns.
Potential benefits with unconstrained implementation of action[2]	5	Reducing tern predation could have significant effects on the survival of stream-type salmonids, as terns have been documented to consume as much as 3 percent of stream-type juveniles migrating through the estuary.
Affected salmonids		Stream-type salmonids; ocean-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Management efforts have helped reduce mortality by relocating terns to nearby habitats. Long-term solutions will require habitat improvements elsewhere for Caspian terns.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-17:

Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.

Primary threat this action would address		**Altered predator/prey relationships.** Predation by double-crested cormorants represents a significant source of mortality for stream-type juveniles migrating to saltwater.
Associated limiting factors		Native birds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to double-crested cormorants.
Potential benefits with unconstrained implementation of action [2]	4	Studies indicate that double-crested cormorants prey on salmonid juveniles in the estuary at a rate equal to or greater than the rate by Caspian terns. Cormorants are estimated to have consumed an average of 7 million juvenile salmonids annually over the years 2001 to 2009.
Affected salmonids		Ocean- and stream-type juvenile salmonids are preyed upon by double-crested cormorants with some fluctuation from year to year. In 2009 double-crested cormorants consumed approximately 11 million juvenile salmonids.
Implementation constraints[3]	4	Double-crested cormorants are more difficult to relocate than Caspian terns. Techniques such as the use of decoys and audio playback have not been as effective compared to terns. Perch habitats are plentiful enough in the estuary that removal of pile dikes and other structures may not be an effective tool.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-18:

Reduce the abundance of shad in the estuary.

Primary threat this action would address		**Altered predator/prey relationships.** Shad returns to the Columbia River number approximately 4 million annually. Shad's effects on the estuary ecosystem and salmonids are poorly understood. However, shad are an introduced species and their biomass alone represents a threat to trophic relationships in the Columbia River.
Associated limiting factors		Exotic fish.
Threat index[1]	3	This threat contributes to many limiting factors, although the management action relates only to shad.
Potential benefits with unconstrained implementation of action [2]	2	The impacts of shad in the estuary are unclear. However, it is likely that reducing shad numbers would have some benefits for salmonids.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	5	Shad are thought to have permanently altered the estuary ecosystem, and their complete removal from the estuary is neither practical nor feasible. Effective management tools to limit shad productivity in the Columbia River basin currently are not available. Research is needed in the near term to determine the significance of this threat and identify potential management actions to manage the abundance of shad.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-19:

Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.

Primary threat this action would address		**Ship ballast practices.** Ship ballast water is responsible for the introduction of non-native aquatic invertebrates in the estuary. The effects of these introductions are poorly understood, but it is likely that exotic invertebrates disrupt food webs and out-compete juvenile salmonids' native food sources.
Associated limiting factors		Introduced invertebrates.
Threat index[1]	3	This threat is a primary contributor to one of the lowest priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	2	Reducing the impacts of non-native aquatic invertebrates would help maintain traditional salmonid food sources and the trophic relationships that salmon have adapted to.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	4	Improvements in ship ballast practices have already been implemented by the industry as a result of new regulations, and stricter regulations are currently being debated at the Federal level. However, there are inherent challenges in managing ballast water that contains organisms from other ecosystems. Also, once non-native aquatic invertebrates have been introduced, they represent a permanent alteration of the ecosystem and opportunities to reduce their effects may be few. Current understanding of how the estuary ecosystem is affected by introductions of exotic invertebrates is very limited.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-20:

Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.[1]

Primary threat this action would address		**Agricultural practices.** Fertilizers include different forms of nutrients that are important for plant growth. When fertilizers make their way to the estuary through overland runoff, they contribute nutrients to the estuary that increase phytoplankton production, alter the food web, and in some instances depress dissolved oxygen levels. Water-soluble contaminants such as simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl enter the estuary as a result of tributary and upstream agricultural practices. DDT and PCBs have been detected at elevated levels in the estuary. These and other agricultural contaminants can cause salmonid mortality through bioaccumulation or non-bioaccumulative toxicity.
Associated limiting factors		Non-bioaccumulative toxicity, bioaccumulation toxicity, and increased microdetrital inputs.
Threat index [2]	12	This threat is a primary contributor to a high-priority limiting factor (non-bioaccumulative toxicity) and a medium-priority limiting factor.
Potential benefits with unconstrained implementation of action [3]	3	Reducing the level of pesticides and herbicides in the estuary would improve survival by reducing ocean-type salmonids' acute and chronic exposure to toxic contaminants and stream-type salmonids' acute exposure.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[4]	4	Impacts from pesticides and fertilizers have lessened dramatically since the 1950s as a result of new application technologies, new products, and better understanding and regulation of these toxins. More extensive compliance with existing regulations and usage guidelines, along with development of additional best management practices, could further reduce the impacts of pesticides and fertilizers. The integration of new practices can be expensive and time-consuming.
Potential benefits with constrained implementation of action	1	

[1] The term best management practices is used here to indicate general methods or techniques found to be most effective in achieving an objective. NMFS envisions that in implementation, specific best management practices would be developed or recommended.

[2] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[3] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[4] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-21:

Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.

Primary threat this action would address		**Urban and industrial practices.** The estuary has been affected by historical and current releases of toxic contaminants, including industrial and commercial pollutants such as PCBs and PAHs. These substances have been found near Portland, Vancouver, Longview, and Astoria. Studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants. In addition, urban and industrial effluent and stormwater runoff are principal sources of nutrients that can support increased phytoplankton levels.
Associated limiting factors		Non-bioaccumulative toxicity, bioaccumulation toxicity, and increased microdetrital inputs.
Threat index[1]	12	This threat is a primary contributor to high- and medium-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	4	Reducing sources of pollutants would lower water temperature, nutrient loading, and the amount of toxic contaminants in the estuary. This would improve both habitat capacity in the estuary and the fitness level of salmonids.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[3]	4	While some discharges of industrial and commercial pollutants are permitted, others are not. Efforts to reduce industrial and commercial pollutants are already under way, and there is potential to reduce point-source emissions. Efforts to reduce sources of pollutants are expensive and time-consuming and often have a negative economic effect on operations.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-22:

Restore or mitigate contaminated sites.

Primary threat this action would address		**Urban and industrial practices.** The estuary has been affected by historical and current releases of toxic contaminants, including industrial and commercial pollutants such as PCBs and PAHs. These substances have been found near Portland, Vancouver, Longview, and Astoria. Studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants. The action is intended to address the need to monitor the entire estuary for contaminants; however, actual restoration activities are feasible only in specific reaches.
Associated limiting factors		Non-bioaccumulative toxicity and bioaccumulation toxicity.
Threat index[1]	12	This threat is a primary contributor to high- and medium-priority limiting factors.
Potential benefits with unconstrained implementation of action [2]	5	Reducing toxic contaminants in the estuary would improve both habitat capacity and the fitness level of salmonids.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[3]	3	Monitoring activities are already occurring; however, actual restoration of contaminated sites is expensive and technically challenging in many cases. In cases where restoration is not feasible, the effects of contaminated sites should be mitigated.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Management Action CRE-23:

Implement stormwater best management practices in cities and towns.[1]

Primary threat this action would address		**Urban and industrial practices.** Municipal stormwater runoff can convey nutrients and toxic contaminants to the estuary, reduce groundwater recharge, and increase the "flashiness" of stream flows. Although cities and towns in the Columbia River basin generally have programs to reduce the impacts of stormwater runoff, stormwater best management practices have not been universally accepted or implemented throughout the basin.
Associated limiting factors		Non-bioaccumulative toxicity, bioaccumulation toxicity, and increased microdetrital inputs.
Threat index[2]	9	This threat is a secondary contributor to a medium-priority limiting factor as it relates to this management action.
Potential benefits with unconstrained implementation of action [3]	2	Identifying and implementing stormwater best management practices throughout the Columbia River basin would improve conditions and provide a net benefit to salmonids in the estuary through a more normal flow regime, reduced exposure to contaminants, and lower water temperatures.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[4]	2	Some cities lack the resources or will to implement or enforce stormwater best management practices. The benefits of improved stormwater practices generally are associated only with new development and do not offset the full impact of the impervious surfaces in those developments, or the existing impervious surfaces in areas that have already been developed.
Potential benefits with constrained implementation of action	1	

[1] The term best management practices is used here to indicate general methods or techniques found to be most effective in achieving an objective. NMFS envisions that in implementation, specific best management practices would be developed or recommended.

[2] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[3] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[4] Indicates the feasibility of implementing the action.
1 = Current constraints to implementation are minimal.
5 = Current constraints to implementation are significant.

Table 5-2 estimates the potential of each management action to benefit salmonids under two different implementation scenarios. Assuming that implementation of most actions is significantly constrained, which management actions would be likely to result in the greatest survival improvements?

In partial answer to this question, Table 5-3 summarizes the potential benefits of each action under both unconstrained and constrained implementation scenarios. It is tempting to sort the actions in Table 5-3 by potential benefit with constrained implementation and view the sorted list as a prioritized list of management actions, with the actions at the top being those predicted to have the greatest benefits. Although Table 5-3 does provide insight into the relative benefits of the various management actions, it is perhaps most useful as a means of contrasting the benefits that might be achieved with unconstrained implementation of an action with the benefits that might be achieved under a more likely scenario of constrained implementation.

To provide greater insight into the relative benefits of each management action, PC Trask & Associates, Inc., developed a second analysis based on survival improvement targets. This analysis, which is presented in the next section of the document, is more refined and specific than the analysis in Table 5-3. For instance, it focuses more on how the potential benefits of the 23 management actions would compare to each other and on the survival benefits that might be gained from each action. It also evaluates the benefits of each action to both ocean- and stream-type salmonids.

TABLE 5-3
Summary of Constraints to Implementation of Management Actions

Number	Action Description	Benefit with Unconstrained Implementation of Action[1]	Benefit with Constrained Implementation of Action[2]
CRE-01	Protect intact riparian areas in the estuary and restore riparian areas that are degraded.	4	2
CRE-02	Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.	3	2
CRE-03	Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.	2	1
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.	5	3
CRE-05	Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.	2	1
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	2	1

Number	Action Description	Benefit with Unconstrained Implementation of Action[1]	Benefit with Constrained Implementation of Action[2]
CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.	2	1
CRE-08	Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.	4	2
CRE-09	Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.	5	3
CRE-10	Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.	5	4
CRE-11	Reduce the square footage of over-water structures in the estuary.	3	1
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	2	1
CRE-13	Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.	4	2
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	3	2
CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.	2	1
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	5	3
CRE-17	Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	4	2
CRE-18	Reduce the abundance of shad in the estuary.	2	1
CRE-19	Prevent new introductions of invertebrates and reduce the effects of existing infestations.	2	1
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.	3	1
CRE-21	Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.	4	3
CRE-22	Restore or mitigate contaminated sites.	5	3
CRE-23	Implement stormwater best management practices in cities and towns.	2	1

[1]Estimate of potential benefit if action is fully implemented, with no constraints.
1 = very low benefits.
5 = very high benefits.

[2]Estimate of potential benefit assuming that implementation is constrained.
1 = very low benefits.
5 = very high benefits.

Evaluation of Management Actions: Survival Improvement Targets

The Columbia River estuary and plume are only two of many ecosystems that salmonids travel in their complex and lengthy journey from headwaters to ocean and back again. Mortality occurs at every stage of this journey. Each year, scientists from the NMFS Northwest Fisheries Science Center estimate the number of juvenile salmonids that enter the estuary from upstream of Bonneville Dam and from estuary tributaries. For 2006, scientists from NMFS estimated that about 168 million juvenile salmonids (both wild and hatchery) would enter the estuary (Ferguson 2006b). Some years later, the surviving fish return to the estuary in varying numbers, with the average return in the last 10 years being approximately 1.7 million fish; roughly 65 to 75 percent of those fish are of hatchery origin.[1] This means that less than 1 percent of the juveniles that enter the estuary are returning as adults.

Estimating Juvenile Mortality in the Estuary and Plume

How much juvenile mortality is occurring in the estuary and plume? The answer to this question is fundamental to developing an understanding of the role the estuary will play in the recovery of salmonid populations basinwide. The answer also is critical in evaluating the benefits and costs of potential management actions because it helps establish the level of effort needed to offset threats to salmonids in the estuary. Unfortunately, determining how much juvenile mortality is occurring in the estuary and plume is challenging for scientists. Counting juveniles in the Columbia River estuary and plume is problematic because available tracking technologies are limited, and it is difficult to monitor juveniles—which tend to move in and out of saltwater—in large, high-energy sites such as the mouth of the Columbia River.

However, some efforts have been made to separate mortality that occurs in the estuary and plume from mortality that occurs in the ocean. One such effort has been the underlying assumptions in the Ecosystem Diagnosis and Treatment (EDT) model, which is used extensively throughout the Columbia River basin. For juveniles entering the estuary from tributaries to the lower Columbia River, EDT assumes mortality rates in the estuary and plume of between 18 and 58 percent, depending on the salmonid species and the amount of time juveniles spend in the estuary (Lower Columbia Fish Recovery Board 2004). In a study of juvenile mortality in the estuary, Schreck et al. (2006) estimated spring/summer Chinook mortality at between 11 and 17 percent, largely from avian predation.

In addition, research is under way by NMFS, the U.S. Army Corps of Engineers, and Battelle Laboratories to estimate the survival rate of juvenile salmonids in the lower Columbia River. This research involves new technologies for miniaturizing acoustic tags to a size capable of tracking yearling and subyearling juveniles. Current technology developed for the project allows for the tracking of subyearlings of sizes down to approximately 90 mm. Results for the first year (2005) indicated an approximate range of survival of 65 to 75 percent for subyearlings and yearlings during their residency in the estuary (Ferguson 2006a). It is probable that actual survival rates are lower than these preliminary estimates suggest

[1] This is an informal estimate; determining the ratio of hatchery-origin fish with more certainty would require stock-by-stock run calculations averaged over many years.

because the research did not address mortality among juveniles smaller than 90 mm or mortality occurring in the plume and nearshore. The studies above have not been conclusive, and separating estuarine and ocean mortality for juvenile salmonids in the Columbia River remains significant challenge.

Some specific estimates of salmonid mortality are known in the estuary; they include estimates for double-crested cormorants and Caspian terns. For other threats to salmonids, such as toxic contamination, ship wake stranding, and pinniped predation, information on mortality in the estuary is incomplete or relatively new in the literature. Still other threats, especially those related to the food web, are poorly understood and have no mortality estimates associated with them, although in some cases the change in conditions from the historical template to the present has been well documented.

Establishing Survival Improvement Targets

An important goal of this estuary recovery plan module is to estimate the potential benefits—in terms of increased survival of salmonids in the estuary—that could result from the implementation of different management actions. To accomplish this goal, PC Trask & Associates, Inc., used available information about limiting factors, threats, and constraints to the implementation of management actions to assign benefits that could possibly result from different actions.

If scientific understanding of the relationships between ecological conditions and biological responses in estuarine systems were robust, it would be attractive to assign specific mortality rates to each of the factors limiting salmonids' biological performance in the Columbia River estuary. Then one could follow a deterministic logic path that associates mortality rates with specific threats, relates the mortality rates to management actions, and ultimately arrives at an estimate of the survival improvement that would be likely to result from each action. This is not possible at this time, and it will likely not be possible until there have been significant advances in scientific understanding of the complex estuarine environment.

To compensate for the lack of detailed information on mortality in the estuary, PC Trask & Associates, Inc., established targets for improved survival of wild ESA-listed salmonids rearing and migrating in the estuary and plume, assuming that the implementation of management actions is constrained to the degree indicated in Table 5-2. PC Trask & Associates, Inc., then allocated these survival targets to individual management actions. These targets are intended to serve as a planning tool useful in characterizing the potential results of actions and describing the level of effort needed to recover salmonids.

The primary purpose of the survival improvement targets is to help compare the potential benefits of different management actions, particularly actions that partially address major limiting factors versus actions that fully address minor limiting factors. In addition, the survival improvement targets provide insight into the specific survival benefits of each action and the differential benefits of each action to stream- and ocean-type salmonids. Numerically, the survival improvement targets in this chapter were based on an estimate of the number of naturally produced ESA-listed ocean- and stream-type juvenile salmonids entering the estuary. The total number of naturally produced ESA-listed juvenile salmonids estimated to enter the estuary in 2006 was approximately 39 million (Ferguson 2006b).[2] Of these, approximately 25 million were estimated to be ocean type and 14 million were estimated to be stream type.

To establish survival improvement targets, PC Trask & Associates, Inc., developed some assumptions about the overall mortality of juvenile salmonids during estuary and plume residency. Ocean-type juveniles were assumed to have an overall mortality rate of 50 percent during their estuary residency; this includes the 35 percent mortality suggested by the unpublished micro-acoustic tagging research (Ferguson 2006a) plus an additional 15 percent to account for juveniles too small to be tracked. Stream-type juveniles were assumed to have an overall mortality rate of 40 percent during estuary and plume residency. This rate was based on the 25 percent mortality found in the micro-acoustic tagging research (Ferguson 2006a) plus an additional 15 percent to account for mortality occurring in the plume, which was not part of study. These assumptions about estuary mortality are based on best professional judgment by PC Trask & Associates, Inc., after a review of pertinent literature and discussions with subject matter experts, including scientists at the NMFS Northwest Fisheries Science Center.

Table 5-4 shows the number of wild, ESA-listed ocean- and stream-type juveniles thought to be entering the lower Columbia estuary and plume, their estimated mortality and survival rates based on the assumptions above, and the number of juveniles estimated to survive their journey through the estuary and plume—again, based on the assumptions above.

TABLE 5-4
Estimated Mortality Rates, Survival Rates, and Survival Improvement Targets for Wild, ESA-Listed Juveniles

Type	Juveniles Entering Estuary*	Assumed Mortality Rate	Assumed Survival Rate	Estimated Number of Juveniles Exiting Estuary and Plume*	Survival Improvement Target (20 percent)**
Ocean Type	25 million	50%	50%	12.5 million	2.5 million***
Stream Type	14 million	40%	60%	8.4 million	1.68 million***

* = Wild, ESA-listed juveniles.

** = Twenty percent of the estimated number of juveniles exiting the estuary and plume; this target represents additional fish surviving their estuary and plume residency.

*** These numbers are used to characterize the potential, relative benefits of implementing various management actions and do not represent actual numbers of additional fish expected to survive.

Table 5-4 also presents survival improvement targets for ocean- and stream-type salmonids in the estuary and plume. For planning purposes only, this estuary recovery plan module selects 20 percent as a target for improvement in the survival rate of wild, ESA-listed ocean- and stream-type juveniles in the estuary and plume. Twenty percent represents a hypothetical level of improvement that might be realized through the implementation of the management actions, assuming that considerable effort is expended to help offset constraints to implementation, such that threats and limiting factors are reduced. For ocean types, increasing survival by 20 percent would result in a total of 15 million juveniles exiting

[2] Current scientific information on the effects of limiting factors and actions does not differentiate between hatchery- and natural-origin salmon and steelhead, or between salmon and steelhead that are listed under the ESA and those that are not. Because ESA recovery is determined by the status of natural-origin fish, the intent of the module is to improve the estuarine survival of naturally produced, ESA-listed salmon and steelhead. Naturally produced fish are the focus of the analysis of survival improvement targets because they are the focus of the module.

the estuary and plume—2.5 million more juveniles than the current estimate of 12.5 million. For stream types, a 20 percent improvement would equal 10.08 million—1.68 million additional juveniles beyond the current 8.4 million that are estimated to exit the estuary and plume. Thus the survival improvement targets for ocean- and stream-type salmonids are 2.5 million and 1.68 million, respectively, as shown in Table 5-4. Targets for both types were set at 20 percent to avoid the appearance of a false level of precision in establishing them. Ocean-type juveniles were assumed to incur more mortality in the estuary and nearshore compared to stream types. Stream types were assumed to incur less mortality in the estuary than ocean types but significantly more mortality in the plume.

PC Trask & Associates, Inc., selected the 20 percent survival improvement number for ocean- and stream-type juvenile salmonids based on a qualitative analysis of the level of improvement that reasonably and plausibly might be expected if the 23 management actions were implemented. In establishing the 20 percent target, PC Trask & Associates, Inc., reviewed existing management plans, other literature sources, and the constraints analysis in Table 5-2. However, setting 20 percent as the target for improvement, rather than 15 or 30 percent, is inherently subjective and relies in part on the following assumptions:

- That estuary mortality for juveniles (currently between 40 and 50 percent, depending on population) can be reduced by initiating restoration projects and reducing uncertainties through research and monitoring
- That mortality rates associated with certain threats, such as Caspian terns and cormorants, are well understood and will be lessened through actions specified in management plans that are reasonably likely to be implemented
- That all of the actions identified in this chapter are implemented to a reasonable degree and historical and current constraints to action implementation are thoroughly challenged

Actual improvements in survival will depend on which management actions are implemented, how fully they are implemented, and their efficacy—factors that at this point are open to interpretation and can be qualitatively estimated only. Although the 20 percent targets for ocean- and stream-type salmonids are intended to be reasonable and plausible given the information available to date, open technical, political, and social discussion could refine the targets until science can substantiate them.

The survival improvement targets in Table 5-4 were developed using ocean- and stream-type life history strategies to characterize the 13 ESUs in the Columbia River basin. As a result, the survival improvement targets do not account for important variations found at the ESU, population, and subpopulation scales. For example, not all ocean-type ESUs in the Columbia River basin exhibit the same run timing, size at estuary entry, or use of particular habitats (Fresh et. al 2005). In fact, this variability in estuarine use by the ESUs is fundamental to the member/vagrant theory proposed by the NMFS Northwest Fisheries Science Center and a central premise of the estuary recovery plan module (see Chapter 2 for more information on the member/vagrant theory). Although genetic and spatial diversity are not explicitly accounted for in survival improvement targets, the suite of management actions identified in the estuary recovery plan module is intended to collectively address all life history strategies historically expressed in the estuary and plume. This further emphasizes that the survival improvement targets are best viewed as a planning tool only. In reality, there will be significant variability among ESUs, populations, and subpopulations in how much additional survival might result from improvements in estuary and plume habitat.

Assigning Survival Improvement Targets to Recovery Actions

The usefulness of the 20 percent target lies not in the 20 percent number itself, but in the distribution of the targets (2.5 million ocean-type juveniles and 1.68 million stream-type juveniles) across the various management actions, as a way of characterizing the relative benefits of the various management actions.[3] Table 5-5 shows this allocation of survival improvement targets to the 22 management actions for juvenile salmonids.[4] In cases where there is good scientific literature that supports the allocation of survival targets, as with terns and cormorants, PC Trask & Associates, Inc., used that information as a basis for the analysis in Table 5-5. In other cases, such as reservoir-related temperature changes, PC Trask & Associates, Inc., estimated survival improvements based on literature discussion of related limiting factors and threats. The reader should view the resulting survival improvement targets as the product of a planning exercise, not a representation of deterministically based estimates. (Appendix B presents more information on how PC Trask & Associates, Inc., allocated survival improvement targets to the different actions.)

Although the survival improvement targets in Table 5-5 are estimates only, they complement the analysis summarized in Table 5-3.[5] In addition, they provide a useful way to show the potential magnitude of juvenile survival at the action scale relative to other actions. The survival improvement targets illustrate how a small increment of implementation of a far-reaching action could offer significantly more potential for recovery than full implementation of an action that is more limited in scope. Comparison of Tables 5-3 and 5-5 and the cost estimates that are developed in the next section form the basis for prioritization of actions in Chapter 7, "Perspectives on Implementation."

A special case in assigning survival improvement targets to actions are those actions (CRE–01 and CRE–09) that use land protection as a means of achieving the target. In theory, protection projects contribute only to maintenance of baseline conditions and not to recovery. However, the estuary recovery plan module does assign a portion of the survival improvement targets to protection projects. The reasoning here is that without protection of baseline environmental conditions, significantly more effort would be required in restoration projects to offset the continued loss of functioning habitat that would result from increases in the human population and corresponding conversion of habitats to economically beneficial land uses. Thus, assigning survival improvement targets to

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3 Although for the purposes of this analysis 20 percent is considered a hypothetical number, it is a plausible number. The 20 percent figure is based on overall estimates of juvenile mortality in the estuary, known mortality that can be attributed to specific threats, and professional judgment regarding the efficacy of the different management actions and the likelihood that constraints to their implementation can be overcome.

4 Although the survival improvement targets are expressed in terms of numbers of natural-origin ESA-listed fish, this is simply to illustrate the potential benefits of actions, not to analyze differential benefits to natural-origin listed fish versus unlisted or hatchery-origin fish; what is important is the allocation of relative benefits among the management actions.

5 Table 5-2 contrasts the difference between constrained and unconstrained implementation of an individual action, while Table 5-5 compares potential benefits across the entire set of actions. Given the two tables' different purposes, there is not a mechanistic relationship between them. However, there is a rough correlation between the potential benefits of constrained implementation in Table 5-2 and where an action falls in the relative rankings presented in Table 5-5.

protection projects reflects the value of avoiding the additional effort that would be required to restore functioning habitats lost because they were not protected.

Uses of the Survival Improvement Targets

The purpose of the survival improvement targets in Table 5-5 is to address a particular planning challenge in the estuary module: how to compare the potential benefits of management actions that are disparate in their scope and feasibility, especially when scientific information about the causes of salmonid mortality in the estuary is incomplete. In the absence of comprehensive scientific data, the targets provide a useful framework for evaluating the relative merits of different actions. However, survival improvement targets do not represent actual numbers of fish.

For example, it would be inappropriate to use the survival improvement targets to estimate total juvenile mortality in the estuary, attribute a level of mortality to a specific limiting factor or threat, or calculate "per-fish" costs of actions. Because the survival improvement targets are not scientifically derived, they have limited use for life-cycle modeling. On the other hand, the targets could serve as a starting point for life-cycle modeling in the absence of rigorous data.

It also would be unwise to predict specific outcomes of an action or suite of actions based solely on the survival improvement targets. Although it would be appropriate to use the targets to guide expenditures and the selection of individual projects that are consistent with the module's management actions, monitoring should accompany any implementation of those projects—to evaluate their effectiveness, test the assumptions underlying the targets, and provide a basis for refining them.

Because the survival improvement targets are a tool for comparing the relative benefits of actions, they are particularly useful in weighing the trade-offs involved in implementing some actions but not others, or implementing actions only partially. For example, in theory, if a certain action were implemented partially or not at all, the potential 20 percent gain in the number of wild, ESA-listed juveniles leaving the estuary and plume could not be achieved unless other actions were implemented to a greater extent than envisioned in the module, to compensate. Survival improvement targets provide a way of evaluating various scenarios for implementation. This is critical because the implementation of every action already is constrained (often significantly) and, in most cases, the opportunities to remove constraints and implement actions more fully are limited.

TABLE 5-5
Survival Improvement Targets Allocated to Management Actions[1]

Number	Action Description	Survival Improvement Target[1] with Constrained Implementation (numbers of wild, ESA-listed fish)			
		Ocean Type[1]	% of Total Improvement Target	Stream Type[1]	% of Total Improvement Target
CRE-01	Protect intact riparian areas in the estuary and restore riparian areas that are degraded.	150,000	6%	100,000	6%
CRE-02	Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.	90,000	4%	20,000	1%
CRE-03	Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.	25,000	1%	20,000	1%
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.	225,000	9%	125,000	7%
CRE-05	Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.	5,000	<1%	5,000	<1%
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	50,000	2%	15,000	<1%
CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	8,000	<1%	10,000	<1%
CRE-08	Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.	150,000	6%	100,000	6%
CRE-09	Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.	400,000	16%	150,000	9%
CRE-10	Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.	450,000	18%	100,000	6%
CRE-11	Reduce the square footage of over-water structures in the estuary.	25,000	1%	3,000	<1%
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	55,000	2%	2,000	<1%

Number	Action Description	Survival Improvement Target[1] with Constrained Implementation (numbers of wild, ESA-listed fish)			
		Ocean Type[1]	% of Total Improvement Target	Stream Type[1]	% of Total Improvement Target
CRE-13	Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.	140,000	6%	122,000	7%
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	N/A[2]	N/A	1,034[2]	N/A
CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.	20,000	<1%	15,000	<1%
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	2,000	<1%	350,000	21%
CRE-17	Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	2,000	<1%	250,000	15%
CRE-18	Reduce the abundance of shad in the estuary.	5,000	<1%	5,000	<1%
CRE-19	Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.	8,000	<1%	2,000	<1%
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.	50,000	2%	42,000	3%
CRE-21	Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.	275,000	11%	72,000	4%
CRE-22	Restore or mitigate contaminated sites.	300,000	12%	142,000	8%
CRE-23	Implement stormwater best management practices in cities and towns.	65,000	3%	30,000	2%
	Total	2.5 million		1.68 million	

[1] Appendix B presents more information on how survival improvement targets were developed.

[2] The survival improvement targets are assigned for juvenile salmonids only. Although CRE-14 relates specifically to adult salmonids, the survival numbers for CRE-14 are not included in the 20 percent survival improvement targets for juvenile salmonids. The stream-type survival number is based upon an estimated 17 percent reduction in adult fish mortality applied to 2010 run-size information reported in U.S. Army Corps of Engineers (2010). Some mortality may be occurring as a result of pinniped predation on ocean-type juvenile salmon and steelhead. The extent to which this is occurring has not been established.

Evaluation of Management Actions: Costs and Schedule

Implementing recovery actions in the estuary will require a long-term commitment by many entities. In Tables 5-2 and 5-5, two approaches were used to portray the potential survival improvements associated with implementing actions. In Table 5-6, each action is broken down into one or more projects that can be considered elements of that action.

For some management actions, the first project involves conducting a study or assembling existing technical information. There are several reasons for this. In some cases, existing information about how to reduce the associated threat to salmonids is limited, and additional study is needed to identify and pilot-test possible actions to determine which ones would be most effective. This is particularly important when funds for implementing management actions are limited. Additionally, conducting a study or assembling technical information involves stakeholders who may have local knowledge about the threat or will be responsible for implementing projects. Lastly, studies and information gathering provide an opportunity to understand the constraints of management actions, to reexamine assumptions about what is and is not possible, and to explore the lengths to which, as a society, we are willing to go to implement actions that will contribute to the recovery of salmon and steelhead in the Columbia River basin. The intent of including studies and information gathering in the management actions, when appropriate, is not to postpone taking on-the-ground action but to ensure that any actions that are taken are truly effective, that stakeholders are involved in the process, and that important dialogue occurs about the value of reducing constraints and implementing management actions as fully as possible, even in situations where implementation is highly constrained.

The recovery plan module does not present a detailed list of projects waiting to be completed in the estuary. This is because in many cases, additional work is needed to develop complex, large-scale projects that will provide maximum benefit, or to work with landowners and other stakeholders to gain their support, or to understand the most effective avenue for implementation.

Table 5-6 provides cost estimates for each of the 23 actions in the estuary recovery plan module and a timeframe for their implementation. Each project in Table 5-6 has a corresponding unit and cost, and the project costs are summed to produce a total cost for each action. The costs identified in this section do not represent a detailed economic analysis; in fact, they are not economic costs in that they have not been discounted across time. Instead, the cost estimates are in constant dollars over a 25-year period. A 25-year implementation period was selected for several reasons. Many of the actions identified in the estuary module include project types that have never been implemented in the estuary, and it will take time to establish or modify programs to implement these projects; some will require new research and monitoring to guide their effective implementation. In addition, a 25-year implementation period will allow time to identify funding sources and build the landowner buy-in and project sponsor capacity needed to implement the 23 actions.

In most cases the costs listed in Table 5-6 are direct, incremental costs, meaning that they are (1) out-of-pocket costs that a public or private interest would pay to initiate and complete a management action, and (2) costs in addition to the baseline costs for existing programs and activities, which may or may not be focused on salmon recovery. This approach is consistent with NMFS Northwest Regional Office guidance on cost estimates for ESA recovery plans. In some cases, distinctions between baseline and incremental costs are clear. For instance, reducing the abundance of shad (CRE-18) is an action that includes only incremental costs because it is a new action that has yet to be implemented in the estuary. Other actions, such as breaching, lowering, or relocating dikes (CRE-10), have been implemented in the estuary at a relatively modest scale. For such actions, the estuary recovery plan module cost estimate is still entirely incremental in that it identifies an additional level of effort needed to achieve the survival improvement targets identified later in this chapter.

Several of the 23 actions do contain some baseline costs, because in some cases these baseline costs represent a small fraction of the overall implementation cost of the action and it was deemed infeasible to separate out the incremental costs. In these cases, this fact is noted in Table 5-6 under the key assumptions for the individual management action. For example, Caspian tern management (CRE-16) is supported by an existing management plan, and some efforts are already under way to implement the action. The other two examples are managing pikeminnow and other piscivorous fish (CRE-13) and implementing stormwater best management practices (CRE-23). In these examples, programs are in place, but major portions of the estuary recovery plan module action have not been implemented to date. In addition, for one action—adjusting the timing, magnitude, and frequency of hydrosystem flows (CRE-4)—the primary costs are the costs of foregone power generation. Generally, recovery action cost estimates do not include such opportunity costs. We have included an estimate of such costs in this case because otherwise this action would have skewed the cost-effectiveness assessment in Chapter 7 (see Table 7-5) in a way that would preclude constructive dialogue about adjusting flows.

The cost estimates in Table 5-6 were developed by PC Trask & Associates, Inc., and reviewed by the Lower Columbia Fish Recovery Board, the Lower Columbia River Estuary Partnership, and NMFS. In addition, an economist at the NMFS Northwest Fisheries Science Center reviewed Chapter 5 and provided comments (although not a detailed evaluation of the costs). Lower Columbia River Estuary Partnership staff contributed substantively to cost estimates for actions for which the Estuary Partnership has some history of implementation. For example, the Estuary Partnership has funded multiple dike breaches (CRE-10), riparian protection projects (CRE-1), and off-channel protection/restoration projects (CRE-9). In other cases, where possible, experts knowledgeable about implementing similar actions were consulted. For example, staff from the NMFS Northwest Regional Office were consulted to estimate costs for managing pinnipeds (CRE-14).

In still other cases, a coarse estimate was established based on the component projects and assumptions about the feasibility of their implementation. These were generally cases in which the extent of on-the-ground actions could not be determined until certain scientific or technical questions have been answered more definitively through studies or information gathering (see, e.g., CRE-2, CRE-7, CRE-12, CRE-18). In these cases, costs of any assessment work were estimated, and then a coarse-scale, placeholder cost estimate was developed based on assumptions about the magnitude and nature of subsequent projects needed to implement the management action. It is expected that such cost estimates will be refined as more specific projects are defined.

Thus the cost estimates in Table 5-6 attempt to establish a realistic cost for recovery, but the precision with which costs can be estimated at this time is limited, and there is considerable uncertainty in all the cost estimates. In Chapter 6, some additional costs are identified for research, monitoring, and evaluation activities (see Table 6-7).

The estuary recovery plan module addresses habitat conditions for all Columbia River basin ESUs during a single stage of their life cycle, but many additional management actions—including actions in the tributaries—will be needed to achieve recovery of any particular ESU. Because the management actions in the module are only a subset of all the actions needed for recovery of an ESU, the costs in Table 5-6 do not reflect the total costs to achieve recovery. Total costs for recovery are more appropriately represented in the recovery plans for each ESU, as these plans deal with multiple life stages for a specific ESU.

Each action in Table 5-6 includes a proposed schedule for implementation. The schedule is designed to place projects in a logical order and spread costs over a long period of time when possible. Costs are estimated over a 25-year span, with some projects being implemented once over a relatively short period and others continuing over the entire 25 years.

Other elements contained in Table 5-6 include the association of actions to specific geographical reaches, key assumptions about actions, a list of potential implementers,[6] notes that help explain how costs were developed, and a brief summary of some of the existing programs that address limiting factors identified in this recovery plan module. The summaries of existing programs are not exhaustive and are intended to emphasize that opportunities exist to build on existing programs to improve salmon and steelhead survival in the estuary. The relationship of actions to the eight geographic reaches and the plume helps to define the breadth of the action and may also indicate which jurisdictions may implement actions in the future. Key assumptions relate primarily to implementation and provide insight into the level of effort reflected in the action costs. Notes are specific information that helps clarify a particular unit or cost.

[6] The list of potential implementers is intended only to indicate entities that *may* have a role in implementation and to serve as a guide to begin discussion of implementation roles. It does not imply any budgetary, regulatory, or other responsibility for implementation.

TABLE 5-6
Estimated Cost and Schedule

Management Action CRE-1:

Protect intact riparian areas in the estuary and restore riparian areas that are degraded.

Project	Unit	Cost	Schedule
1. Educate landowners about the ecosystem benefits of intact riparian areas and the costs of degraded riparian areas.[1]	20 years @ $50,000/year	$1 million	2008 - 2028
2. Encourage and provide incentives for local, state, and Federal regulatory entities to maintain, improve (where needed), and enforce consistent riparian area protections throughout the lower Columbia region.[2]	10 years @ $500,000/year	$5 million	2008 - 2018
3. Actively purchase riparian areas from willing landowners in urban and rural settings when the riparian areas cannot be effectively protected through regulation or voluntary or incentive programs and (1) are intact, or (2) are degraded but have good restoration potential.	Rural: 3,500 acres at $5,000/acre[3] Urban: 100 acres at $75,000/acre	$25 million	2007 - 2031
4. Restore and maintain ecological benefits in riparian areas; this includes managing vegetation on dikes and levees to enhance ecological function and adding shoreline/instream complexity for juvenile salmonid refugia.	28 miles @ $250,000/mile	$ 7 million	2006 - 2031

Total costs: $38 million

Geographical priority: Reaches A-H and the Lower Willamette reach.

Key assumptions: (1) New homes, businesses, and industry will increase with population growth in the basin. (2) Some intact riparian areas are not adequately protected. (3) Protecting intact riparian areas would be cheaper than restoring degraded areas. (4) Some degraded riparian areas could be restored and gain ecological function, with associated downstream benefits. (5) Comprehensive protection and restoration of riparian habitats would occur concurrently with population growth, which will continue at a high rate.

Existing efforts: Protection of riparian areas relies heavily on local governments; the content and implementation of their land use plans specifically for shoreline and floodplain protection will be key to this action. Multiple Federal and state resource agencies provide funding for land acquisition and restoration, and multiple entities such as land trusts and watershed councils actively acquire and restore lands in the lower river. The Division of State Lands in Oregon and the Department of Natural Resources in Washington own and/or regulate submerged and submersible lands. The Natural Resource Conversation Service and conservation districts provide technical assistance to private landowners. Where water quality issues (such as toxic or conventional contaminants) are involved, agencies such as Washington's Department of Ecology and Oregon's Department of Environmental Quality may provide additional support.

Potential implementers:

- U.S. Army COE
- BPA
- WA Dept. of Fish & Wildlife
- OR Dept. of Fish & Wildlife
- Cities\Counties
- Port districts
- Conservation districts
- Columbia Land Trust
- The Wetlands Conservancy
- The Nature Conservancy
- Ducks Unlimited
- Natl. Fish & Wildlife Foundation
- Tribes
- OR Watershed Enhance. Bd.
- Salmon Recovery Fund. Bd.
- Lower Col. River Est. Partnership
- National Marine Fisheries Service
- Col. River Estuary Study Taskforce
- Utility districts
- Watershed councils

Notes:

[1] Projects CRE-1.1 and CRE-9.1 both call for outreach efforts. Outreach efforts for these two actions will be combined in a single outreach program whose costs will be shared.

[2] Projects CRE-1.2 and CRE-9.2 both call for incentives for local, state, and Federal entities to maintain, improve, and enforce regulatory protections. Given their similarities, activities for CRE-1.2 and CRE-9.2 could be coordinated or combined into one effort.

[3] Acreage amounts are 25-year targets that depend on willing sellers and funding.

Management Action CRE-2:

Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.

Project	Unit	Cost	Schedule
1. Conduct a reservoir heating study to determine the extent of the issue and identify hydrosystem operational changes (including design) that would reduce effects and/or mitigate downstream temperature issues.	1 study	$2.5 million	2007 - 2013
2. Implement hydrosystem operational changes to reduce temperature effects; if no change is possible, mitigate effects through restoration of tributary riparian areas.	25 years @ $700,000/year[1]	$17.5 million	2010 - 2032

Total costs: $20 million

Geographical priority: Reaches A-H and the plume.

Key assumption: (1) Either there is potential to alter management practices in the hydrosystem to reduce flow temperatures or a commensurate level of mitigation in tributaries would reduce temperatures in the estuary. (2) If temperatures continue to increase above 19° C, the estuary could become completely lethal for salmonids and other native species.

Existing efforts: The U.S. Environmental Protection Agency (EPA) is concerned about water temperature issues in the Columbia and Snake River system and their impacts on ecosystem health, particularly in light of global climate change. Oregon and Washington have listed the Columbia River as impaired for temperature under the Clean Water Act Section 303(d). In 2003, EPA issued a Preliminary Draft Total Maximum Daily Load (TMDL) for the mainstem Columbia River, but the TMDL has not been finalized. EPA plans to work with the states of Oregon and Washington to revisit the TMDL and decide how to address mainstem Columbia River temperature issues.

Potential implementers:

- Bonneville Power Administration
- U.S. Army Corps of Engineers
- Utility districts
- Oregon Department of Environmental Quality
- Washington State Department of Ecology

Notes:

[1] Assumes that some level of improvement is possible but that the level of possible improvement is likely to be minor because of complexities of the hydrosystem; assumes that mitigation will be needed to offset temperature increases.

Management Action CRE-3:

Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.

Project	Unit	Cost	Schedule
1. Explore technical options and develop policy recommendations on instream flows.	5 years @ $1 million/year	$5 million	2007 - 2015
2. Implement instream flow regulations in accordance with the policy recommendations in Project No. 1.	5 years @ $1 million/year	$5 million	2015 - 2023

Total costs: $10 million

Geographical priority: Reaches A–H and the plume.

Key assumptions: (1) Demand for water for human use will grow as the human population in the basin increases. (2) Additional instream flows in the Columbia River mainstem and tributaries could be established through the efforts of affected parties basinwide. (3) Establishing an instream flow regime would protect flows entering the estuary in the future. (4) An instream flow regime would help develop additional water conservation efforts and guide land use development in concert with water availability. (5) Protecting and/or enhancing estuary instream flows would require coordination with the Columbia River hydrosystem to achieve lasting results.

Existing efforts: Resource agencies can request instream flows to support fish and wildlife, water quality, and recreational needs in tributaries entering the estuary. In Oregon, the Department of Environmental Quality, Department of Fish and Wildlife, and Department of Parks & Recreation are authorized to request instream water rights to support their statutory obligations. The Oregon Water Resources Department and Commission review these requests and establish instream water rights. In Washington, the Department of Ecology established instream flows in all of the major Washington tributaries entering the estuary. Tributary flows also are often addressed in the relicensing processes for hydropower facilities regulated by the Federal Energy Regulatory Commission. Over the past decade, many tributary hydropower facilities (e.g., the Cowlitz River Project and the Lewis River Hydroelectric Projects) have been relicensed. Establishing an instream flow regime for the estuary would involve many Federal and state agencies and would require an organizational framework that currently does not exist.

Potential implementers:

- States (Washington, Oregon, Idaho, Montana)
- Cities and counties
- Irrigators
- Tributary hydropower utilities
- U.S. Army Corps of Engineers
- Bonneville Power Administration
- U.S. Bureau of Reclamation

Management Action CRE-4:

Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.

Project	Unit	Cost	Schedule
1. Conduct a flood study to determine the risks and feasibility of returning to more normative flows in the estuary.	2 years @ $500,000/year	$1 million	2009 - 2010
2. Conduct a study to determine the habitat effects of increasing the magnitude and frequency of hydrosystem flows (i.e., how much access of river to off-channel habitats would increase).	3 years @ $500,000/year	$1.5 million	2009 - 2011
3. Conduct additional studies to determine the extent of other constraints, including international treaties, systemwide fish management objectives, and power management.	4 years @ $500,000/year	$2 million	2010 - 2014
4. Make policy recommendations to action agencies on flow, taking into consideration beneficial estuary flows, flood management, power generation, irrigation, water supply, fish management, and other interests.	25 years @ $100,000/year	$2.5 million	2010 - 2035
5. Implement modified estuary flow regime annually in concert with other interests, including hydroelectric, flood control, and water withdrawals.	25 years @ $1.5 million/year[1]	$37.5 million	2011 - 2036

Total costs: $44.5 million

Geographical priority: All reaches (A-H) and the plume.

Key assumptions: (1) Even incremental changes in the magnitude and frequency of hydrosystem flows would improve salmonid habitat opportunity and food inputs, which would have benefits throughout the ecosystem. (2) Studies of flood risk and the effect of flow changes on estuarine habitat would provide data useful in modifying hydrosystem operations to benefit salmonids. (3) Studies of constraints to implementation would identify some obstacles that could be overcome. (4) Small to moderate changes in the magnitude, frequency, and timing of flows would improve sediment transport-related habitat opportunity in the estuary. (5) Increased spring freshets would yield greater sediment transport-related benefits than would other flow modifications.

Existing efforts: Large-scale efforts to adjust flows entering the estuary and return hydrology to more historical conditions have not yet begun because of the level of uncertainty regarding potential scenarios for adjusting the timing and volume of flow and the associated habitat benefits. Significant efforts have been undertaken by Bonneville Power Administration, the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation to manage the hydrosystem for passage of juvenile salmonids. In addition, flows entering the estuary currently are managed to minimum seasonal flows to protect chum redds in the mainstem below Bonneville Dam.

Potential implementers:

- Bonneville Power Administration
- U.S. Army Corps of Engineers
- U.S. Bureau of Reclamation

Notes:

[1] Assumes $1.5 million per year cost of decreased hydrosystem generation revenues associated with minor and incremental adjustments to flows; also assumes that the flood risk associated with beneficial estuary flows does not increase significantly. The $1.5 million per year cost is included primarily as an indicator that there would be some foregone revenues even with minor changes in the flow regime. Specific costs will be evaluated during implementation as specific scenarios for modifying flows are developed and considered.

Management Action CRE-5:

Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.

Project	Unit	Cost	Schedule
1. Identify the effects of reservoir sediment entrapment on economic and ecological processes; this includes effects on ship channels, turning basins, port access, jetty activities, and habitat availability.	1 study	$2 million	2008 - 2011
2. Develop a regionwide sediment plan for the estuary to address salmonid habitat-forming processes.	10 years @ $100,000/year	$1 million	2006 – 2031
3. Implement projects recommended in the plan to mitigate the effects of sediment entrapment.	5 projects @ $1 million/project	$5 million	2010 - 2020

Total costs: $8 million

Geographical priority: Reaches A-H and the plume.

Key assumptions: (1) Sediment entrapment in reservoirs will continue. (2) Sediment entrapment has negative effects, both ecologically and economically. (3) The extent of these effects warrants exploration and implementation of potential mitigation measures. (4) Studying potential mitigation measures would identify some actions that would be effective and could be implemented. (5) Synergistic ecological effects may be realized as a result of implementing CRE-5 and CRE-6, which could increase sediment inputs into the estuary (CRE-5) and optimize beneficial uses of dredged materials (CRE-6).

Existing efforts: The Lower Columbia Solutions Group, a bi-state organization made up of local, state, and Federal governmental and non-governmental stakeholders, was formed by the governors of Washington and Oregon to address activities related to the disposal of dredged materials in the estuary. Developing a sediment budget is one of the activities of the Lower Columbia Solutions Group; it is likely that this sediment management budget will include the effects of reservoir sediment entrapment.

Potential implementers:

- U.S. Army Corps of Engineers
- Bonneville Power Administration

Management Action CRE-6:

Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.

Project	Unit	Cost	Schedule
1. Develop a regionwide sediment plan for the estuary and littoral cell.	See CRE-5.	See CRE-5.	See CRE-5.
2. Identify and implement dredged material beneficial use demonstration projects, including the notching and scrape-down of previously disposed materials and placement of new materials for habitat enhancement and/or creation.	100 acres @ $10,000/ acres	$1 million	2006 - 2012
3. Dispose of dredged materials using techniques identified through the demonstration projects and regionwide planning.	500 acres @ $10,000/acre[1]	$5 million	2008 - 2033

Total costs: $6 million

Geographical priority: Reaches A, B, C, and G, the Lower Willamette reach, and the plume and nearshore.

Key assumptions: (1) Dredging activities will continue or increase over time. (2) Opportunities to beneficially use dredged materials for habitat can be identified. (3) Beneficial use of dredged material would have a positive effect on sediment transport and habitat-forming processes in the estuary, plume, and littoral cell.

Existing efforts: Several agencies and organizations are actively engaged in the evaluation of dredged material for ecosystem-based beneficial uses. The Lower Columbia Solutions Group currently is focused on reducing the disposal of dredged materials in open waters off the mouth of the Columbia River in favor of supplementing the nearshore littoral cell with sediments. The Portland District of the U.S. Army Corps of Engineers is exploring tidal wetland development in the estuary based on an assessment of wetlands that have formed accidentally where dredged materials were placed historically. The Port of Portland also is exploring the use of dredged materials for potential development of subtidal habitats.

Potential implementers:

- U.S. Army Corps of Engineers
- Port districts
- Cities
- Lower Columbia River Solutions Group
- Oregon Department of Environmental Quality
- Oregon Department of State Lands
- Oregon Department of Fish and Wildlife
- Oregon Department of Land Conservation and Development
- Washington Department of Ecology
- Washington Department of Fish and Wildlife

Notes:

[1]Unit cost is funding to pay for activities beyond the minimum required by law, to achieve regional-scale ecosystem benefits.

Management Action CRE-7:

Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.

Project	Unit	Cost	Schedule
1. Identify and evaluate dredge operation techniques designed to reduce entrainment and other habitat effects.	1 project	$500,000	2008 - 2010
2. Initiate demonstration projects designed to test and evaluate dredge operations.	5 projects @ $200,000/project	$1 million	2009 - 2012
3. Implement best management techniques.	10 years @ $250,000/year[1]	$2.5 million	2011 – 2036
4. Study the effects of entrainment of juvenile salmonids from ship ballast water intake.	1 study @ $250,000	$250,000	2009 – 2011
5. Implement a demonstration project to evaluate the feasibility of reducing entrainment of juvenile salmonids from ship ballast intake.	1 project @ $250,000	250,000	2012 -- 2015

Total costs: $4.5 million

Geographical priority: Reaches A, B, C, D, E, F, G, and the Lower Willamette reach.

Key assumptions: (1) Improved best management practices can be identified that would help reduce the impact of dredging. (2) Mitigation activities would help offset changes to the estuary caused by dredging.

Existing efforts: The U.S. Army Corps of Engineers and ports in the lower Columbia River have studied the effects of entrainment on aquatic species and have implemented actions to reduce negative effects. Screening and other ship ballast activities to decrease entrainment of juvenile salmonids have been implemented.

Potential implementers:

- U.S. Army Corps of Engineers
- Port districts
- Private entities, such as ports and sand and gravel dredgers
- Counties and cities

Notes:

[1]This is an estimate of the incremental cost above permitted dredge activities. Cost may vary significantly depending on site-specific conditions.

Management Action CRE-8:

Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.

Project	Unit	Cost	Schedule
1. Inventory, assess, and evaluate in-channel pile dikes for their economic value and their negative and positive impacts on the estuary ecosystem; develop working hypotheses for removal or modification.	1 plan	$250,000	2007 - 2009
2. Implement demonstration projects designed to test working hypotheses and guide future program priorities.	4 pile dike removal projects @ $125,000/project	$500,000	2009 - 2010
3. Remove or modify priority pilings and pile dikes.	25 years @ $1 million/year	$25 million	2008 - 2033
4. Monitor the physical and biological effects of pile dike removal and/or modification.	10 years @ $150,000/year	$1.5 million	2010 - 2020

Total costs: $27.25 million

Geographical priority: Reaches A – H and the Lower Willamette reach.

Key assumption: (1) Many pilings, pile dikes, and similar structures could be removed or modified without compromising the shipping channel or protection of property. (2) Over time, the removal or modification of superfluous pile dikes would improve conditions for salmonids and the ecosystem.

Existing efforts: This action was incorporated into the 2008 Federal Columbia River Power System Hydropower Biological Opinion (BiOp) Remand as Reasonable and Prudent Alternative 38: Piling and Dike Removal Program. A project team composed of the Lower Columbia River Estuary Partnership, Bonneville Power Administration, and the U.S. Army Corps of Engineers is working to develop a strategic plan to remove, modify, or retain pile structures within the mainstem lower river. (Modification could include adding large wood to make complex habitat, for example.) The program currently is funded at a level of $1 million per year and is expected to be funded through 2018 if the program proves successful in providing benefits to salmonids.

Potential implementers:

- U.S. Army Corps of Engineers
- Bonneville Power Administration
- Washington Department of Natural Resources
- Washington Department of Fish and Wildlife
- Oregon Department of Fish and Wildlife
- Oregon Department of Lands
- Lower Columbia River Estuary Partnership
- Counties and cities
- Tribes

Management Action CRE-9:

Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.

Project	Unit	Cost	Schedule
1. Educate landowners about the ecosystem benefits of protecting and stewarding intact off-channel areas and the costs of restoring degraded areas.[1]	(See CRE-1.1)	$500,000	2008 - 2028
2. Encourage and provide resources for local, state, and Federal regulatory entities to maintain, improve (where needed), and consistently enforce habitat protections throughout the lower Columbia region.[2]	10 years @ $500,000 million/year	$5 million	2008 - 2018
3. Actively purchase off-channel habitats in urban and rural settings that (1) cannot be effectively protected through regulation, (2) are degraded but have good restoration potential, or (3) are highly degraded but could benefit from long-term restoration solutions.[3]	Rural: 5,000 acres at $3,000/acre Urban:150 acres at $100,000/acre	$30 million	2007 – 2031
4. Restore degraded off-channel habitats with high intrinsic potential for increasing habitat quality.	Rural: 6,000 acres at $5,000/acre Urban: 500 acres at $5,000/acre	32.5 million	2007 - 2031

Total costs: $68 million

Geographical priority: Reaches A, B, C, and G and the Lower Willamette reach.

Key assumptions: (1) Protection opportunities can be increased over the next decade through public awareness, educational, regulatory, and acquisition programs. (2) Protection of off-channel habitats is less expensive than restoration. (3) High-quality off-channel habitats offer benefits to salmonids that cannot be provided in other ways. (4) Protection will be needed to offset increasing threats resulting from human population increases in the estuary and basin. (5) Restoring off-channel habitat function in the estuary is critical to ecosystem processes. (6) Restoring off-channel habitats enhances juvenile salmonid growth by increasing access to food sources and provides refugia from high flows and predation.

Existing efforts: Protection of off-channel habitats relies heavily on local governments; the content and implementation of their land use plans specifically for shoreline and floodplain protection will be key to this action. Multiple Federal and state resource agencies provide funding for land acquisition and restoration, and multiple entities such as land trusts and watershed councils actively acquire and restore lands in the lower river. The Division of State Lands in Oregon and the Department of Natural Resources in Washington own and/or regulate submerged and submersible lands. The Natural Resource Conversation Service and conservation districts provide technical assistance to private landowners. Where water quality issues (such as toxic or conventional contaminants) are involved, agencies such as Washington's Department of Ecology and Oregon's Department of Environmental Quality may provide additional support. The Lower Columbia River Estuary Partnership's Habitat Restoration Program largely is directed toward this action, CRE-1, and CRE-10. Organizations such as the Columbia Land Trust and the Columbia River Estuary Study Taskforce are actively involved in off-channel restoration activities.

Potential implementers:

- U.S. Army COE
- BPA
- Columbia Land Trust
- The Wetlands Conservancy
- Ducks Unlimited
- Col. River Est. Study Taskforce
- The Nature Conservancy
- Lower Col. River Est. Partnership
- Watershed councils
- OR Watershed Enhancement Bd.
- OR Dept. of Fish and Wildlife
- WA Dept. of Ecology
- Port districts
- Cities
- Conservation districts
- Other special districts
- Tribes

Notes:

[1] Projects CRE-1.1 and CRE-9.1 both call for outreach efforts. Outreach efforts for these two actions will be combined in a single outreach program whose costs will be shared.

[2] Projects CRE-1.2 and CRE-9.2 both call for incentives for local, state, and Federal entities to maintain, improve, and enforce regulatory protections. Given their similarities, activities for 1.2 and 9.2 could possibly be coordinated or combined into a single effort.

[3] Assumes purchases are made over a 25-year period with willing sellers.

Management Action CRE-10:

Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.

Project	Unit	Cost	Schedule
1. Breach, lower the elevation of, or relocate dikes and levees; create and/or restore tidal marshes, shallow-water habitats, and tide channels.	5,000 acres[1] @ $10,000/acre	$50 million	2006 - 2031
2. Remove tide gates to improve the hydrology between wetlands and the channel and to provide juveniles with physical access to off-channel habitat; use a habitat connectivity index to prioritize projects.	2,000 acres[1] @ $10,000/acre	$20 million	2006 - 2031
3. Upgrade tide gates or perched culverts where (1) no other options exist, (2) upgraded structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.	1,000 acres[1] @ $5,000/acre	$5 million	2006 - 2031

Total costs: $75 million

Geographical priority: Reaches A, B, C, E, F, and G and the Lower Willamette reach.

Key assumptions: (1) Additional opportunities to restore off-channel habitats can be developed through long-term outreach and improved landowner relationships. (2) Restoration of sites, including elevation restoration, would yield broad-scale ecosystem benefits over time. (3) A habitat connectivity index would help target efforts toward the projects that would provide the greatest benefits. (4) Restoration of highly degraded sites may be necessary to yield long-term benefits.

Existing efforts: Multiple Federal and state resource agencies provide funding for restoration activities, including improving hydrologic conditions and access for juvenile salmonids. In the estuary, the U.S. Army Corps of Engineers, Columbia River Estuary Taskforce, and Columbia Land Trust have significant experience breaching dikes or retrofitting tide gates. Other entities, including watershed councils, conservation districts, and private firms, also have experience but sometimes lack sufficient technical and infrastructure capacity. Extensive community outreach and long-term relationship building will be needed to implement this action. The Lower Columbia River Estuary Partnership's Habitat Restoration Program largely is directed toward this action, CRE-1, and CRE-9.

Potential implementers:
- U.S. Army Corps of Engineers
- Bonneville Power Administration
- U.S. Fish and Wildlife Service
- Oregon Watershed Enhancement Board
- Oregon Department of Fish and Wildlife
- Columbia Land Trust
- Columbia River Estuary Study Taskforce
- Salmon Recovery Funding Board
- Conservation districts
- Other districts
- Cities
- Counties
- Lower Columbia River Estuary Partnership
- Lower Columbia Fish Recovery Board
- Watershed councils
- Tribes

Notes:
[1]Acreage equals amount of affected area. Costs include those associated with protecting other land uses from renovated hydrology (i.e., moving dikes and levees).

Management Action CRE 11:

Reduce the square footage of over-water structures in the estuary.

Project	Unit	Cost	Schedule
1. Inventory over-water structures and develop a GIS layer with detailed metadata files.	2 projects @ $150,000/project	$300,000	2007 - 2009
2. Initiate a planning process to evaluate existing and new over-water structures for their economic, ecological, and recreational value.	2 phases[1] @ $100,000/phase	$200,000	2009 - 2013
3. Remove or modify over-water structures to provide beneficial habitats.	10 projects @ $500,000/project[2]	$5 million	2012 - 2037
4. Establish criteria for new permit applications to consider the cumulative impacts of over-water structures.	1 project	$300,000	2008 - 2010

Total costs: $5.8 million

Geographical priority: Reaches D and G and the Lower Willamette reach.

Key assumptions: (1) Over-water structures pose some threat to salmonids. (2) A fair number of over-water structures are no longer in use or have relatively minor value to owners. (3) An inventory of over-water structures would aid in assessing individual structures' economic, ecological, and recreational value.

Existing efforts: Over-water structures are regulated by specific sections of the Federal Clean Water Act, state statute, or both. These laws are administered by Federal agencies (U.S. Army Corps of Engineers, U.S. Environmental Protection Agency) or state agencies (Oregon Department of Environmental Quality, Oregon Division of State Lands, Oregon Department of Land Conservation and Development, Washington Department of Ecology, and Washington Department of Natural Resources). The Lower Columbia River Estuary Partnership created a shoreline condition inventory that maps all over-water structures using GIS. Currently, there are no targeted efforts to remove over-water structures in the estuary.

Potential implementers:

- U.S. Army Corps of Engineers
- Cities
- Washington Department of Natural Resources
- Oregon Department of Land Conservation and Development
- Oregon Department of State Lands

Notes:

[1]The first phase is technical and the second phase is policy.

[2]A project is defined as a set of structures that have been identified for removal; cost is level of effort.

Management Action CRE-12:

Reduce the effects of vessel wake stranding in the estuary.

Project	Unit	Cost	Schedule
1. Analyze factors contributing to ship wake stranding to determine potential approaches to reducing mortality in locations where juveniles are most vulnerable. Design and implement demonstration projects and monitor their results.	1 study @ $1 million	$1 million	2007 - 2010
2. Implement projects identified in Project No. 1 that are likely to result in the reduction of ship wake stranding events.	12 projects @ $1 million/project[1]	$12 million	2011 - 2026

Total costs: $13 million

Geographical priority: Reaches C, D, E, and F.

Key assumptions: (1) Vessel wake stranding is a significant issue for ocean- and stream-type salmonids employing the fry life history strategy in the estuary.

Existing efforts: The U.S. Army Corps of Engineers initiated a two-phase study on vessel wake stranding associated with the channel deepening project. Phase 1 was completed in 2006 as part of the channel deepening project. Results could be used to design follow-up studies analyzing factors that contribute to ship wake stranding. In addition, in 2008 the Port of Vancouver completed a study designed to estimate the total acres of estuary shoreline (downstream of the port) that may contribute to ship wake stranding.

Potential implementers:

- U.S. Army Corps of Engineers
- Columbia River pilots
- Ports
- US Coast Guard
- River and bar pilots

Notes:

[1] This is a level-of-effort cost approach that will require information generated in Projects No. 1 and 2.

Management Action CRE-13:

Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.

Project	Unit	Cost	Schedule
1. Monitor the abundance levels of pikeminnow, smallmouth bass, walleye, and channel catfish.	5 monitoring events @ $100,000/event (every 5 years)	$500,000	2006 - 2031
2. Implement actions as necessary to prevent population growth (i.e., modify habitat)[1]; increase the northern pikeminnow bounty program in the estuary.	25 years @ $500,000/year	$12.5 million	2006 - 2031

Total costs: $13 million

Geographical priority: Reaches D, E, F, G, and H and the Lower Willamette reach.

Key assumption: Management techniques would maintain populations at levels that would maintain or reduce predation impacts to salmonids. A pikeminnow management plan exists and is being implemented. Costs associated with this action are partly covered as a baseline cost. Costs associated with managing other piscivorous fish, including smallmouth bass, walleye, and channel catfish, are entirely incremental costs.

Existing efforts: Bonneville Power Administration funds the Northern Pikeminnow Sport Reward Fishery Program whereby anglers receive $4 to $8 for every qualifying northern pikeminnow 9 inches or longer returned to a registration station. Since 1990, more than 3.1 million northern pikeminnow have been removed from the Snake and Columbia rivers as a result of this program. The annual budget for the Northern Pikeminnow Management Program has varied from $2.0 to $6.4 million, with an average of about $3.0 million basinwide.

Potential implementers:

- U.S. Army Corps of Engineers
- Washington Department of Fish and Wildlife
- Oregon Department of Fish and Wildlife
- Bonneville Power Administration
- National Marine Fisheries Service

Notes:

[1] It is unknown whether projects will be needed to manage warm-water fish. In some cases, there may be warm-water habits close to juvenile habitat, in which case site-specific action would be required.

Management Action CRE-14:

Identify and implement actions to reduce salmonid predation by pinnipeds.

Project	Unit	Cost	Schedule
1. Expand Federal and state activities at Bonneville Dam to test non-lethal and potentially lethal methods of reducing pinniped populations throughout the estuary. This includes efforts to manage pinnipeds through the Marine Mammal Protection Act.	5 years @ $500,000/year	$2.5 million	2007 - 2011
2. Implement actions likely to reduce pinniped predation on adult salmonids.	25 years @ $500,000/year[1]	$12.5 million	2007 - 2032

Total costs: $15 million

Geographical priority: Reaches A-H (especially H).

Key assumptions: (1) Mortality from pinnipeds throughout the lower Columbia River may be a larger source of salmonid mortality than previously understood. (2) Further study would clarify the impact of pinniped predation on salmonids; studies by the U.S. Army Corps of Engineers at Bonneville Dam represent a good start on this task. (3) Mortality from pinniped predation could be reduced through non-lethal and lethal methods. (4) The Marine Mammal Protection Act could be modified over time to allow more tools for managing pinnipeds in the estuary. In 2008, NMFS granted authority under Section 120 of the Marine Mammal Protection Act to the states of Oregon, Washington, and Idaho to intentionally take, by lethal methods, individually identifiable California sea lions that prey on Pacific salmon and steelhead at Bonneville Dam (Federal Register 2008).

Existing efforts: The National Marine Fisheries Service, Oregon and Washington, the U.S. Army Corps of Engineers, and Bonneville Power Administration have initiated efforts to manage pinnipeds, primarily at Bonneville Dam. As of 2010, efforts included both lethal and non-lethal methods sanctioned under Section 120 of the Marine Mammal Protection Act.

Potential implementers:

- U.S. Army Corps of Engineers
- Bonneville Power Administration
- National Marine Fisheries Service
- Columbia River Inter-Tribal Fish Commission
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife

Notes:

[1] Units are years; given the constraints to this action, it is likely that ongoing efforts to prevent predation will continue over the next 25 years.

Management Action CRE-15:

Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.

Project	Unit	Cost	Schedule
1. Increase public awareness of exotic plant species and proper stewardship techniques.[1]	10 years @ $100,000/year	$1 million	2008 – 2018
2. Inventory exotic plant species infestations and develop a GIS layer with detailed metadata files.	5 phases @ $200,000/phase	$1 million	2007 – 2012
3. Implement projects to address infestations on public and private lands.	10,000 acres @ $1,000/acre	$10 million	2008 – 2028
4. Monitor infestation sites.	20 years @ $25,000/year	$500,000	2010 - 2030

Total costs: $12.5 million

Geographical priority: Reaches A-H and the Lower Willamette reach).

Key assumptions: (1) Aquatic invasive plants have a negative effect on the estuary ecosystem and affect juvenile salmonids by altering habitat and causing food webs to deteriorate. (2) Additional information is needed on the location, extent, and type of infestations and their effects on the estuary ecosystem. (3) Because introductions of invasive plants can permanently alter the estuary ecosystem, prevention activities are crucial. (4) Education, outreach, and monitoring would help prevent further introductions of invasive plants.

Existing efforts: The fish and wildlife departments of Oregon and Washington have management responsibilities for fish and wildlife, including the control of non-indigenous species. The Washington Department of Fish and Wildlife has developed an Aquatic Non-indigenous Species Management Plan. The Pacific States Marine Fisheries Commission promotes interstate communication and facilitates the coordination of aquatic non-indigenous species activities on the West Coast. The Oregon and Washington Sea Grant programs combined to form the Northwest Marine Invasive Species Team to raise the level of awareness about the threats of invasive species. The Invasive Alien Species Executive Order at the Federal level created the Invasive Species Council and directed development of an Invasive Species Management Plan. Multiple Federal and state resource agencies provide funding for restoration projects that remove exotic invasive plants, and entities such as land trusts and watershed councils actively eradicate exotic native plants and plant native species in the lower river. Noxious weed control entities exist in Oregon and Washington to help educate landowners and control invasive plants.

Potential implementers:

- U.S. Army Corps of Engineers
- Bonneville Power Administration
- US Fish and Wildlife Service
- State agencies
- Conservation districts
- Noxious weed districts
- Counties
- Cities
- Tribes
- Watershed councils
- Lower Columbia River Estuary Partnership
- The Nature Conservancy
- Landowners

Notes:

[1]This project is recommended for upstream mainstem and tributaries, but the costs presented here are for activities in the estuary only. Many exotic plants have established themselves upstream and represent a constant downstream threat to the estuary.

Management Action CRE-16:

Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.

Project	Unit	Cost	Schedule
1. Enhance or create tern nesting habitat at alternative sites in Washington, Oregon, and California.	3 sites @ $1 million/site	$3 million	2008 - 2012
2. Reduce tern nesting habitat on East Sand Island from 6 acres to 1 to 1.5 acres.	1 project @ $4.5 million/project	$4.5 million	2007 - 2010
3. Monitor the regional tern population.	25 years @ $100,000/year	$2.5 million	2010 - 2035

Total costs: $10 million

Geographical priority: Reaches A and B.

Key assumption: Ongoing and new management actions directed to Caspian tern nesting habitat would continue to reduce salmonid mortality from tern predation. A management plan exists and is being implemented. Costs associated with this action are partially covered as a baseline cost.

Existing efforts: The U.S. Army Corps of Engineers has recently constructed alternative habitat for Caspian terns outside of the estuary. The Corps also funds studies assessing Caspian tern population levels and predation rates on juvenile salmonids. These studies track terns along the West Coast to determine whether management actions in the lower river result in redistribution of terns elsewhere along the West Coast. A predatory bird Web site (www.birdresearchnw.org) keeps the public and others informed on the status of management plans and research.

Potential implementers:

- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife

Management Action CRE-17:

Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.

Project	Unit	Cost	Schedule
1. Identify, assess, and evaluate methods of reducing double-crested cormorant abundance numbers.	1 multiphase study	$1 million	2007 - 2011
2. Implement demonstration projects resulting from Project No. 1 (i.e., decoys and audio playback methods).	5 pilot projects @ $500,000/project	$2.5 million	2010 - 2015
3. Implement projects resulting in reduced predation by cormorants.[1]	10 years @ $700,000/year	$7 million	2013 - 2023

Total costs: $10.5 million

Geographical priority: Reaches A and B.

Existing efforts: The U.S. Army Corps of Engineers funds studies assessing cormorant population levels and predation rates on juvenile salmonids. These studies track cormorants along the West Coast to determine whether management actions in the lower river result in redistribution elsewhere along the West Coast. A predatory bird Web site (www.birdresearchnw.org) keeps the public and others informed on the status of management plans and research.

Potential implementers:

- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife

Notes:

[1]This is a level-of-effort cost estimate; efforts to manage cormorants in the estuary are significantly lagging Caspian tern management efforts and will likely be more difficult to implement.

Management Action CRE-18:

Reduce the abundance of shad in the estuary.

Project	Unit	Cost	Schedule
1. Organize existing technical information about shad and identify data gaps and potential control methods.	2 phases @ $250,000/phases	$500,000	2007 - 2011
2. Implement demonstration projects to evaluate effective shad management methods.	4 projects @ $500,000/project	$2 million	2008 - 2015
3. Implement shad population management techniques.[1]	10 years @ $250,000/year	$2.5 million	2010 - 2015
4. Monitor and evaluate shad management techniques.	10 years @ $50,000/year	$500,000	2011 - 2021

Total costs: $5.5 million

Geographical priority: Reaches A-H and the Lower Willamette reach.

Key assumptions: (1) Shad have negative affects on salmonids in the estuary. (2) Additional research would shed light on how shad affect salmonids and suggest new management techniques. (3) New management techniques would be unlikely to cause significant change.

Existing efforts: The U.S. Geological Survey, with funding from Bonneville Power Administration, is studying the presence of American shad in the Columbia River throughout the year, assessing shad diet trends, and PIT tagging up to 1,000 adult pre-spawn shad in the estuary to examine their time of arrival at dams using PIT tag detection technologies in fishways.

Potential implementers:
- U.S. Army Corps of Engineers
- U.S. Geological Survey
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife

Notes:
[1]This is a level-of-effort cost estimate; currently there are no plans to manage shad abundance levels in the Columbia River.

Management Action CRE-19:

Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.

Project	Unit	Cost	Schedule
1. Assemble existing technical information on introduced aquatic invertebrates in the estuary and develop a plan for managing existing infestations and preventing new infestations.	2 phases @ $250,000/phase	$500,000	2007 - 2010
2. Implement recommendations from the plan for managing existing infestations and preventing new infestations (Project No. 1, above).[1]	5 projects @ $500,000/project	$2.5 million	2008 – 2013

Total costs: $3 million

Geographical priority: Reaches A-H and the Lower Willamette reach.

Key assumptions: (1) Ship ballast practices could be improved to help prevent further degradation of the estuary ecosystem. (2) Additional research would help scientists understand the effects of exotic invertebrates on the ecosystem. (3) Because the effects of exotic invertebrates on the ecosystem usually cannot be reversed, it is important to prevent introductions when possible.

Existing efforts: Following the direction of the 2007 Oregon Legislature, the Shipping Transport of Aquatic Invasive Species Task Force was convened in 2008 to examine how Oregon can better handle aquatic invasive species coming into the state via shipping activities. The task force compiled a report outlining various aspects of preventing the introduction of aquatic invasive species from shipping-related pathways. The report also recommended steps that the Oregon Department of Environmental Quality, working with other agencies and the shipping industry, can take to bolster efforts to halt the arrival and spread of aquatic invasive species that degrade existing ecosystems and displace native species.

Likewise, the Aquatic Nuisance Species Unit of the Washington Department of Fish and Wildlife (WDFW) has implemented the Washington State ballast water program since 2000. This program receives state funds for program management, vessel report tracking, and vessel inspection efforts. Two vessel inspectors stationed in Puget Sound and the SW/Columbia River regions target high-risk vessels for boarding and ballast sampling. Washington established discharge standards that, as of 2009, had not yet been implemented.

In 2008, the Environmental Protection Agency issued a Vessel General Permit (VGP) as part of the National Pollutant Discharge Elimination System under the Federal Water Pollution Control Act. This permit is intended to regulate discharges resulting from the normal operation of all non-recreational vessels 79 feet or longer. In addition, the ballast water discharge provisions apply to any non-recreational vessel of less than 79 feet and commercial fishing vessels of any size discharging ballast water, and require adoption of best management practices for discharges. Currently, the VGP regulations adopt U.S. Coast Guard ballast water exchange requirements and coastal exchange requirements for domestic voyages along the West Coast but do not include ballast water treatment technology. Under the Clean Water Action Section 401 certification requirements, states can adopt more stringent conditions than the VGP in their certifications if so needed to meet requirements of either the Clean Water Act or state law.

Potential implementers:

- Port districts
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife
- U.S. Fish and Wildlife Service
- Oregon Department of Agriculture
- Washington State Department of Agriculture
- Portland State University
- Oregon State Marine Board
- Washington State Parks and Recreation Commission
- Oregon Department of Environmental Quality

Notes:

[1]This is a level-of-effort cost estimate.

Management Action CRE-20:

Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.

Project	Unit	Cost	Schedule
1. Educate landowners, businesses, and other users about practices to reduce usage and the effects of pesticides and fertilizers.[1]	10 years @ $50,000/year	$500,000	2008 - 2018
2. Implement pesticide, fertilizer, and nutrient best management practices to reduce contaminants entering the estuary.	10 years @ $1.15 million/year[2]	$11.5 million	2008 – 2018
3. Evaluate the adequacy of best management practices and update as needed.	2 reviews @ $250,000	$500,000	2012 and 2017

Total costs: $12.5 million

Geographical priority: Reaches A-H and the Lower Willamette reach.

Key assumptions: (1) Some users of pesticides and fertilizers are not adequately informed about best management practices for these toxic contaminants. (2) Additional benefits to salmonids could be realized through continued efforts by farmers, chemical manufacturers, and regulatory programs to reduce impacts from fertilizers and pesticides. (3) Benefits to salmonids would increase over a relatively long period of time as agricultural practices improve. Several of the projects identified in this action are being implemented and therefore could be considered baseline costs. The costs in this action are considered additive to baseline costs because of the significant effort needed to reduce nutrients and toxic contaminants entering the estuary.

Existing efforts: Both Washington and Oregon produce and encourage implementation of best management practices (BMP) manuals to address non-point sources of pollution. In both states, load allocations and reduction strategies are identified through the total maximum daily load (TMDL) process. The Oregon Department of Environmental Quality is now conducting “pesticide stewardship partnerships” in five Oregon watersheds that eventually flow into the Columbia or Willamette rivers. These partnership programs work through outreach with the agricultural community to implement BMPs that will reduce pesticides in rivers and streams. The U.S. Department of Agriculture, through Senate Bill 1010 authorities, is developing plans to ensure BMPs on agricultural lands. The U.S. Environmental Protection Agency convened the Columbia River Basin Toxics Reduction Working Group in 2005 to coordinate monitoring, cleanup, and reporting efforts basinwide. In September 2010, the working group produced the Columbia River Basin Toxics Reduction Action Plan.

Potential implementers:

- Washington Department of Agriculture
- Oregon Department of Agriculture
- Cities
- Conservation districts
- U.S. Environmental Protection Agency
- Washington Department of Ecology
- Oregon Department of Environmental Quality
- Lower Columbia River Estuary Partnership
- Natural Resources Conservation Service

Notes:

[1] Projects CRE-20.1 and CRE 21.1 both call for outreach efforts. Outreach efforts for these two projects will be combined into a single outreach program whose costs will be shared.

[2] Unit cost includes estimates for the estuary and estuary tributaries only; the action recommends similar upstream activities.

Management Action CRE-21:

Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.

Project	Unit	Cost	Schedule
1. Educate the industrial and commercial sectors and the general public on how to reduce the introduction of pollutants into the estuary and its tributaries.[1]	10 years @ $20,000/year	$200,000	2008 - 2028
2. Identify sources, loads, and pathways of pollutants in the estuary.	8 years @ $100,000/year	$800,000	2010 - 2018
3. Provide cost-share incentives for National Pollution Discharge Elimination System (NPDES) permit holders to upgrade effluent above their permit requirements.	10 years @ $1.5 million/year	$15 million	2010 – 2020
4. Study and establish threshold treatment standards for pharmaceuticals and other unregulated substance discharges; update existing NPDES permits to reflect the new standards.	5 years @ $2 million/year	$10 million	2007 – 2012
5. Provide grants and low-cost loans to permit holders required to treat effluent to standards established in Project No. 3.	10 years @ $2 million/year	$20 million	2012 - 2017

Total costs: $46 million

Geographical priority: Reaches D and G and the Lower Willamette reach.

Key assumptions: (1) Non-permitted discharges that currently are occurring would be identified and curtailed. (2) Financial incentives or support would motivate NPDES permit holders to raise their effluent treatment levels above permit requirements. (3) Releases of industrial and commercial pollutants into the estuary would be reduced over time. Several of the projects identified in this action are being implemented and therefore could be considered baseline costs. The costs in this action are considered additive to baseline costs because of the significant effort needed to reduce inputs of pollutants.

Existing efforts: In both Oregon and Washington, pollutant load allocations and reduction strategies are identified through the total maximum daily load (TMDL) process. The Oregon Department of Environmental Quality's (DEQ) Water Quality Program is developing a list of key, persistent bioaccumulative toxic contaminants that have a documented effect on human health, wildlife, and aquatic life. The Oregon Legislature has directed DEQ to report on where persistent bioaccumulative toxic contaminants are coming from and options to reduce their discharge. In addition, legislation required Oregon's 52 largest municipal wastewater treatment plants to develop plans by 2011 to reduce priority persistent pollutants through pollution prevention and toxic reduction. Initial monitoring and reduction efforts are to focus on the Willamette River. The U.S. Environmental Protection Agency convened Columbia River Basin Toxics Reduction Working Group in 2005 to coordinate monitoring, cleanup, and reporting efforts basinwide. In September 2010, the working group produced the Columbia River Basin Toxics Reduction Action Plan. The Lower Columbia River Estuary Partnership has created a long-term monitoring strategy that calls for baseline conventional and toxic contaminant data along with data sufficient to assess trends and biological integrity.

Potential implementers:

- U.S. Environmental Protection Agency
- Washington Department of Ecology
- Oregon Department of Environmental Quality
- Cities
- Trade groups such as the Oregon Association of Clean Water Agencies that represent wastewater dischargers

Notes:

[1] Projects CRE-20.1 and CRE-21.1 both call for outreach efforts. Outreach efforts for these two actions will be combined into a single program whose costs are shared.

Management Action CRE-22:

Restore or mitigate contaminated sites.

Project	Unit	Cost	Schedule
1. Develop criteria and a process for evaluating contaminated sites to establish their restoration potential.	1 phase @ $500,000/phase	$500,000	2007 - 2017
2. Develop an integrated multi-state funding strategy to address contamination cleanup in the estuary from non-identifiable upstream sources.	Out-of-Estuary[1]	n/a	2007 - 2012
3. Restore those contaminated sites that will yield the greatest ecological and economic benefits.	20 years @ $3 million/year	$60 million	2007 - 2027

Total costs: $60.5 million

Geographical priority: Reaches A-H and the Lower Willamette reach.

Key assumptions: (1) Monitoring will continue to provide vital data needed to understand the toxic contaminant problem and identify potential solutions. (2) Monitoring will identify hot spots of contamination. (3) Contamination sites will be identified for which responsible parties cannot be determined. (4) Additional analysis would identify contamination sites whose restoration would yield significant ecological and economic benefits. (5) Restoration of contaminated sites would benefit salmonids and the ecosystem over time. (6) The action will include improving the condition of habitats that have been impaired by the contaminants, not just removing pollutants. (7) Clean up will be to levels that support survival and recovery in both the short-term and long-term. Several of the projects identified in this action are being implemented and therefore could be considered baseline costs. The costs in this action are considered additive to baseline costs because of the significant effort needed to address contamination cleanup.

Existing efforts: The U.S. Environmental Protection Agency regulates cleanup of contaminated sites under Superfund and other programs, which include monitoring of these sites. The U.S. Environmental Protection Agency convened the Columbia River Basin Toxics Reduction Working Group in 2005 to coordinate monitoring, cleanup, and reporting efforts basinwide. In September 2010, the working group produced the Columbia River Basin Toxics Reduction Action Plan. The Lower Columbia River Estuary Partnership has created a long-term monitoring strategy that calls for baseline conventional and toxic contaminant data along with data sufficient to assess trends and biological integrity. The Estuary Partnership, U.S. Geological Survey, and NMFS completed a 3-year study that compiled and analyzed monthly toxic and conventional pollutant data at five sites, primarily for PAHs, PCBs, estrogenic compounds, flame retardants, current-use pesticides, nutrients, and trace elements. Toxics monitoring of juvenile salmon also was conducted at six sites (for PCBs, PAHs, organochlorine pesticides, and flame retardants) (Lower Columbia River Estuary Partnership 2007). In addition, the Estuary Partnership and NMFS developed three models that describe the role that toxics play in a salmon's life history: a conceptual model of the interactions between contaminants and endangered salmonid species, a contaminant transport and uptake model, and an ecological risk model to provide a quantitative measure of the impact of contaminant exposure on salmonid populations in the Columbia River basin (Spromberg and Johnson 2008, Leary et al. 2005, and Leary et al. 2006).

Potential implementers:

- Lower Col. River Est. Partnership
- Col. River Est. Study Taskforce
- Cities
- Conservation districts
- OR Dept. of Env. Quality
- WA State Dept. of Ecology
- Port districts
- U.S. Geological Survey
- Federal regulatory agencies such as the National. Marine Fisheries Service and U.S. Geological Survey

Notes:

[1] Cost is considered to be outside the purview of estuary-specific projects.

Management Action CRE-23:

Implement stormwater best management practices in cities and towns.

Project	Unit	Cost	Schedule
1. Monitor stormwater outputs to measure treatment compliance with existing local and state regulations throughout the basin; develop a network of monitoring sites and establish a data repository that includes data collected by permittees.	10 years @ $200,000/year	$2 million	2007 - 2015
2. Establish a fund source for regulatory agencies and local governments to use when insufficient resources are available to (1) access best available science, (2) develop standards beyond requirements, or (3) adequately enforce regulations.	3 years @ $2 million/year	$6 million	2009 – 2011
3. Evaluate the adequacy of best management practices and update as needed.	3 evaluations @ $500,000	$1.5 million	2010 – 2025
4. Provide incentives for low-impact development practices.	20 years @ $500,000/year	$10 million	2010 - 2030

Total costs: $19.5 million

Geographical priority: Reaches D and G and the Lower Willamette reach.

Key assumptions: (1) Population growth in the Columbia River basin will continue to influence the hydrology and water quality in the estuary. (2) Stormwater practices could be improved by monitoring and enforcing compliance with existing regulations, making best scientific information available, and developing higher standards. (3) The resulting improvements in hydrology and contaminant exposure in the estuary would occur slowly over time. (4) This action is protective in nature; costs are not associated with retrofitting existing stormwater facilities. Several of the projects identified in this action are being implemented and therefore could be considered baseline costs. The costs in this action are considered additive to baseline costs because of the significant effort needed to address stormwater-related water quality issues.

Existing efforts: Both the Washington Department of Ecology and Oregon Department of Environmental Quality produce best management practices manuals to address certain non-point sources. Local governments develop and update land use plans that include stormwater practices and that guide future development. The Lower Columbia River Estuary Partnership has worked with three schools on Schoolyard Stormwater Projects and engaged corporate partners to design and construct stormwater facilities.

Potential implementers:

- Cities and counties
- Washington Department of Ecology
- Oregon Department of Environmental Quality
- U.S. Environmental Protection Agency
- Lower Columbia River Estuary Partnership

Notes:
This action is recommended for upstream mainstem and tributaries, but the costs presented here are for activities in the estuary only.

Table 5-7 is a summary of costs for the 23 management actions. The total estimated budget for constrained implementation of the actions as described in Table 5-6 approaches is $528.05 million over 25 years. This number contrasts with the $1.1 billion estimated to help restore salmon in Puget Sound tributaries over a 10-year period. Other major ecosystem restoration efforts across the United States, including San Francisco Bay, Chesapeake Bay, the Everglades, and the Louisiana Coast, are estimated to cost several billion dollars apiece.

TABLE 5-7
Summary of Costs of Management Actions

Number	Action Description	Cost for Constrained Implementation	%*
CRE-01	Protect intact riparian areas in the estuary and restore riparian areas that are degraded.	$38 million	7%
CRE-02	Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.	$20 million	4%
CRE-03	Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.	$10 million	2%
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.	$44.5 million	8%
CRE-05	Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.	$8 million	2%
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	$6 million	1%
CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.	$4.5 million	1%
CRE-08	Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.	$27.25 million	5%
CRE-09	Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.	$68 million	13%
CRE-10	Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.	$75 million	14%
CRE-11	Reduce the square footage of over-water structures in the estuary.	$5.8 million	1%
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	$13 million	2%

Number	Action Description	Cost for Constrained Implementation	%*
CRE-13	Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.	$13 million	2%
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	$15 million	3%
CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.	$12.5 million	2%
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	$10 million	2%
CRE-17	Implement projects to reduce double-breasted cormorant habitats and encourage dispersal to other locations.	$10.5 million	2%
CRE-18	Reduce the abundance of shad in the estuary.	$5.5 million	1%
CRE-19	Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.	$3 million	1%
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.	$12.5 million	2%
CRE-21	Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.	$46 million	9%
CRE-22	Restore or mitigate contaminated sites.	$60.5 million	11%
CRE-23	Implement stormwater best management practices in cities and towns.	$19.5 million	4%
	Total	$528.05 million	

*Column shows the relative percentage of each action to the total cost. Percentages do not add up to 100 percent because of rounding.

Summary

The estuary and plume ecosystems are especially vulnerable to threats because these ecosystems are affected by factors across a wide geographic range—from upstream to the estuary itself, and even well out in the Pacific Ocean. A set of actions has been identified to help reduce threats to salmonids in the estuary and plume. Other recovery venues must also address upstream threats to effectively improve degraded habitats in the estuary. This estuary recovery plan module uses survival improvement targets to help estimate the level of effort required and the costs of that effort.

CHAPTER 6

Research, Monitoring, and Evaluation[1]

Research, monitoring, and evaluation (RME) is a critical element of recovery planning for ESA-listed species (Crawford and Rumsey 2010). RME provides essential information for planners, implementers, and managers of recovery programs on the effectiveness of their programs, whether individual actions are improving the performance[2] of listed salmonids, and how limiting factors and threats are affecting salmonids. This chapter describes RME needed to assess juvenile salmonid performance in the estuary and to evaluate the effectiveness of the 23 management actions described in Chapter 5. It also describes existing monitoring plans, programs, and projects that relate to estuary module RME needs and identifies gaps and potential projects to fill those gaps.

Monitoring plans for ESA-listed Columbia Basin salmonids have been or will be drafted for all domain recovery plans in the basin. These monitoring plans address the most basic question in recovery planning: Is the status of the listed population or ESU improving? Estuary RME will address other key questions, such as whether the performance of juvenile salmonids passing through and using the estuary is improving or worsening, and whether the limiting factors that affect the status of a population or ESU within the estuary are changing. Accordingly, estuary RME will complement monitoring for recovery plans for all domains in the Columbia River basin. Additional questions addressed by estuary RME are as follows:

- Are the actions identified in the estuary recovery plan module being implemented correctly, in sufficient scope, and according to schedule?
- What are the effects of estuary management actions on juvenile salmonids and their habitat?
- Are additional actions needed?
- Are there additional or new threats and limiting factors within the estuary beyond those considered in the estuary recovery plan module?
- How will the monitoring data be managed, analyzed, interpreted, and disseminated?
- How will monitoring data be incorporated into management decisions to best allow an adaptive management approach?

Monitoring for this estuary recovery plan module needs to build on ongoing efforts. In particular, *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary*

[1] Catherine Corbett of the Lower Columbia River Estuary Partnership and Gary Johnson of Pacific Northwest National Laboratories provided the principal input to this chapter.

[2] Salmonid performance refers to life history diversity, foraging success, spatial structure, and growth (Bottom et al. 2005).

Program (ERME) (Johnson et al. 2008) is an appropriate monitoring plan on which to base the estuary recovery plan module RME. The ERME monitoring plan is important because it formed the basis for estuary RME in the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (National Marine Fisheries Service 2008a and 2008b), and was carried over into the 2010 FCRPS Supplemental Biological Opinion (National Marine Fisheries Service 2010). In addition, versions of the ERME monitoring plan have been reviewed by the Independent Scientific Review Panel of the Northwest Power and Conservation Council (Independent Scientific Review Panel 2006a and 2006b), along with state and tribal fisheries management agencies. Finally, the ERME monitoring plan was initially developed and refined by an inter-agency estuary/ocean subgroup for Federal RME that included members from the Bonneville Power Administration, the U.S. Army Corps of Engineers, the Lower Columbia River Estuary Partnership, NMFS, and the Pacific Northwest National Laboratory. This chapter borrows greatly from the Johnson et al. (2008) ERME plan.

In addition to the *Research, Monitoring, and Evaluation Program for the Federal Columbia River Estuary* (Johnson et al. 2008), nine other monitoring plans and guidance documents are applicable to a framework for estuary recovery plan module RME (see Table 6-1). The earliest planning document for estuary RME—*Lower Columbia River Estuary Plan, Aquatic Ecosystem Monitoring Strategy for the Lower Columbia River and Information Management Strategy* (Lower Columbia River Estuary Partnership 1998)—outlined a general monitoring strategy that addressed coordination and oversight, data management and quality assurance, conventional and toxic contaminants, habitat, exotic species, and primary production. This document continues to be germane today. More recently, NMFS produced a document for recovery plans called *Guidance for Monitoring Recovery of Pacific Northwest Salmon and Steelhead Listed under the Federal Endangered Species Act* (Crawford and Rumsey 2010). This chapter is consistent with the guidance provided in that document, especially regarding the monitoring framework and adaptive management approach.

RME Framework

The main elements of estuary RME are status and trends monitoring, action effectiveness research, critical uncertainties research, and implementation and compliance monitoring. These elements inform an adaptive management approach that includes synthesis, reporting, and evaluation of monitoring data and use of results to modify management actions and monitoring programs. The main elements of the estuary RME are described below.

Status and Trends Monitoring

The overall objective of status and trends monitoring in the estuary is to determine the status of ESA-listed salmonids, determine environmental conditions that are ecologically significant to listed species, and track how the status changes over time. The results of status and trends monitoring should provide information on ambient environmental conditions and insight into the cumulative effects of existing and new management actions and anthropogenic impacts as they occur.

TABLE 6-1
Monitoring Plans Applicable to Estuary RME

Title	Lead Agency(s)	Description	Application
Guidance for Monitoring Recovery of Pacific Northwest Salmon and Steelhead Listed under the Federal Endangered Species Act (Crawford and Rumsey 2010)	NMFS	This document provides general guidance for monitoring and evaluation within an adaptive management framework for recovery plans for ESA-listed salmonids in the Pacific Northwest.	Estuary recovery plan module RME used the monitoring elements and adaptive management approach espoused in this work.
Lower Columbia River Estuary Plan, Volume 2: Aquatic Ecosystem Monitoring Strategy (Lower Columbia River Estuary Partnership 1998)	Estuary Partnership	The *Monitoring Strategy* makes specific recommendations for monitoring oversight, data management, and monitoring and research on pollutants, toxics, habitat, exotic species, and primary production.	Many of the recommendations in this strategy pertain to the management actions in the estuary recovery plan module and, thus, were inherently applied to module RME.
Columbia River Basin Research Plan (Northwest Power and Conservation Council 2006a)	NPCC	This plan identifies key uncertainties that, if resolved, would support actions to conserve and recover fish and wildlife populations addressed in the BPA/NPCC's Fish and Wildlife Program. There are three uncertainties listed for the estuary, one of the plan's focal areas.	Research called for in this plan informs many of the management actions in the estuary recovery plan module.
Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program (Johnson et al. 2008)	BPA/ NMFS/ NPCC/USACE	This plan for RME in the tidally influenced area, from Bonneville Dam to the ocean, including the plume, has specific goals and objectives, a conceptual ecosystem model, monitored indicators, method and protocols, and an action plan. This is a working document that is periodically updated based on new knowledge and program maturation.	Estuary recovery plan module RME relied on applicable content in this plan.
Guidance for Developing Monitoring and Evaluation as a Program Element of the Fish and Wildlife Program (Northwest Power and Conservation Council 2006b)	NPCC	This report concerns monitoring and evaluation for the Fish and Wildlife Program. It develops monitoring and evaluation guidance at two levels: Council policy-makers and project implementers. The Council's Fish and Wildlife Program was last approved in 2009.	The guidance in this report, although general, is basic to monitoring and evaluation planning and was applied as appropriate in estuary recovery plan module RME.
Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan (Lower Columbia Fish Recovery Board 2010)	LCFRB	The plan includes an extensive section on monitoring and research designed to evaluate biological status of listed salmon and steelhead, tributary habitat status, implementation compliance, and action effectiveness.	Applicability to estuary recovery plan module RME is limited because the material focuses on tributary watersheds of the lower Col. R. and estuary.
Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead (ODFW 2010)	ODFW	This plan includes an extensive section on monitoring and research designed to evaluate biological status of listed salmon and steelhead, status of tributary habitat and other limiting factors, implementation compliance, and action effectiveness.	Applicability to estuary recovery plan module RME is limited because the material focuses on tributary watersheds of the lower Col. R. and estuary
FCRPS 2008 Biological Opinion and 2010 Supplemental Biological Opinion (NMFS 2008 and NMFS 2010)	NMFS	The Reasonable and Prudent Alternative in the 2008 BiOp includes estuary RME actions and subactions. These were incorporated by reference into the 2010 Supplemental BiOp.	There is some overlap between the management actions in the estuary recovery plan module and the RPAs in the Biological Opinions. As appropriate, RME from the Biological Opinions was incorporated into estuary recovery plan module RME.

Title	Lead Agency(s)	Description	Application
Supplement to the Mainstem Lower Columbia River and Estuary Subbasin Plan (Lower Columbia River Estuary Partnership 2004b)	Estuary Partnership	This supplement clarifies and provides additional details about the key elements in the subbasin plan for the estuary. It does not, however, explicitly develop an RME plan.	The supplement supports estuary RME, although specific recommendations are not provided.
Upper Columbia Monitoring and Evaluation Plan (Upper Columbia Technical Recovery Team 2007)	Upper Columbia Technical Recovery Team	This working draft provides a comprehensive plan for tributary RME. Many of the monitoring concepts are consistent with those used in the estuary.	Estuary recovery plan module RME used the monitoring guidance categories in this plan.

The U.S. Environmental Protection Agency (2000) developed 15 guidelines for developing environmental indicators that provide this type of information, including the following:

- Relevance to the assessment. Monitored indicators should be responsive to an identified question and provide information useful for management decisions.
- Linkage to management action. An indicator is useful only if it can provide adequate information to support management decisions or quantify the success of past decisions.
- Temporal variability across years. Although an indicator may show inter-annual variability, the indicator should reflect true trends in environmental conditions for the assessment question. To determine variability across years, monitoring must proceed for several years at relatively stable sites. Having a long time series of data is particularly important in the estuary, where the benefits of habitat restoration could be masked by salmonid population changes that are due to variable ocean conditions.

Examples of indicators include direct measurements (such as nutrient concentrations), indices, and multimetrics (fish assemblage, for example) (U.S. Environmental Protection Agency 2000).

There are two major objectives for status and trends monitoring in the estuary: (1) assess habitat conditions and limiting factors and threats as described in the estuary recovery plan module and (2) assess juvenile salmonid performance in the estuary. Johnson et al. (2008) list the following status and trends objectives for the estuary:

1. Status and Trends Monitoring (STM): Habitat Conditions – Determine the status and trends of monitored indicators for estuary/ocean conditions that are ecologically significant to listed salmonids in the lower river, estuary, plume, and nearshore ocean.

    STM 1. Map bathymetry and topography of the estuary as needed for RME.

STM 2. Establish a hierarchical habitat classification system based on hydrogeomorphology, ground-truth it with vegetation cover monitoring data, and map existing habitats.

STM 3. Develop an index of habitat connectivity and apply it to each of the eight reaches of the study area.

STM 4. Monitor habitat conditions periodically, including water surface elevation, vegetation cover, plant community structure, substrate characteristics, dissolved oxygen, temperature, conductivity, and primary and secondary production at representative locations in the estuary and plume.

2. Status and Trends Monitoring: Juvenile Salmonid Performance – Determine the status and trends of monitored indicators for juvenile salmonid performance in the estuary and plume.

STM 5. Evaluate migration characteristics, including juvenile salmonid abundance, residence times, growth rates, diets, and prey resources at representative locations in the estuary and plume to understand habitat usage and relative ecological importance of various habitats to juvenile salmonids.

STM 6. Monitor and evaluate juvenile salmonid survival from Bonneville Dam through the estuary into the plume.

STM 7. Develop an index and monitor and evaluate life history diversity of juvenile salmonid populations at representative locations in the estuary.

STM 8. Monitor and evaluate temporal and spatial species composition, abundance, and foraging rates of juvenile salmonid predators at representative locations in the estuary and plume.

Johnson et al. (2008) also provide guidance on potential indicators that can be monitored to provide information relevant to these objectives. Additional information about status and trends monitoring objectives can be found in the *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program* (Johnson et al. 2008).

Action Effectiveness Research

The overall objective of action effectiveness research in the estuary is to provide information about the effects of management actions. Using a representative set of management actions, such as specific types of habitat restoration, researchers monitor a suite of variables to evaluate the effects of individual actions on juvenile salmon and their estuarine habitats and provide feedback on potential methods for improving techniques, locations, or other aspects of the action. Action effectiveness research usually involves project-scale monitoring of site-specific conditions to determine whether implemented actions were effective in creating the desired change and whether project- or program-specific performance goals were met. This type of monitoring also can include long-term post-project implementation monitoring to see whether the actions continue to function as they were designed or intended. In some cases the information needed for action effectiveness monitoring may be provided by status and trends monitoring, but action effectiveness research generally requires focused evaluations of more specific parameters directly associated with actions.

The intent of action effectiveness research (AER) is to use quantitative studies to demonstrate how habitat restoration actions affect factors controlling ecosystem structures and processes at site and landscape scales and produce changes in juvenile salmonid performance. The following sub-objectives are from Johnson et al. (2008):

Using a representative set of projects, monitor and evaluate the effects of habitat restoration actions in the estuary, as follows:

AER 1. Develop a limited number of reference sites for typical habitats, e.g., tidal swamp, marsh, island, and tributary delta, to use in action effectiveness evaluations.

AER 2. Evaluate the effects of selected individual habitat restoration actions at project sites relative to reference sites and evaluate post-restoration trajectories based on project-specific goals and objectives. ("Effectiveness Monitoring")

AER 3. Develop and implement a methodology to estimate the cumulative effects of habitat conservation and restoration projects in terms of cause-and-effect relationships between ecosystem controlling factors, structures, and processes affecting salmon habitats and performance. ("Validation Monitoring")

Critical Uncertainties Research

The overall objective of critical uncertainties research in the estuary is to investigate uncertainties in the state-of-the-science that are pivotal to understanding fish performance within the estuary. Uncertainties include cause-and-effect relationships among fish, limiting factors, threats, and activities meant to protect or enhance fish performance. The following three critical uncertainties were identified as particularly relevant to this module:

- Extent of density dependence mortality in the estuary and the role of large releases of hatchery fish in density dependence
- Effects of climate cycles and global warming on salmonid performance in the estuary
- The amount of increased juvenile survival in the estuary that could reasonably be expected if all 23 management actions in the module were implemented, and the proportion of that increased survival that could be attributed to each action

Critical uncertainties were also identified in Johnson et al. (2008). The following sub-objectives pertain to critical uncertainties research (CUR):

CUR 1. Continue work to define the ecological importance of the tidal freshwater, estuary, plume and nearshore ocean environments to the viability and recovery of listed salmonid populations in the Columbia Basin.

CUR 2. Continue work to define the causal mechanisms and migration/behavior characteristics affecting survival of juvenile salmon during their first weeks in the ocean.

CUR 3. Investigate the importance of the early life history of salmon populations in tidal freshwater of the lower Columbia River.

CUR 4. Investigate the effects of hatchery fish on wild (naturally produced) fish in the estuary.

CUR 5. Understand the wetting and drying of the floodplain habitats caused by complex hydrodynamic interactions of tides, mainstem and tributary flows, and the effect of the FCRPS on river conditions.

By testing assumptions related to these and other critical uncertainties, recovery program planners, implementers, and managers can refine the foundation, implementation, and effectiveness of the management actions described in Chapter 5 to incorporate the best available science as it becomes accessible.

Implementation and Compliance Monitoring

The overall objective of implementation and compliance monitoring is to determine whether projects that address management actions are being implemented correctly, in sufficient quantities, and according to schedule. This monitoring is important for evaluating whether recovery programs are meeting objectives and performance measures, such as the number of estuary habitat acres conserved or restored annually. Objectives and performance measures for implementation and compliance monitoring are specific to the programs they evaluate; thus, in this case, performance measures and the resulting implementation monitoring would need to reflect targets derived from the 23 management actions in Chapter 5. Johnson et al. (2008) identified the following implementation and compliance monitoring (ICM) objectives:

ICM 1. Determine whether restoration projects were carried out as planned, i.e., whether specified project criteria were met ("Implementation Monitoring").

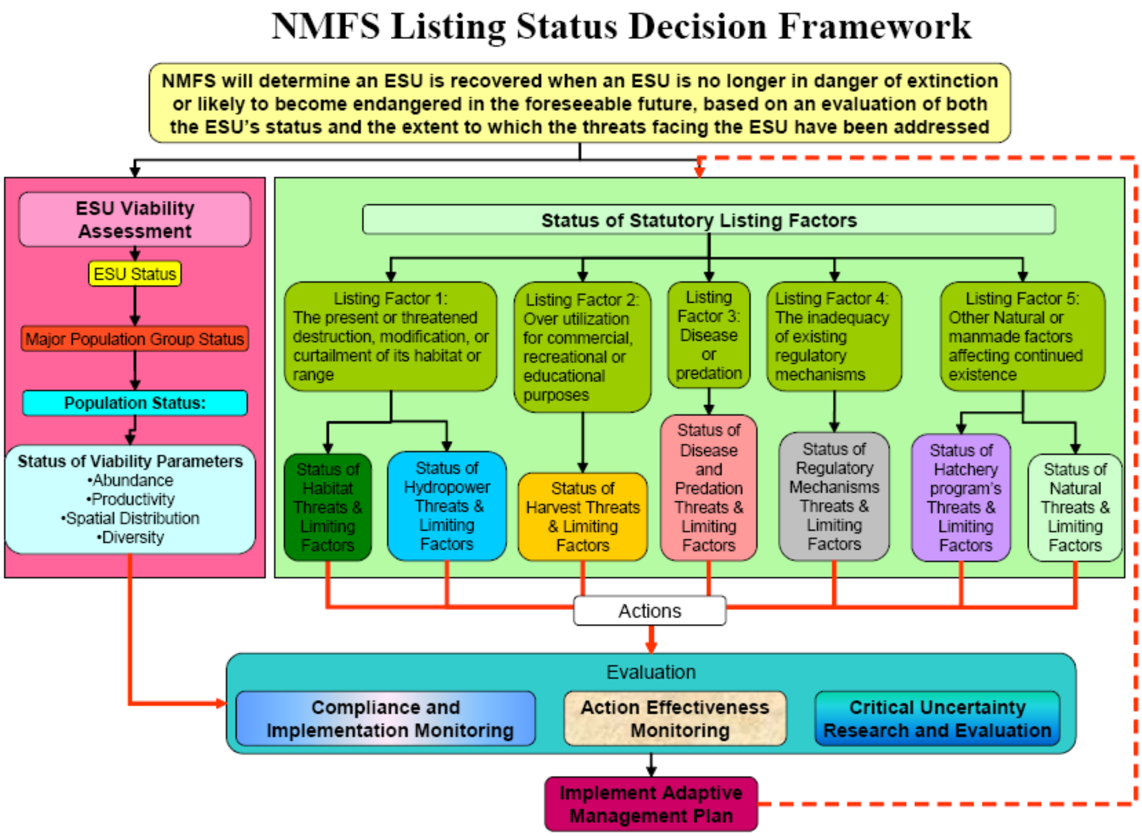
ICM 2. Total the amount of estuary habitat conserved and restored annually by habitat type.

Adaptive Management Approach

Estuary recovery plan module RME will employ an adaptive management approach. Adaptive management is the process of adjusting management actions based on new information. Management actions must be taken in an adaptive, experimental manner because ecosystems are inherently variable and highly complex (Independent Scientific Review Panel 2007). The process works by coupling decision making with the collection and evaluation of performance data and offering an explicit process through which alternative strategies to achieve the same ends can be proposed, prioritized, and implemented when necessary (Crawford and Rumsey 2010).

Figure 6-1 shows the role of RME and adaptive management in NMFS decisions regarding listing salmonids under the Endangered Species Act. The estuary recovery plan module addresses limiting factors and threats, which led to the management actions listed in Chapter 5. The RME described in this chapter will result in new information for use in evaluating the status of statutory listing factors and limiting factors and adjusting management actions as needed.

FIGURE 6-1
NMFS Listing Status Decision Framework (Crawford and Rumsey 2010)



The adaptive management approach in the estuary recovery plan module is intended to achieve effective management actions in the Columbia River estuary ecosystem. For the estuary recovery plan module, adaptive management entails the following:

- Management actions
- Research, monitoring, and evaluation actions
- Coordination and implementation
- Data and information management
- Synthesis, reporting, and evaluation
- Decisions

Estuary-scale adaptive management will benefit from adaptive management planning by individual organizations (such as the Lower Columbia River Estuary Partnership and the U.S. Army Corps of Engineers) for their habitat restoration projects and programs (see Thom et al. 2007).

Coordination

Coordination is critical in implementing RME for the Columbia River estuary, where multiple entities collect data for numerous individual projects with various objectives and potentially different monitoring protocols. Successful implementation and evaluation of estuary recovery plan module RME will require that ongoing and future RME efforts be coordinated and carried out within an adaptive management framework. An estuary RME information-sharing forum should be established that includes technical representatives of Federal, state, and local government agencies; the Lower Columbia River Estuary Partnership; and other entities involved in research, monitoring, and implementation of recovery actions. This forum would be a valuable mechanism for fulfilling the coordination need and would complement corresponding groups of policy representatives responsible for implementation.

Data and Information Management

Data and other information pertinent to estuary RME are collected by many parties for a wide variety of applications. Data analysis and management are performed at a project and sometimes agency level, but not often at the estuary-wide level. It is neither desirable nor feasible to centrally manage or analyze all data within the Columbia River estuary. However, data should be managed so that synthesis and evaluation occurs through a coordinated, communal information network that includes the following elements:[3]

- Incorporation of data produced by existing programs and information systems to avoid duplication of effort.
- Integration with other basinwide and regional RME groups, including the Pacific Northwest Aquatic Monitoring Partnership.
- Regular written project-level reporting by RME partners within a coordinated system for peer review of project plans and reports.
- Periodic estuary RME workshops to present new data, discuss findings, and exchange information on future plans.
- A system for tracking implementation of RME projects throughout the estuary.
- Establishment of a central, Web-accessible repository and library for estuary data and references.
- Guidelines for metadata standards to facilitate data exchange and application.
- Centrally facilitated program-level review for comprehensive synthesis and evaluation of pertinent information relative to the goals and objectives of this plan.
- Periodic program-level summary reports.
- Communication and information exchange with other West Coast estuary and adaptive management programs, such as the Puget Sound Partnership.
- Consistent participation and funding commitments by partners.

A data management program for the estuary should build on existing efforts, such as the Lower Columbia River Estuary Partnership's monitoring and data management activities. The Estuary Partnership's science work group (and board of directors)

[3] Adapted from Johnson et al. (2008) and Lower Columbia River Estuary Partnership (2004a).

includes technical representatives of Federal, state, and local government agencies and other entities involved in restoration, monitoring, and implementation of recovery programs. This work group complements corresponding groups of policy representatives.

Synthesis, Reporting, and Evaluation

The information from status and trends monitoring, action effectiveness research, critical uncertainties research, and implementation and compliance monitoring should be synthesized and integrated in periodic reports for decision makers and other interested parties. The intent is to "roll up" project-specific data into program-level information. Annual reporting at the project level should be a key mechanism for data dissemination; biennial reporting at the program level should be key to disseminating results of evaluations. The estuary RME information-sharing forum described above could guide the synthesis and roll-up in the biennial report. In an adaptive management process, program evaluation includes adjusting program objectives and methodologies based on new information. As Noon (2003) stated, monitoring programs "must be constantly revisited and revised as scientific knowledge is acquired." Procedures should be established that link decision makers to estuary RME monitoring overseers and data managers. To conclude, Johnson et al. (2008) recommended the following synthesis and evaluation activities:

SE 1. Upload, compile, manage, and disseminate project-level data at the Estuary Program level.

SE 2. Synthesize the data and periodically report it to the region.

SE 3. Use the synthesized data to evaluate the Estuary Program and refine the estuary RME effort as necessary.

Existing Programs and Projects and Additional Monitoring Needs

Activities conducted as part of the ERME program (Johnson et al. 2008) and other efforts do not fully address all of the monitoring needs associated with the 23 management actions identified in the module. The following sections describe (1) existing monitoring programs and projects and their applicability to the 23 management actions identified in the module; (2) gaps between existing monitoring efforts and needed monitoring for the management actions; (3) additional monitoring activities to fill those gaps and ensure monitoring to support all of the 23 management actions; (4) recommended indicators and protocols; and (5) estimated costs of estuary module RME.

Existing Programs and Projects

Estuary recovery plan module RME will take advantage of ongoing monitoring programs and the projects implemented within them wherever possible to avoid duplication of effort. At least 21 ongoing programs include projects that address aspects of research and monitoring in the estuary (see Table 6-2). The largest RME programs are the Columbia Basin Fish and Wildlife Program, which is funded by Bonneville Power Administration via the Northwest Power and Conservation Council, and the

Anadromous Fish Evaluation Program, which is funded by the U.S. Army Corps of Engineers. These two programs address estuary RME explicitly. The other programs exist for purposes other than estuary RME, but are applicable in a limited fashion.

The research and monitoring effort in the estuary includes at least 42 projects (see Table 6-3). This project list was derived from data in Johnson et al. (2008), the Estuary Partnership's RME inventory (conducted by K. Jones), and the Pacific Northwest Aquatic Monitoring Partnership's RME Project Inventory (database provided by M. Banach, Pacific States Marine Fisheries Commission). The projects include status and trends monitoring, action effectiveness research, and critical uncertainties research.

RME Needs, Existing Project Coverage, and Recommended Projects

Table 6-4 identifies monitoring needs for each of the 23 management actions in the estuary recovery plan module (see Tables 5-2 and 5-6), lists existing projects and programs that help address the needs, and identifies gaps. Table 6-5 identifies potential new projects to fill the RME gaps identified in Table 6-4. In addition, all of the management actions will require implementation and compliance monitoring.

Monitoring Recommendations

Table 6-6 provides recommendations specific to each need identified in Table 6-4. Recommendations include sampling design, spatial and temporal scale, measured variables, measurement protocols, derived variables, analysis, possible funding entities, and potential entities for implementation and coordination. Many of the measured variables and measurement protocols were obtained from Johnson et al. (2008). Specific monitoring methods will developed on a project basis. Habitat restoration monitoring protocols for the Columbia River estuary have been developed and disseminated in Roegner et al. (2009) (Table 6-3, Project J15). Mention of possible funding entities in Table 6-6 does not imply a funding commitment of any kind.

Estimated Costs

Table 6-7 presents estimates of costs and implementation schedules for estuary recovery plan module RME. These cost estimates were developed by Gary Johnson of Pacific Northwest National Laboratories, Catherine Corbett of the Lower Columbia River Estuary Partnership, and Phil Trask of PC Trask & Associates, Inc., by researching existing programs and estimates. The costs identified in this section do not represent a detailed economic analysis; in fact, they are not economic costs, in that they have not been discounted across time. Instead, the cost estimates are in constant dollars over a 25-year period. As mentioned previously, some module actions included specific RME projects and associated cost estimates (see Table 5-6). In those cases, Table 5-6 is referenced. Other costs in Table 6-7 ($64.1 million) were estimated by evaluating the monitoring needs in Table 6-6. The total cost of the RME projects identified in the estuary recovery plan module is $85.1 million.

Summary

Monitoring, research, and evaluation elements identified in *Guidance for Monitoring Recovery of Pacific Northwest Salmon and Steelhead Listed under the Federal Endangered*

Species Act (Crawford and Rumsey 2010) and *Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program* (Johnson et al. 2008) provide a consistent methodology that supports the RME detailed in this chapter for the estuary recovery plan module. As management actions identified in the module are implemented, it will be important that monitoring and research data are returned to the managers of the recovery effort to determine whether the management actions in the estuary recovery plan module are achieving the desired results.

TABLE 6-2
Ongoing Monitoring Programs Applicable to Estuary RME (as of July 2009). *The program "ID" number was invented for the purpose of this module to provide linkages to Table 6-3.*

ID	Program	Lead Entity	Description	More Information
P1	National Stream Quality Accounting Network (reported in National Streamflow Information Program)	USGS (and OHSU)	Monitoring at Beaver Terminal (RM54); includes water quality and discharge measurements. Water quality components enhanced by OHSU collaboration since summer 2009.	NASQAN: http://water.usgs.gov/nasqan/ Water quality (as of summer 2009): http://columbia.loboviz.com/loboviz/ Columbia River Factsheet: http://water.usgs.gov/ nasqan/progdocs/factsheets/ clmbfact/clmbfact.html
P2	National Water-Quality Assessment Program	USGS	Routine water quality monitoring nationwide; it includes the Willamette basin, but not the estuary.	NAWQA: http://water.usgs. gov/nawqa/ Willamette page: http://or.water.usgs.gov/ projs_dir/pn366/ nawqa.html
P3	Columbia Basin Fish and Wildlife Program	BPA/ NPCC	Contains a measure addressing the question, "Is the Columbia River estuary improving or deteriorating relative to desired conditions?" BPA/NPCC implements estuary RME projects here.	http://www. nwcouncil.org/ library/2000/
P4	Columbia River Channel Improvements Project	USACE	Monitoring occurs as required for ESA concerns.	https://www.nwp. usace.army.mil/ issues/crcip/
P5	Mouth of the Columbia River Project	USACE/ Ports	Monitoring occurs as required for ESA concerns.	https://www.nwp. usace.army.mil/op/n/ projects/
P6	Anadromous Fish Evaluation Program (AFEP)	USACE	Implements the Columbia River Fish Mitigation Project designed to improve survival through the hydrosystem. The USACE does estuary research in AFEP.	https://www.nwd. usace.army.mil/ps/
P7	NOAA General Funds Program	NOAA	Provides funds for specific estuary/ocean research projects by NOAA.	Unknown
P8	Oregon Dept. of Environmental Quality/106/General Funds	ODEQ	Focus is on Willamette, including its confluence with the Columbia River.	http://www.deq.state. or.us/lab/ wqm/watershed.htm
P9	Total Dissolved Gas Monitoring Program	USACE/ USGS	Routine monitoring.	USGS: http://or.water.usgs.gov/ projs_dir/pn307.tdg/ USACE: http:// 137.161.202.92/TMT/ WQ/2001/ MonitorPlan/ tdgmgt01.pdf
P10	Washington Dept. of Ecology Ambient Monitoring Program	WDE	Usually includes at least one mainstem site, in addition to tributary water quality monitoring.	Monitoring Home: http://www.ecy.wa.gov/ programs/eap/ fw_riv/rv_main.html

ID	Program	Lead Entity	Description	More Information
P11	Water Resources Development Act – Ecosystem Restoration Programs	USACE	USACE conducts monitoring of specific restoration actions conducted under these authorities; monitoring maximum cost is 3% total project cost.	https://www.nwp. usace.army.mil/pm/lcr/
P12	Lower Columbia River Ecosystem Restoration General Investigations Feasibility Study (GI Study)	USACE	The purpose of the GI Study is to “investigate and recommend appropriate solutions to accomplish ecosystem restoration in the lower Columbia River and estuary, including wetland/riparian habitat restoration, stream and fisheries improvement, water quality, and water-related infrastructure improvements.”	https://www.nwp.usace.army.mil/ pm/cr/envres.asp
P13	Portland Harbor Superfund Assessment Program	EPA	Implements cleanup at the Superfund site in Portland harbor.	EPA: http://yosemite.epa.gov/R10/ CLEANUP.NSF/sites/ ptldharbor
P14	Estuary Partnership Ecosystem, Action Effectiveness and Pile Structure Monitoring Programs	Estuary Partnership	Implements an Ecosystem Condition Status and Trends Monitoring Strategy, Restoration Actions Effectiveness Research and Pile Structure Modification action effectiveness research and critical uncertainties. Funding by BPA/NPCC, EPA, NOAA, and others.	http://www.lcrep.org
P15	NOAA Tides and Currents	NOAA	Geodetic monitoring	http://tidesandcurrents.noaa.gov/
P16	Surface Water Data Collection Program	USGS	Water quality monitoring (at Beaver Terminal combined with OHSU as of summer 2009)	http://columbia.loboviz.com/loboviz/
P17	Volunteer Water Quality Monitoring Program	Will. River Keeper	Volunteer water quality monitoring	
P18	Zebra Mussel Monitoring Program	Portland State Univ.	Monitoring of zebra mussels, an invasive species	Contact: Steven Wells
P19	National Fish and Wildlife Foundation, Columbia River Estuarine Coastal Fund	National Fish and Wildlife Foundation (NFWF)	The Columbia River Estuarine Coastal Fund was established in 2004 to receive community service payments ordered by court settlements resulting from violations of Federal pollution laws.	http://www.nfwf.org/
P20	Ship-wake program	Port of Vancouver/NOAA	Spatial analysis of beach susceptibility for stranding of juvenile salmonids by ship wakes	
P21	(Untitled)	City of Portland	Monitoring of project effectiveness, fish and wildlife, water quality, and stormwater within Portland’s waterways, including the lower Willamette River. The City is in the process of revising its monitoring approach, modeling the design on EPA’s Environmental Monitoring and Assessment Program.	http://www.portlandonline.com/bes/ Kaitlin.Lovell@bes.ci.portland.or.us

TABLE 6-3
Ongoing Projects Addressing Estuary RME (as of July 2009)
The project "ID" number (e.g., J4) was invented for the purpose of this module to provide linkages to Table 6-4. Project numbers (e.g., 2000-012-00) are specific to the respective program. Program numbers (e.g., P3) correspond to the program ID numbers in Table 6-2.

ID	Title	Project No.	Program	Monitoring Entity
J1	ODEQ Ambient Water Quality Monitoring	Unknown	P8	OR Dept. of Env. Quality
J2	WDOE Ambient Water Quality Monitoring	Unknown	P10	WA Dept. of Ecology
J3	USGS Discharge and Water Quality Monitoring	Unknown	P1	USGS
J4	Ives Is. Chum Salmon Monitoring	2000-012-00	P3	USFWS
J5	Lower Columbia River and Estuary Ecosystem Monitoring Project	2003-007-00	P14 + P3	Estuary Partnership/ NOAA/PNNL/UW/USGS
J6	Total Dissolved Gas Monitoring	PNAMP#409	P9	USGS
J7	Avian Predation on Juvenile Salmonids	1997-024-00	P3	OSU
J8	Tenasillahe Is. Monitoring	Unknown	P11	USFWS
J9	Canada-US Shelf Salmon Survival Study	2003-009-00	P3	DFO
J10	Life History, Habitat Connectivity, and Survival Benefits of Restoration	EST-P-09-01	P6	PNNL/UW
J11	Estimation of Salmon Survival Using Miniaturized Acoustic Tags	EST-P-02-01	P6	NMFS/ PNNL
J12	Tidal Fluvial Habitats and Juvenile Salmon – Current and Historical Linkages	EST-P-10-01	P6	NMFS
J13	Sampling PIT Tagged Juvenile Salmonids Migrating in the Estuary	BPS-W-00-11	P6	NMFS
J14	Survival and Growth of Juvenile Salmonids in the Columbia River Plume	1998-014-00	P3	NMFS
J15	Evaluation of Cumulative Ecosystem Response to Restoration	EST-P-02-04	P6	PNNL/ NMFS/ CREST
J16	Action effectiveness research on habitat restoration projects	EST-P-09-02	P6	USFWS
J17	Historic Habitat Opportunities and Food-Web Linkages of Juvenile Salmon	2003-010-00	P3	NMFS/ OHSU/ PSU/ UW
J18	Acoustic Tracking for Survival (POST)	2003-114-00	P3	Kintama
J19	Relationship Among Time of Ocean Entry, Physical, & Biological Characteristics of Estuary/Plume	EST-P-02-03	P6	NMFS
J20	Effectiveness Monitoring at Sites in Young's Bay	Unknown	P19	CREST
J21	Habitat Restoration Program – Habitat GIS, Reference Sites, Restoration Actions Effectiveness Research and Pile Structure Modification Critical Uncertainties	2003-011-00	P14 + P3	Estuary Partnership
J22	Monitoring at Smith and Bybee Lakes	Unknown	Unknown	Ducks Unlimited

ID	Title	Project No.	Program	Monitoring Entity
J23	Ramsey Lake Restoration Project Monitoring	Unknown	14	City of Portland
J24	Impact of American Shad	2007-275-00	P3	USGS
J25	Caspian Tern Management	2006-002-00	P3	OSU
J26	Tidal Freshwater Monitoring of Juvenile Salmonids	2005-001-00	P3	PNNL/ODFW/UW/NMFS
J27	Effects of Total Dissolved Gas on Chum Fry	SPE-P-07-01	P6	PNNL
J28	CORIE	Unknown	P3+	OHSU
J29	Pile Structure Removal and Modification Study	Unknown	P14	Estuary Partnership/BPA/ USACE
J30	Julia Butler Hansen Tide Gate Replacement	Unknown	P11	USFWS
J31	Comparison of Juvenile Salmonid Stranding Before and After Channel Improvements	Unknown	P4	PNNL/UW
J32	Bonneville Sea Lion Exclusion Study	ADS-02-16	P6	USCAE Fisheries Field Unit
J33	Sea Lion Deterrent System	BPA/NPCC	P3	Smith Root
J34	Caspian Tern Management Measures	AVS-P-08-01	P6	OSU
J35	Double-Crested Cormorant Management Measures	AVS-P-08-02	P6	OSU
J36	Impact of Avian Predation on Smolts	AVS-W-03-01	P6	NMFS
J37	Tides and currents	Unknown	P15	NOAA
J38	Northern Pikeminnow Surveys	1990-077-00	P3	ODFW
J39	Effectiveness Monitoring in the Lower Grays R.	PNAMP#529	P3	CREST
J40	Ives Island – Adult Chum Salmon Monitoring	PNAMP#277	P3	ODFW
J41	Volunteer Water Quality Monitoring	PNAMP#575	P17	Willamette River Keeper
J42	Zebra Mussel Monitoring	PNAMP#425	P18	PSU

TABLE 6-4
Management Actions, Associated Monitoring Needs, and Existing Coverage
Existing projects with "J" prefixes refer to projects listed in Table 6-3.

Management Action	Type	Monitoring Need	Existing Projects and Gaps
CRE-1: Protect intact riparian areas in the estuary and restore riparian areas that are degraded.	STM	Periodic mapping and areal measurement of riparian habitats and their condition using aerial photography to inform prioritization efforts	J5 and J21, although the projects do not do this at this time, but eventually could.
CRE-2: Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.	STM	Water temperature monitoring in the estuary to establish baseline	J1, J2, J28
	AER	Monitoring during the hydrosystem temperature experiment	At dams, the US Army Corps of Engineers (USACE) monitors water temperature; revive hydrodynamic modeling
	UR	Reservoir heating study and downstream effects	No existing projects.
CRE-3: Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.	STM	Continuous monitoring of Col. River discharge at Beaver Terminal in the estuary	J3 USGS National Streamflow Information Program
CRE-4: Adjust the timing, magnitude and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.	STM/ AER	Continuous monitoring of Col. River discharge at Beaver Terminal in the estuary and at Bonneville dam Plume turbidity monitoring using remote sensing	J3 USGS National Streamflow Information Program; J36 NOAA Tides and Currents
	UR	Flood, habitat, and constraints study(s)	No existing projects; revive modeling, e.g., Jay and Kukulka 2003
CRE-5: Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.	UR	Effects of reservoir sediment entrapment	No existing projects; the USACE measured sediment entrapment previously.
CRE-6: Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	UR	Evaluate the long-term trajectory of beneficial use of shallow- water habitat creation sites	No existing projects; the USACE applies dredged material for beneficial uses when possible
CRE-7: Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.	UR	Dredge technique and operations study	No existing projects; the USACE studied crab entrainment previously (Pearson et al. 2006).
CRE-8: Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.	STM	Periodic mapping and length and density measurements of pile structures using the Estuary Partnership's estuary GIS system	J29, J21
	AER	Monitor physical and biological effects of pile removal	J29, J21
	UR	Study fundamental physical and biological characteristics to understand where removal or modification would be advantageous	No existing projects.

Management Action	Type	Monitoring Need	Existing Projects and Gaps
CRE-9: Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.	STM	Periodic mapping and areal measurement of off-channel habitat types to inform prioritization and monitoring efforts	J5 and J21
CRE-10: Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.	STM	Periodic mapping and length measurements of dike structures using the Estuary Partnership's estuary GIS system.	J21 GIS map of dikes and tide gates
	AER	Effectiveness monitoring studies of tidal reconnections	J30 JBH study, J15 Cumulative effects, J20 Young's Bay
	UR	Ecological importance of tidal reconnections	J15 Cumulative effects J17 Habitat linkages
CRE-11: Reduce the square footage of over-water structures in the estuary.	STM	Periodic mapping and areal measurements of over-water structures using the Estuary Partnership's estuary GIS system. Track permits for construction of shoreline structures	J21 GIS map of over-water structures – needs to be expanded to areal extent, not just linear extent
	UR	Study fundamental physical and biological characteristics to understand where removal would be advantageous	No existing projects in the estuary.
CRE-12: Reduce the effects of vessel wake stranding in the estuary.	STM	Total stranding estimate for entire estuary	No existing projects.
	UR	Factors and stranding reduction study	J31 Before/after CRCIP addresses factors
CRE-13: Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.	STM	Monitor trends in predator abundance	J38
CRE-14: Identify and implement actions to reduce salmonid predation by pinnipeds.	STM	Pinniped predation monitoring	J32
	AER	Effectiveness of actions. Monitor actions under Section 120 of the Marine Mammal Protection Act	J32, J33 Section 120 monitoring
	UR	Magnitude of pinniped impact in the estuary	J32 (at BON) - expand to include magnitude of impact throughout estuary
CRE-15: Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.	STM	Inventory and map invasive plants	No existing projects; revive Sytsma et al. 2004
	AER	Effectiveness monitoring	Wahkiakum. Community Foundation Columbia Estuary Environmental Education Program (LCEEEP) identification and treatment of invasive weeds on Julia Butler Hansen Wildlife Refuge
CRE-16: Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	STM	Tern monitoring	J25, J34 Tern monitoring
	AER	Effectiveness of habitat shift	J25, J34 Tern management
CRE-17: Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	STM	Cormorant monitoring	J35
	AER	Methods to reduce cormorant abundance	J35 Cormorant management

Management Action	Type	Monitoring Need	Existing Projects and Gaps
CRE-18: Reduce the abundance of shad in the estuary.	STM	Monitor passage of adult shad at Bonneville Dam	USACE Fish counting
	AER	Evaluate effectiveness of control methods	No existing projects.
	UR	Assess ecological effects of shad	J24 Shad impact study
CRE-19: Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.	STM	Monitor trends in abundance, distribution, and species composition of invertebrate invasives	No existing projects; revive Sytsma et al. 2004
CRE-20: Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.	STM	WQ/toxics monitoring downstream of Bonneville Dam	No existing projects.
	AER	Pre- and post-project monitoring	No existing projects.
	UR	Source tracking; fish health; sublethal and lethal thresholds	No existing projects; J5; no existing projects.
CRE-21: Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.	STM	WQ/toxics monitoring	No existing projects; minimal WQ in J1, J2, J3, J5
	AER	Pre- and post-project monitoring	No existing projects.
	UR	Source tracking; fish health; sublethal and lethal threshold.	No existing projects; J5; none
CRE-22: Restore or mitigate contaminated sites.	STM	WQ/toxics monitoring	No existing projects; minimal WQ in J1, J2, J5
	AER	Pre- and post-project monitoring	No existing projects.
	UR	Source tracking; fish health; sublethal and lethal thresholds	No existing projects; J5; none
CRE-23: Implement stormwater best management practices in cities and towns.	STM	Stormwater monitoring	No existing projects; limited monitoring with NPDES permit requirements
	AER	Directed stormwater monitoring	No existing projects.
	UR	Source tracking; improve BMPs and regulations	No existing projects.

TABLE 6-5
Recommended New RME Projects or New Objectives in Existing Projects
These projects would fill gaps where "no existing projects" were noted in Table 6-4.

Action	Type	Project
CRE-2	UR	Water temperature monitoring and modeling for a reservoir heating study
CRE-4	UR	Flood, habitat, and constraints study(s) of the effects of "more normative" flows in the estuary
CRE-5	UR	Measurement of sediment entrapment in mainstem Columbia River reservoirs
CRE-6	UR	Demonstration study of beneficial use of dredged material to create shallow-water habitat
CRE-7	UR	Dredging technique and operations to minimize entrainment of juvenile salmonids
CRE-8	UR	Study fundamental physical and biological characteristics to understand where removal would be advantageous
CRE-11	UR	Assessment of impacts and benefits of removing over-water structures
CRE-12	STM	Total, estuary-wide stranding estimates by species of juvenile salmonid
CRE-15	STM	Routine monitoring of percent cover and distribution of invasive plants by species
CRE-18	AER	Effectiveness study of shad control methods
CRE-19	STM	Routine monitoring of percent cover and distribution of invasive aquatic invertebrates by species
CRE-20, 21, 22, 23	STM	Water quality, stormwater, and toxic contaminants monitoring below Bonneville Dam
CRE-20, 21, 22, 23	AER	Pre- and post-project implementation water quality, stormwater and toxic contaminants monitoring below Bonneville Dam
CRE-20, 21, 22, 23	UR	Determine sources, concentrations, timing, types, and pathways of water quality and toxic contaminant pollutants; sublethal and lethal thresholds in fish and food web

TABLE 6-6
Monitoring Guidance for Estuary Recovery Plan Module RME. Adapted from Appendix C, Johnson et al. (2008).

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
CRE-1	Periodic mapping and areal measurement of riparian habitats and their condition	Complete census with ground-truthing	Estuary-wide every 5 years	Length of riparian habitat by type of habitat	GIS-linked aerial photography, Landsat imagery and videography (Evans et al. 2006)	Proportions for each riparian habitat type	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership
CRE-2	Water temperature monitoring in the estuary to establish baseline	Stratified random sampling by reach	At representative sites throughout the estuary essentially continuously	Water temperature	Data loggers (Callaway et al. 2001)	Maximum daily/weekly maximum, seasonal averages	Trend analysis	BPA/NPCC, USGS	BPA/NPCC Fish and Wildlife Program
	Hydrosystem temperature experiment	Modeling	Estuary-wide	Water temperature	Hydrodynamic model	Maximum daily/weekly maximum, seasonal averages	Compare/ contrast	BPA/NPCC, EPA, USGS	Ibid.
	Reservoir heating study and downstream effects	Systematic sampling and modeling	At representative sites throughout the estuary essentially continuously	Water temperature	Data loggers (Callaway et al. 2001)	Maximum daily/weekly maximum, seasonal averages	Compare/ contrast	BPA/NPCC	Ibid.
CRE-3	Continuous monitoring of Columbia River discharge at Beaver Terminal in the estuary	Systematic sampling	Hourly sampling at Beaver Terminal	Stream discharge (cfs)	USGS gauging station	Annual maximum and minimum, seasonal averages	Trend analysis	USGS	USGS program

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
CRE-4	Continuous monitoring of Columbia River discharge at Beaver Terminal in the estuary and at Bonneville Dam	Systematic sampling	Hourly sampling at Beaver Terminal and BON	Stream discharge (cfs)	USGS gauging station	Annual maximum and minimum, seasonal averages	Trend analysis	USGS, USACE	USGS program (See CRE-3); also USACE O&M program for mainstem dams
	Plume turbidity monitoring using remote sensing	Complete census with ground-truthing	Plume-wide every 5 years	Turbidity	GIS-linked aerial photography	Time series of turbidity maps	Trend analysis	BPA/NPCC, NOAA	BPA/NPCC Fish and Wildlife Program (See CRE-2)
	Flood, habitat, and constraints effects study(s)	Modeling effort	Estuary-wide	Inundation	Hydrodynamic model	Cumulative inundation curves	Compare/ contrast	BPA/NPCC, NOAA	USACE's AFEP
CRE-5	Effects of reservoir sediment entrapment	Complete census	All 13 main-stem Snake and Columbia dams every 5 years	Thickness of reservoir sediment	Acoustic bottom typing (multibeam sonar)	Sediment maps	Trend analysis	USACE	USACE's AFEP (See CRE-4)
CRE-6	Evaluation of beneficial use of dredged material – create shallow-water habitat	Before-after-control-impact (BACI)	Site-specific, 1 year before and 5 years after	Vegetation, bathymetry	Roegner et al. 2009, bathymetry	Percent cover, shallow-water habitat	Effectiveness evaluation	USACE	USACE's Sediment Management Program
CRE-7	Dredge technique and operations study	Focused field experiments	TBD	Crab entrainment	Pearson et al. 2006	Entrainment rates	Statistical analysis	USACE	USACE's Sediment Management Program (See CRE-6)
CRE-8	Periodic mapping and length and density measurements of pile structures	Complete census with ground-truthing	Estuary-wide every 5 years	Length of pile structure	GIS-linked videography (Evans et al. 2006)	Length and locations of pile structure	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1)
	Monitor physical and biological effects of pile removal	BACI	Site-specific, 1 year before and 3 years after	Water velocity, fish species composition and abundance	Data loggers (Callaway et al. 2001), fish by Roegner et al. 2009	Annual max and min velocity, fish species composition proportions	Effectiveness evaluation	USACE	Ibid.

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
	Study fundamental physical and biological characteristics to understand where removal would be advantageous	Systematic sampling	Selected sites for all four seasons over 3 years	Ibid.	Ibid.	Ibid.	Ecological characterization	Ibid.	Ibid.
CRE-9	Periodic mapping and areal measurement of off-channel habitat types	Complete census with ground-truthing	Estuary-wide every 5 years	Length of riparian habitat by type of habitat	GIS-linked aerial photography	Amount of off-channel habitat	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8)
CRE-10	Periodic mapping and length measurements of dike structures	Complete census with ground-truthing	Estuary-wide every 5 years	Length of dike/levee structures	GIS-linked aerial photography	Length of dike/levee structures	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9)
	Effectiveness monitoring studies of tidal reconnections	BACI	Site-specific, 1 year before and 5 years after	Hydrology, vegetation, fish	Roegner et al. 2009	Water surface elevation, percent cover, fish species comosition proportions	Statistical comparison	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9), BPA/NPCC Fish and Wildlife Program (See CRE-2, 4), USACE's AFEP (See CRE-4,5)
	Ecological importance of tidal reconnections	BACI	Site-specific, 1 year before and 5 years after	Prey availability, fish diet, fish residence time, fish stock	Roegner et al. 2009	Diet composition charts	Ecological characterization	BPA/NPCC, USACE, NOAA	Ibid.
CRE-11	Periodic mapping and areal measurements of over-water structures	Complete census with ground-truthing	Estuary-wide every 5 years	Length of over-water structures	GIS-linked aerial photography and videography	Length of over-water structures	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9, 10)
	Track construction permits for shoreline structures	Census	Estuary-wide annually	No. and location of shoreline structures	Contact permitting agencies	Map of structures planned or under construction	Trend analysis	USACE	USACE Regulatory Program

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
	Study fundamental physical and biological characteristics	Systematic sampling	Selected sites for all four seasons over 3 years	Water velocity, light, fish species composition and abundance	Data loggers (Callaway et al. 2001), fish by Roegner et al. 2009	Annual max and min velocity and light levels, fish species composition proportions	Ecological characterization	USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9, 10), BPA/NPCC Fish and Wildlife Program (See CRE-2, 4, 10), USACE's AFEP (See CRE-4, 5, 10)
CRE-12	Total stranding estimate for entire estuary	Stratified random sampling by reach	Estuary-wide over all four seasons of 1 year	Number of juvenile salmonids stranded	Direct counts	Extrapolation to total no. stranded; map of stranding densities	Correlation analysis of factors associated with stranding	USACE	USACE's Channel Improvement Project
	Factors and stranding reduction study	BACI	Selected sites	Ibid.	Ibid.	Average no. stranded w/ and w/o the reduction device	Statistical comparison	USACE	Ibid.
CRE-13	Monitor trends in piscivorous predator abundance	Stratified random sampling by reach	Estuary-wide annually	Catch per unit effort	Electrofishing	Predator densities by location	Trend analysis	BPA/NPCC, USACE, NOAA	USACE's AFEP (See CRE-4, 5, 10, 11)
CRE-14	Pinniped predation monitoring	Systematic sampling	At BON during spring and summer	Number of pinnipeds	Observers	Weekly average abundance	Trend analysis	BPA/NPCC, USACE	USACE's AFEP (See CRE-4, 5, 10, 11, 13)
	Effectiveness of actions (monitor actions under Sec. 120)	BACI	Ibid.	Ibid.	Ibid.	Average abundance	Statistical comparison	USACE	Ibid.
	Magnitude of pinniped impact	Stratified random sampling by reach	Estuary-wide annually	Number of pinnipeds; number of salmon and steelhead consumed per predator; sampling rate	Observers, scat analysis	Estimate of the total number of salmon and steelhead consumed	Trend analysis	NOAA	Ibid.

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
CRE-15	Inventory and map invasive plants	Stratified random sampling by reach	Estuary-wide every 5 years	Species composition, abundance, distribution	Site surveys (Sytsma et al. 2004)	Percent cover, maps	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9, 10, 11)
	Effectiveness monitoring	BACI	At selected sites over 3 years	Ibid.	Ibid.	Average percent cover	Statistical comparison	Ibid.	Ibid.
CRE-16	Tern monitoring	Systematic sampling	Reach A during April-August annually	Number of birds	Observers	Number of mating pairs, total local population size	Trend analysis	BPA/NPCC, USACE, NOAA, USFWS	USACE's AFEP (See CRE-4, 5, 10, 11, 13, 14)
	Effectiveness of habitat shift	BACI	Reach A during April-August for 3-5 years	Ibid.	Ibid.	Ibid.	Statistical comparison	Ibid.	Ibid.
CRE-17	Double-crested cormorant monitoring	Systematic sampling	Reach A during April-August annually	Number of birds	Observers	Number of mating pairs, total local population size	Trend analysis	BPA/NPCC, USACE, NOAA, USFWS	USACE's AFEP (See CRE-4, 5, 10, 11, 13, 14, 16)
	Methods to reduce cormorant abundance	Site experiments	Reach A over 1-3 years	Ibid.	Ibid.	Ibid.	Compare/ contrast	Ibid.	Ibid.
CRE-18	Monitor passage of adult shad at BON	Census	Continuous monitoring at BON	Number of adult shad	Observers	Total number per year, weekly and monthly averages	Trend analysis	USACE	BPA/NPCC Fish and Wildlife Program (See CRE-2, 4, 10, 11), USACE's AFEP (See CRE-4, 5, 10, 11, 13, 14, 16, 17)
	Evaluate effectiveness of control methods	Site experiments	Selected sites	Ibid.	Seine, sonar	Number of shad by treatment	Statistical comparison	BPA/NPCC, USACE, NOAA	Ibid.
	Assess ecological effects of shad	Systematic sampling	Selected sites for summer over 3 years	Number of shad, diet, distribution, sex ratio	Various	Total population size, fecundity, etc.	Ecological characterization	BPA/NPCC	Ibid.

Mngt. Action	Monitoring Need[1]	Sampling Design	Spatial/ Temporal Scale	Measured Variables	Measurement Protocols	Derived Variables	Analysis	Possible Funding Entities	Possible Implementation & Coordination
CRE-19	Monitor trends in abundance, distribution, and species composition of invasive invertebrates	Stratified random sampling by reach	Estuary-wide every 5 years	Species composition, abundance, distribution	Site surveys (Sytsma et al. 2004)	Density distribution maps	Trend analysis	BPA/NPCC, USACE, NOAA	Estuary Partnership (See CRE-1, 8, 9, 10, 11, 15)
CRE-20, 21, 22, 23	Water quality and toxics monitoring downstream of BON	Stratified random sampling by reach, directed source and load tracking	Estuary-wide annual	Concentrations and loads of pollutants, contaminants by source and type	Various	Maps of distribution of pollutant concentration loads, pathways, and sources by type	Every 3 years - trend analysis; concentration loads, and yields by tributary and source	EPA, NOAA, USGS, ODEQ, WDOE	Estuary Partnership (See CRE-1, 8, 9, 10, 11, 15, 19)
	Fish health, sublethal and lethal thresholds	Focused experiments	Laboratory	Fish health/ mortality	Ibid.	Dose response curves	Statistical analysis	Ibid.	Ibid.

[1]Monitoring needs are those identified in Table 6-4.

TABLE 6-7
Estimated Cost and Schedule for Monitoring Needs (includes ongoing projects in some cases)

Management Action	Monitoring Need	Unit	Est. Cost	Schedule
CRE-1: Protect intact riparian areas in the estuary and restore riparian areas that are degraded.	Periodic mapping and areal measurement of riparian habitats and their condition using aerial photography to inform prioritization efforts	Every 5 years, base flyover for data acquisition @ $250K and analysis for riparian zones @ $200K	$1M base plus $800K riparian	2007-2022
CRE-2: Operate the hydrosystem to reduce the effects of reservoir surface heating, or conduct mitigation measures.	Water temperature monitoring in the estuary to establish baseline	Continuous monitoring at four sites (Bonneville Dam, Beaver, St. Helens, and Astoria) for 3 years @ $20K per year and one retrospective study of temperature	$60K (new data from Beaver, St. Helens) plus $50K study	2007-2009
	Monitoring during the hydrosystem temperature experiment	Continuous monitoring at four sites (Bonneville Dam, Beaver, St. Helens, and Astoria) for 5 years @ $20K per year	$100K	2010-2014
	Reservoir heating study and downstream effects	see Table 5-6	see Table 5-6	see Table 5-6
CRE-3: Protect and/or enhance estuary instream flows influenced by Columbia River tributary/mainstem water withdrawals and other water management actions in tributaries.	Continuous monitoring of Columbia River discharge at Beaver Terminal in the estuary	Data collection and dissemination are routine and ongoing.	$0 (already covered)	2007-2035
CRE-4: Adjust the timing, magnitude and frequency of hydrosystem flows (especially spring freshets) entering the estuary and plume to better reflect the natural hydrologic cycle, improve access to habitats, and provide better transport of coarse sediments and nutrients in the estuary and plume.	Continuous monitoring of Columbia River discharge at Beaver Terminal in the estuary and at BON dam	See CRE-3	$0 (already covered)	2007-2035
	Plume turbidity monitoring using remote sensing (satellite)	3 years @ $100K/year	$300K	2009-2011
	Flood, habitat, and constriant study(s)	see Table 5-6	see Table 5-6	see Table 5-6
CRE-5: Study and mitigate the effects of entrapment of fine sediment in reservoirs, to improve nourishment of the estuary and plume.	Effects of reservoir sediment entrapment	see Table 5-6	see Table 5-6	see Table 5-6
CRE-6: Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	Evaluate the beneficial use of dredged material – create shallow-water habitat	see Table 5-6	see Table 5-6	see Table 5-6
CRE-7: Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities and ship ballast intake in the estuary.	Dredge technique and operations study	see Table 5-6	see Table 5-6	see Table 5-6

Management Action	Monitoring Need	Unit	Est. Cost	Schedule
CRE-8: Remove or modify pilings and pile dikes when removal or modification would benefit juvenile salmonids and improve ecosystem health.	Periodic mapping and length and density measurements of pile structures using the Estuary Partnership's estuary GIS system	One assessment every 5 years @ $200K per assessment	$800K	2007-2022
	Monitor physical and biological effects of pile removal	see Table 5-6	see Table 5-6	see Table 5-6
	Study fundamental physical and biological characteristics to understand where removal would be advantageous	One study for 3 years @ $250K/year	$750K	2007-2009
CRE-9: Protect remaining high-quality off-channel habitat from degradation and restore degraded areas with high intrinsic potential for high-quality habitat.	Periodic mapping and areal measurement of off-channel habitat types to inform prioritization and monitoring efforts	See CRE-1 cost for base flyover, plus analysis of off-channel habitats every 5 years @ $200K per assessment	$800K	2007-2022
CRE-10: Breach, lower, or relocate dikes and levees to establish or improve access to off-channel habitats.	Periodic mapping and length measurements of dike structures using the Estuary Partnership's estuary GIS system.	See CRE-9; additional analysis @ $50K per assessment every 5 years	$200K	2007-2022
	Effectiveness monitoring studies of tidal reconnections	Two case studies each in Reaches A-E and one study each in Reaches F-H with samplings in Years 0, 1, 4, 7 @ $100K per sampling-year	$5.2M	2007-2035
	Ecological importance of tidal reconnections	Building on the data from the effectiveness monitoring, one study for 5 years @ $400K per year	$2M	2007-2011
CRE-11: Reduce the square footage of over-water structures in the estuary.	Periodic mapping and areal measurements of over-water structures using the Estuary Partnership's estuary GIS system.	Assessments every 5 years @ $250K per assessment	$1M	2007-2022
	Track permits for construction of shoreline structures	Annual compilation and reporting @ $60K per year	$1.5M	2007-2031
	Study fundamental physical and biological characteristics to understand where removal would be advantageous	One study for 3 years @ $250K/year	$750K	2008-2010
CRE-12: Reduce the effects of vessel wake stranding in the estuary.	Total stranding estimate for entire estuary	One study with sampling three seasons per year at eight sites for 2 years @ $1M per yr	$2M	2009-2010

Management Action	Monitoring Need	Unit	Est. Cost	Schedule
	Factors and stranding reduction study	see Table 5-6	see Table 5-6	see Table 5-6
CRE-13: Manage pikeminnow and other piscivorous fish, including introduced species, to reduce predation on salmonids.	Monitor trends in predator abundance	see Table 5-6	see Table 5-6	see Table 5-6
CRE-14: Identify and implement actions to reduce salmonid predation by pinnipeds.	Pinniped predation monitoring	One study estuary-wide for 5 years @ $250K per year	$2.5M	2008-2012
	Effectiveness of actions. Monitor actions under Sec. 120	Study every 5 years for 20 years @ $200K (see above)	$0 (already covered)	2013-2032
	Magnitude of pinniped impact in estuary	See pinniped predation monitoring above	$0 (already covered)	2008-2012
CRE-15: Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of invasive plants.	Inventory and map invasive plants	see Table 5-6	see Table 5-6	see Table 5-6
	Effectiveness monitoring	see Table 5-6	see Table 5-6	see Table 5-6
CRE-16: Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	Tern monitoring	see Table 5-6	see Table 5-6	see Table 5-6
	Effectiveness of habitat shift	see Table 5-6	see Table 5-6	see Table 5-6
CRE-17: Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	Cormorant monitoring	see Table 5-6	see Table 5-6	see Table 5-6
	Methods to reduce cormorant abundance	see Table 5-6	see Table 5-6	see Table 5-6
CRE-18: Reduce the abundance of shad in the estuary.	Monitor passage of adult shad at Bonneville Dam	Data collection and dissemination are routine and ongoing.	$0 (already covered as part of adult fish counts)	2007-2035
	Evaluate effectiveness of control methods	see Table 5-6	see Table 5-6	see Table 5-6
	Assess ecological effects of shad	One study for 3 years @ $300K per year	$900K	2008-2010
CRE-19: Prevent new introductions of aquatic invertebrates and reduce the effects of existing infestations.	Monitor trends in abundance, distribution, and species composition of invasive invertebrates	Recurring study every 3 years for 30 years @ $500K per year	$5M	2008-2037

Management Action	Monitoring Need	Unit	Est. Cost	Schedule
CRE-20: Implement pesticide and fertilizer best management practices to reduce estuarine and upstream sources of nutrients and toxic contaminants entering the estuary.	WQ/toxics monitoring downstream of Bonneville Dam	Annual ambient and directed sampling for 25 years @ $1M/year	$25M	2008-2032
	Pre- and post-project monitoring	Twice annual upstream + downstream sites @ $10K per project @ one project per year for 25 years	$250,000	2008-2032
	Source tracking, fish health, sublethal and lethal thresholds	One study for 5 years @ $500K; fish health @ 5-6 sites per year @ $250K for 25 years; one study for eight priority toxics @ $1.5M for 3 years	$8.25M	2008-2032
CRE-21: Identify and reduce terrestrially and marine-based industrial, commercial, and public sources of pollutants.	WQ/toxics monitoring	See CRE-20	See CRE-20	See CRE-20
	Pre- and post-project monitoring	Ibid.	Ibid.	Ibid.
	Source tracking, fish health, sublethal and lethal thresholds	Ibid.	Ibid.	Ibid.
CRE-22: Restore or mitigate contaminated sites.	WQ/toxics monitoring	See CRE-20	See CRE-20	See CRE-20
	Pre- and post-project monitoring	Ibid.	Ibid.	Ibid.
	Source tracking, fish health, sublethal and lethal thresholds	Ibid.	Ibid.	Ibid.
CRE-23: Implement stormwater best management practices in cities and towns.	Stormwater monitoring	see Table 5-6	see Table 5-6	see Table 5-6
	Directed stormwater monitoring	Twice annual @ 5 cities @ $24K per site for 25 years	$3M	2008-2032
	Source tracking, improve BMPs and regulations	1 study for 5 years @ $500K (see CRE-20); 1 study for 3 years @ $1.5M	$2M	2008-2013

CHAPTER 7

Perspectives on Implementation

Substantial investment is being made in the Columbia River basin to recover listed Chinook, coho, steelhead, and chum. How much of this investment should be made in the estuary? How much do the estuary and plume environments contribute to the survival of upstream ESUs, and is recovery of upstream ESUs possible without a healthier estuary ecosystem? If not, what does the information in Chapters 3, 4, and 5 tell us about which management actions to implement in the estuary?

Chapter 7 explores issues related to the selection of management actions to be implemented in the estuary and how those choices will shape future conditions for salmonids in the estuary and plume. It also suggests next steps in implementation and identifies implementation challenges.

Putting the Estuary in Context

This recovery plan module reflects current scientific understanding that the Columbia River estuary and plume provide habitat that wild salmonids need to complete their life cycles. Historically, juveniles from hundreds of distinct salmonid populations, at various life history stages, used the estuary for refuge and rearing as they prepared physiologically for life in the ocean. Over evolutionary time populations developed life history strategies in which juveniles from different populations staggered their use of the estuary throughout the year, exploiting estuarine habitats in different ways for different lengths of time. Although the estuary posed risks to juvenile salmonids, the diversity in life history strategies allowed salmon and steelhead to take maximum advantage of estuarine resources, which offered tremendous opportunities for refuge and growth. Unlike an upstream tributary, through the year the estuary provided habitat for all of the salmonid populations in the Columbia River basin during a critical stage in their life cycles.

Over the last 200 years the ability of the Columbia River estuary to meet the needs of salmon and steelhead has been seriously compromised. There is no question about the extent of changes in the estuary: the timing, magnitude, and duration of flows do not resemble those of historical flows, access to the estuary floodplain has been virtually eliminated, sediment transport processes that depend on flows and upstream sediment sources are radically different than they were historically, water quality has degraded as a result of contamination, temperatures are approaching and sometimes exceeding lethal limits, and there have been fundamental changes at the base of the estuarine food web, with associated alterations in inter- and intra-species relationships. A central premise of this recovery plan module is that although the estuary ecosystem is degraded, it can be improved, and that a healthier estuary ecosystem would contribute meaningfully to the basinwide recovery of ESA-listed salmonids.

Factors That Influence Decision Making

Decisions about implementation would be easy if protecting and restoring salmonids were the only consideration. However, as much as we value healthy native fish runs, as a society we also value a stable economy, financial opportunity for individuals and businesses, public safety, and property rights. These values will play into decisions about which management actions to implement, as will the three factors used to evaluate the management actions in Chapter 5: cost, constraints, and potential benefits to salmonids.

Also affecting choices about implementation is scientific uncertainty. Although fisheries science has matured over the last 100 years, how salmonids interact in complex ecosystems is not well understood; this is especially true in the estuary and plume. Yet we cannot wait until uncertainty has been eliminated before taking action. In the face of scientific uncertainty, then, decisions about implementing management actions will have to be made using the most current scientific information available, combined with best professional judgment. Historically, it has been a mix of science and policy choices that have guided decisions that affected the estuary; it is likely that these same forces will also determine the effectiveness of science-driven recovery efforts.

Significance of Constraints to Implementation

Not a single management action identified in Table 5-1 will be easy to implement. In one way or another, implementation of each of the 23 actions is constrained, in some cases greatly. Understanding the nature and magnitude of constraints to the implementation of management actions is important for several reasons. First, it grounds the actions in the real world and tempers expectations for results. Second, it provides insights into the level of effort that would be required for an action to have a sizable impact on salmonid populations. Third and most important, it reveals that every proposed action in this recovery plan module has significant obstacles to implementation.

Because it will be difficult to implement any single action fully and gain all of its potential benefit to salmonids, it will be important to implement a relatively large number of the proposed management actions. In other words, if each management action in the estuary has significant constraints, it may take partial implementation of all or most of the actions to improve the health of the estuary ecosystem to the point that the ecosystem provides the benefits that salmonids need to recover.

To illustrate the relative constraints of different actions, Table 7-1 presents management actions by degree of constraint to implementation, in descending order.

Table 7-1
Management Actions Sorted by Degree of Constraint

#	Action	Degree of Constraint
CRE-02	Operate the hydrosystem to reduce reservoir heating.	5
CRE-03	Protect/enhance instream flows influenced by water withdrawals and other water management actions in tributaries.	5
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows.	5
CRE-05	Mitigate entrapment of fine sediment in reservoirs.	5
CRE-18	Reduce shad abundance.	5
CRE-19	Prevent aquatic invertebrate introductions.	5
CRE-14	Reduce predation by pinnipeds.	4
CRE-15	Reduce invasive plants.	4
CRE-17	Redistribute cormorants.	4
CRE-21	Identify and reduce sources of pollutants.	4
CRE-20	Implement pesticide/fertilizer BMPs.	4
CRE-9	Protect/restore high-quality off-channel habitat	3
CRE-10	Breach, lower, or relocate dikes and levees.	3
CRE-12	Reduce vessel wake stranding.	3
CRE-22	Restore or mitigate contaminated sites.	3
CRE-11	Reduce over-water structures.	3
CRE-01	Protect/restore riparian areas.	3
CRE-06	Use dredged materials beneficially.	3
CRE-16	Redistribute Caspian terns.	2
CRE-07	Reduce entrainment/habitat effects of dredging and ballast.	2
CRE-13	Manage pikeminnow and other piscivorous fish.	2
CRE-23	Implement stormwater BMPs.	2
CRE-08	Remove or modify pilings and pile dikes	2

Another useful table when considering implementation constraints is Table 5-3, which shows the differences in potential benefit to salmonids if implementation of actions is unconstrained, versus constrained, which represents a more realistic scenario. However, although Table 5-3 demonstrates the size of the gap between unconstrained and constrained implementation of actions, it does not adequately characterize the magnitude of response that might be expected from constrained implementation. The next section of this document is intended to help show the potential benefit from constrained implementation of actions.

Management Actions Offering the Greatest Survival Benefits

If we were to increase our investment in restoration of the Columbia River estuary by an order of magnitude, what would the ecological return on that investment be? Our ability to answer that question is limited by a lack of understanding of how much mortality actually occurs in the estuary and plume. Still, we do have some information about potential gains that reasonably could be expected as a result of such investment.

Juvenile Survival Improvement. In Chapter 5, survival improvement targets were developed as a tool for comparing the potential benefits of implementing different management actions. This planning exercise used the best available information about estuary mortality for wild, ESA-listed stream- and ocean-type juveniles and then established a 20 percent survival improvement target for the 22 management actions that would affect the survival of juveniles. The survival improvement targets were then allocated across the various management actions to help characterize where survival gains might occur. The results are not intended to represent a deterministically based analysis; however, they do reflect information in the scientific literature, especially about mortality resulting from terns, cormorants, ship wake stranding, contaminants, and pinnipeds.

Tables 7-2 and 7-3 summarize the results of this planning exercise, sorting actions by their potential to improve survival of stream- and ocean-type juveniles, respectively, assuming that implementation of the actions is constrained. This ordering is simply an exercise to hypothesize where survival improvements equal to 20 percent of the number of juveniles exiting the estuary and plume might be expected for stream-type and ocean-type juveniles.

For stream-type salmonids, the following observations can be made from Table 7-2:

- Approximately 60 percent of the survival improvements are assigned to the top five actions, which include adjusting flow, protecting or restoring off-channel habitat, restoring or mitigating contaminated sites, and managing birds that prey on salmonids.
- Approximately 30 percent of the survival improvements are assigned to establishing or improving access to off-channel habitat, protecting and restoring riparian areas, reducing sources of pollutants, managing piscivorous fish, and removing or modifying pilings and pile dikes.
- Approximately 10 percent of the survival improvements are assigned across the remaining actions, with varying degrees of improvements.

For ocean-type salmonids, the following observations can be made from Table 7-3:

- Approximately 65 percent of the survival improvements are assigned to the top five actions, which include adjusting flows, establishing or improving access to off-channel habitat, protecting or restoring off-channel habitat, and addressing issues of contamination.
- Approximately 30 percent of the survival improvements are assigned to protecting and restoring riparian areas, reducing reservoir heating, removing or modifying pilings and pile dikes, reducing vessel wake stranding, using dredged materials beneficially,

managing piscivorous fish, and implementing pesticide, fertilizer, and stormwater BMPs.

- Approximately 5 percent of the survival improvements are assigned across the remaining actions, with varying degrees of improvements.

Table 7-2
Management Actions Sorted by Benefit to Stream-type Juveniles

#	Action	Survival Target (Stream Types)	Percentage of Target Improvements
CRE-16	Redistribute Caspian terns.	350,000	~60%
CRE-17	Redistribute cormorants.	250,000	
CRE-09	Protect/restore high-quality off-channel habitat.	150,000	
CRE-22	Restore or mitigate contaminated sites.	142,000	
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows.	125,000	
CRE-13	Manage pikeminnow and other piscivorous fish.	122,000	~30%
CRE-10	Breach, lower, or relocate dikes and levees.	100,000	
CRE-01	Protect/restore riparian areas.	100,000	
CRE-08	Remove or modify pilings and pile dikes	100,000	
CRE-21	Identify and reduce sources of pollutants.	72,000	
CRE-20	Implement pesticide/fertilizer BMPs.	42,000	~10%
CRE-23	Implement stormwater BMPs.	30,000	
CRE-02	Operate the hydrosystem to reduce reservoir heating.	20,000	
CRE-03	Protect/enhance instream flows influenced by water withdrawals and other water management actions in tributaries.	20,000	
CRE-06	Use dredged materials beneficially.	15,000	
CRE-15	Reduce invasive plants.	15,000	
CRE-07	Reduce entrainment/habitat effects of dredging and ballast.	10,000	
CRE-05	Mitigate entrapment of fine sediment in reservoirs.	5,000	
CRE-18	Reduce shad abundance.	5,000	
CRE-11	Reduce over-water structures.	3,000	
CRE-19	Prevent aquatic invertebrate introductions.	2,000	
CRE-12	Reduce vessel wake stranding.	2,000	
	Total:	1.68 million	

TABLE 7-3
Management Actions Sorted by Benefit to Ocean-type Juveniles

#	Action	Survival Target (Ocean Types)	Percentage of Target Improvements
CRE-10	Breach, lower, or relocate dikes and levees.	450,000	~65%
CRE-09	Protect/restore high-quality off-channel habitat.	400,000	
CRE-22	Restore or mitigate contaminated sites.	300,000	
CRE-21	Identify and reduce sources of pollutants.	275,000	
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows.	225,000	
CRE-01	Protect/restore riparian areas.	150,000	~30%
CRE-08	Remove or modify pilings and pile dikes	150,000	
CRE-13	Manage pikeminnow and other piscivorous fish.	140,000	
CRE-02	Operate the hydrosystem to reduce reservoir heating.	90,000	
CRE-23	Implement stormwater BMPs.	65,000	
CRE-12	Reduce vessel wake stranding.	55,000	
CRE-20	Implement pesticide/fertilizer BMPs.	50,000	
CRE-06	Use dredged materials beneficially	50,000	
CRE-03	Protect/enhance instream flows influenced by water withdrawals and other water management actions in tributaries.	25,000	~5%
CRE-11	Reduce over-water structures.	25,000	
CRE-15	Reduce invasive plants.	20,000	
CRE-07	Reduce entrainment/habitat effects of dredging and ballast.	8,000	
CRE-19	Prevent aquatic invertebrate introductions.	8,000	
CRE-05	Mitigate entrapment of fine sediment in reservoirs.	5,000	
CRE-18	Reduce shad abundance.	5,000	
CRE-16	Redistribute Caspian terns.	2,000	
CRE-17	Redistribute cormorants.	2,000	
	Total:	2.5 million	

While many of the actions are highly constrained, the planning exercise summarized in Tables 7-2 and 7-3 assumes that, even with incremental changes associated with constrained implementation, certain actions could yield significant results, especially when coupled with complementary actions. For example, ocean-type juveniles rely heavily on off-channel habitats for food sources and rearing opportunities. The two primary actions intended to improve access to off-channel habitats are CRE-10, “Breach, lower, or relocate dikes and levees,” and CRE-4, “Adjust the timing, magnitude, and frequency of hydrosystem flows.” Implementation of both of these actions is highly constrained, yet they could have synergistic effects and their joint implementation—even if only partial—could result in significant survival improvements for ocean-type salmonids. In contrast, if only one of these actions were implemented (or, worse yet, neither), other actions would need to be implemented as fully as possible in an attempt to compensate for the foregone opportunity to address one of the main factors limiting juvenile salmonid performance in the estuary.

Adult Survival Improvement. Because CRE-14, “Reduce predation by pinnipeds,” is the only action that directly addresses the adult life history stage of salmonids, this action is treated separately and is not included in Tables 7-2 and 7-3. In 2010, which saw the largest spring Chinook and steelhead runs from 2002 to 2010, pinniped predation on spring Chinook and steelhead (both of which are stream types) at Bonneville Dam was estimated to be 2.2 percent. This equates to 6,081 spring Chinook and steelhead out of a run size of 267,194 fish (U.S. Army Corps of Engineers 2010). Projects to reduce pinniped predation have had limited success, and more stringent management techniques are constrained by protections afforded by the Marine Mammal Protection Act. Although the act does provide for lethal control, the process for implementing that provision is challenging. In 2008, NMFS granted authority under Section 120 of the Marine Mammal Protection Act to the states of Oregon, Washington, and Idaho to intentionally take, by lethal methods, individually identifiable California sea lions that prey on Pacific salmon and steelhead at Bonneville Dam, but the effectiveness of this approach is unknown. Given these constraints, PC Trask & Associates, Inc., in consultation with NMFS Northwest Regional Office staff, estimated that CRE-14 might result in a 17 percent reduction in pinniped-related mortality of adults at Bonneville Dam each year (approximately 1,034 fish annually as applied to 2010 run returns).

Costs for Constrained Implementation of Management Actions

As discussed in Chapter 5, estimating the cost of the management actions in this module is inherently difficult and involves significant uncertainties. This is partly because in many cases, the constraints to implementation have not yet been explored in enough detail to be able to determine what is and is not possible, and key scientific and technical questions about the estuary have not yet been answered. In Chapter 5, Table 5-6 established cost estimates for constrained implementation of actions by assuming an optimistic view—that constraints can be reduced through focused effort and that positive changes in the estuary can be made. A more pessimistic view would likely yield a significantly lower cost estimate, with correspondingly smaller survival improvements. Costs were assigned at the project scale to help identify possible components to actions, with the expectation that future refinements would yield a more sophisticated estimate. Finally, project costs were estimated over a 25-year time horizon.

Table 7-4 organizes management actions by total estimated cost (from Table 5-6). The following observations can be made:

- Costs for the top six actions total $332 million, or about 63 percent of the entire budget. The actions include restoring contaminated sites, modifying flows, reducing sources of pollutants, establishing or improving access to off-channel habitats, protecting or restoring off-channel habitats, and protecting and restoring riparian areas.
- Costs for the next six actions on the list equal $108 million, or about 20 percent of the budget. This group of actions consists of reducing reservoir-related temperature changes, implementing stormwater BMPs, addressing vessel wake stranding, removing or modifying pilings and pile dikes, and managing fish and pinnipeds that prey on salmonids.
- The final 11 actions on the list equal $88 million, or about 17 percent of the budget.

TABLE 7-4
Management Actions Sorted by Estimated Cost

#	Action	Cost of Action	Cost per Group of Actions
CRE-10	Breach, lower, or relocate dikes and levees.	$75 million	~$332 million, or 63% of total
CRE-09	Protect/restore high-quality off-channel habitat.	$68 million	
CRE-22	Restore or mitigate contaminated sites.	$60.5 million	
CRE-21	Identify and reduce sources of pollutants.	$46 million	
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows.	$44.5 million	
CRE-01	Protect/restore riparian areas.	$38 million	
CRE-08	Remove or modify pilings and pile dikes	$27.25 million	~$108 million, or 20% of total
CRE-02	Operate the hydrosystem to reduce reservoir heating.	$20 million	
CRE-23	Implement stormwater BMPs.	$19.5 million	
CRE-14	Reduce predation by pinnipeds.	$15 million	
CRE-13	Manage pikeminnow and other piscivorous fish.	$13 million	
CRE-12	Reduce vessel wake stranding.	$13 million	
CRE-15	Reduce invasive plants.	$12.5 million	~$88 million, or 17% of total
CRE-17	Redistribute cormorants.	$10.5 million	
CRE-20	Implement pesticide/fertilizer BMPs.	$12.5 million	
CRE-03	Protect/enhance instream flows influenced by water withdrawals and other water management actions in tributaries.	$10 million	
CRE-16	Redistribute Caspian terns.	$10 million	
CRE-05	Mitigate entrapment of fine sediment in reservoirs.	$8 million	
CRE-06	Use dredged materials beneficially.	$6 million	
CRE-11	Reduce over-water structures.	$5.8 million	
CRE-18	Reduce shad abundance.	$5.5 million	
CRE-07	Reduce entrainment/habitat effects of dredging and ballast.	$4.5 million	
CRE-19	Prevent aquatic invertebrate introductions.	$3 million	
	Total:	$528.05 million	

As also discussed in Chapter 5, there is significant uncertainty in these cost estimates because of the ambiguity about the degree to which constraints to implementation can be overcome, the level of effort that would be required to achieve a measurable result, and how new information could change current understanding about the cost and effectiveness of management actions. However, it is assumed that if restoring the ecosystem of the Columbia River estuary were established as a goal, this would require financial investment on a par with that for other major ecosystem recovery efforts around the United States.

Cost-Effectiveness of Management Actions

Cost-effectiveness is an important consideration when attempting to achieve large goals with limited resources, and the more limited the resources with respect to the goal, the more important it is that the maximum benefit be obtained from each expenditure. In the case of the Columbia River estuary, improving conditions for salmonids is likely to be an expensive and long-term effort—one that will require careful consideration of the survival benefits and costs of possible actions.

The linkage between the survival benefits and costs in this recovery plan module is difficult to characterize accurately because of the margin of error that, at this point, exists in both the estimated costs and the survival targets. Because the survival improvement targets were allocated across the set of actions as a planning exercise rather than as results of a scientific analysis, it is the allocation that is most important, not the target numbers themselves. In the case of costs, estimates were made assuming that constraints to implementation of actions could be partially overcome; this assumption served as a way to explore the degree of constraints and the level of effort that would be required to bring about significant benefits to salmonids. The resulting costs should be viewed as preliminary numbers useful in starting critical discussions about decisions that will shape the future of the estuary.

Understanding that, as outlined above, there are limitations governing the survival improvement targets and cost estimates, these sets of numbers can be compared to provide clues about which management actions might be the most cost-effective. Table 7-5 makes such a comparison, using cost information from Table 7-4 and target survival improvements from Table 7-3 to estimate the cost-effectiveness of each action, expressed as a cost/survival index. The actions are sorted in ascending order to show the most cost-effective actions first.

Table 7-5 is intended as a general indication of cost-effectiveness to help frame the discussion about implementing management actions. Also, some actions were assigned very conservative survival improvement numbers because of the level of uncertainty about underlying ecological processes. This is the case with several actions related to the food web because the connection between food web changes and effects on juveniles is not fully defined. As a result, the cost-effectiveness ratings of these actions appear high.

TABLE 7-5
Management Actions Sorted by Cost/Survival Index

#	Action	Survival (Ocean Types)	Survival (Stream Types)	Total Survival	Cost of Action	Cost/ Survival Index
CRE-16	Redistribute Caspian terns.	2,000	350,000	352,000	$10 million	28
CRE-17	Redistribute cormorants.	2,000	250,000	252,000	$10.5 million	42
CRE-13	Manage pikeminnow and other piscivorous fish.	140,000	122,000	262,000	$13 million	50
CRE-06	Use dredged materials beneficially.	50,000	15,000	65,000	$6 million	92
CRE-08	Remove or modify pilings and pile dikes	150,000	100,000	250,000	$27.25 million	109
CRE-09	Protect/restore high-quality off-channel habitat.	400,000	150,000	550,000	$68 million	124
CRE-04	Adjust the timing, magnitude, and frequency of hydrosystem flows.	225,000	125,000	350,000	$44.5 million	127
CRE-21	Identify and reduce sources of pollutants.	275,000	72,000	347,000	$46 million	133
CRE-20	Implement pesticide/fertilizer BMPs.	50,000	42,000	92,000	$12.5 million	136
CRE-10	Breach, lower, or relocate dikes and levees.	450,000	100,000	550,000	$75 million	136
CRE-22	Restore or mitigate contaminated sites.	300,000	142,000	442,000	$60.5 million	137
CRE-01	Protect/restore riparian areas.	150,000	100,000	250,000	$38 million	152
CRE-02	Operate the hydrosystem to reduce reservoir heating.	90,000	20,000	110,000	$20 million	182
CRE-23	Implement stormwater BMPs.	65,000	30,000	95,000	$19.5 million	205
CRE-11	Reduce over-water structures.	25,000	3,000	28,000	$5.8 million	207
CRE-03	Protect/enhance instream flows influenced by water withdrawals and other water management actions in tributaries.	25,000	20,000	45,000	$10 million	222
CRE-12	Reduce vessel wake stranding.	55,000	2,000	57,000	$13 million	228
CRE-07	Reduce entrainment/habitat effects of dredging and ballast.	8,000	10,000	18,000	$4.5 million	250
CRE-19	Prevent aquatic invertebrate introductions.	8,000	2,000	10,000	$3 million	300
CRE-15	Reduce invasive plants.	20,000	15,000	35,000	$12.5 million	357
CRE-18	Reduce shad abundance.	5,000	5,000	10,000	$5.5 million	550
CRE-05	Mitigate entrapment of fine sediment in reservoirs.	5,000	5,000	10,000	$8 million	800

The following observations can be made from Table 7-5:

- The median of all assigned cost/survival index numbers is 144. (The median is the middle number of a group of numbers, with half the numbers having values greater than the median and half having values less than the median).
- Some of the actions that appeared most cost-prohibitive in Table 7-4, such as establishing or improving access to off-channel habitat (CRE-10), adjusting flows (CRE-04), and restoring or mitigating contaminated sites (CRE-22), emerge as cost-effective when viewed in the context of the survival improvements they could bring about. All three of these actions have a cost/survival index value that is less than the median and that puts them in the top—or more cost-effective—half of Table 7-5.
- Several actions, including redistributing terns (CRE-16), redistributing cormorants (CRE-17), and managing piscivorous fish such as pikeminnow (CRE-13), appear to be very cost-effective.

In this planning exercise, the total survival improvement of actions listed above the median is 3.5 million juveniles (2.0 million ocean type and 1.5 million stream type), or about 17 percent of the total number of juveniles currently thought to be exiting the estuary.

Improving Ecosystem Health

The Columbia River estuary and plume ecosystems are degraded compared to historical conditions. One hypothesis of this recovery plan module is that if the estuary and plume remain in their degraded state, recovery of all 13 ESUs may not be possible. The remainder of this section is intended to help characterize choices that will ultimately govern the health of the estuarine ecosystem in the Columbia River.

Is there really a problem for salmonids in the estuary? Sources such as *Salmon at River's End* (Bottom et al. 2005), and emerging micro-acoustic tagging studies make clear that the mortality rate in the estuary is very high and almost certainly approaches 50 percent for some ESUs. This alone argues for discarding the old paradigm of the estuary as primarily a transportation corridor for salmonids on their journey to the ocean. Stream- and ocean-type salmonids clearly rely on estuary and plume habitats for crucial rearing and refuge opportunities during one of the stages in their life cycles. Chapters 3 and 4 of this estuary recovery module describe the mechanisms by which a degraded estuarine ecosystem puts juvenile salmonids at risk.

Is ecosystem restoration necessary in the estuary, or can we surgically reduce specific threats to improve salmonid survival? Ecosystem health in the estuary and plume is the cumulative result of many stressors that originate within the estuary and also outside of the estuary. The level of constraint observed in each of the management actions identified in this estuary recovery module is high, and it is extremely unlikely that one or more actions could be implemented to the degree that they would essentially eliminate a threat to salmonids. Thus each management action should be implemented to the greatest degree practical, unless it is proven that to do so would seriously undermine public safety, the economy, or property rights.

What suite of actions is most important to implement for ocean-type salmonids? There is no single correct answer to this question. In the long term, ecosystem restoration will provide the most stable, self-supporting conditions for salmonids and other native species. Ocean-type juvenile salmonids rear longer in the estuary than stream types do and therefore would benefit the most from improved ecosystem health.

The analysis and planning exercises in this recovery plan module suggest that the following actions are most important for ocean-type salmonids:

- CRE-01: Protect/restore riparian areas.
- CRE-02: Operate the hydrosystem to reduce reservoir heating.
- CRE-04: Adjust the timing, magnitude, and frequency of hydrosystem flows.
- CRE-08: Remove or modify pilings and pile dikes.
- CRE-09: Protect/restore high-quality off-channel habitat.
- CRE-10: Breach, lower, or relocate dikes and levees.
- CRE-13: Manage pikeminnow and other piscivorous fish.
- CRE-21: Identify and reduce sources of pollutants.
- CRE-22: Restore or mitigate contaminated sites.

Implementing this suite of actions would cost approximately $392.3 million and would be expected to yield survival improvements of roughly 2.2 million wild, ESA-listed ocean-type juveniles, or 88 percent of the survival target for ocean-type salmonids. In other words, for ocean-type juveniles, 88 percent of the gain to be had from the management actions could be achieved by implementing these nine actions.

What suite of actions is most important to implement for stream-type salmonids? Stream-type salmonids prefer deeper waters with higher velocities than ocean-types do. They also reside in the estuary for shorter periods of time, but they tend to use the plume more extensively than do ocean-type salmonids. Stream-type juveniles are thought to actively feed in the estuary; information indicates that stream types travel out of the channel to forage and may encounter predators such as the northern pikeminnow (Casillas 2006). For stream types, it is very important to reduce Caspian tern and double-crested cormorant predation. In addition, predation by pinnipeds on adult spring Chinook and winter steelhead is a significant threat.

The analysis and planning exercises in this recovery plan module suggest that the following actions are most important for stream-type salmonids:

- CRE-01: Protect/restore riparian areas.
- CRE-04: Adjust the timing, magnitude, and frequency of hydrosystem flows.
- CRE-08: Remove or modify pilings and pile dikes.
- CRE-09: Protect/restore high-quality off-channel habitat.
- CRE-10: Breach, lower, or relocate dikes and levees.
- CRE-13: Manage pikeminnow and other piscivorous fish.
- CRE-14: Reduce predation by pinnipeds.
- CRE-16: Redistribute Caspian terns.
- CRE-17: Redistribute cormorants.
- CRE-21: Identify and reduce sources of pollutants.
- CRE-22: Restore or mitigate contaminated sites.

Implementing this suite of actions would cost approximately $407.8 million and would be expected to yield survival improvements of roughly 5,000 stream-type adults (ESA-listed and non-listed adults) and 1.51 million wild, ESA-listed stream-type juveniles, or 90 percent of the survival target for stream-type juveniles. In other words, for stream-type juveniles, 90 percent of the gain to be had from the management actions could be achieved by implementing these 11 actions.

How cost-effective are the top actions for ocean- and stream-type salmonids? Of the top 11 priority actions for stream- and ocean-type salmonids, nine are listed at or above the median cost/survival index.

What would be gained by implementing actions that benefit both ocean- and stream-type salmonids? The lists of priority actions identified above for ocean- and stream-type salmonids contain eight actions that are predicted to benefit both types of salmonids. These actions are as follows:

- CRE-01: Protect/restore riparian areas.
- CRE-04: Adjust the timing, magnitude, and frequency of hydrosystem flows.
- CRE-08: Remove or modify pilings and pile dikes.
- CRE-09: Protect/restore remaining high-quality off-channel habitat.
- CRE-10: Breach, lower, or relocate dikes and levees.
- CRE-13: Manage pikeminnow and other piscivorous fish.
- CRE-21: Identify and reduce sources of pollutants.
- CRE-22: Restore or mitigate contaminated sites.

Implementing this set of actions would cost approximately $372.25 million and would be expected to yield survival improvements of roughly 3 million wild, ESA-listed juvenile salmonids (ocean- and stream-types combined). Although the majority of these would be ocean types, there is an argument to be made for favoring actions that would benefit both salmonid types—namely, that implementing such actions would be likely to provide benefits across the spectrum of life history strategies that juvenile salmonids of both types employ in the estuary. Many of the actions that benefit stream-type salmonids would also benefit ocean types displaying less dominant life history strategies, while many actions benefiting ocean-type salmonids would also benefit stream types displaying less dominant life history strategies. Actions that benefit both ocean and stream types, then, presumably would affect a wide range of less dominant life history strategies and thus would help preserve the diversity that contributes to salmonids' ability to persist in the face of changing environmental conditions.

However, this is not to suggest implementation only of those actions that would benefit both ocean- and stream-type juveniles because there are limitations to this approach. For instance, avian and pinniped predation actions, which would primarily benefit stream types, are cost-effective and critical to improving the survival of stream-type salmonids.

Will management actions have synergistic effects? Many of the management actions could have far-reaching effects if they were implemented together, either because they address multiple interrelated threats, such as flow regulation and impaired sediment transport, or because their effects could amplify the benefits of other, complementary management actions. An example would be the two actions of improving flows and establishing access to off-channel habitat by breaching dikes or levees. Although each action by itself would increase salmonid access to off-channel habitat, implementing both actions has the potential to offer exponentially greater access, as well as contribute macrodetrital inputs to the food web and offer other ecosystem benefits. Although such benefits are difficult to quantify, the potential for synergistic effects of complementary actions is real and should be taken into consideration when management actions are selected.

The U.S. Army Corps of Engineers currently is studying the cumulative effects of various combinations of restoration activities in the estuary; results of the study are expected to provide valuable data on the potential synergistic effects of the management actions presented in the estuary recovery plan module. Meanwhile, several actions have the potential to be complementary in their effects, at the very least, and possibly to offer significant synergistic benefits. While it is not possible to identify all such actions, examples include using dredged materials to reduce vessel wake stranding (CRE-6 and CRE-12) or improving access to off-channel habitats by breaching dikes and adjusting flows (CRE-10 and CRE-4). At the same time, management actions need to be sequenced to avoid possible negative synergistic effects, such as by restoring contaminated sites (CRE-22) in off-channel habitat before restoring access to that habitat through dike breaching and flow modifications (CRE-10 and CRE-4). Considering the possible complementary, cumulative, or synergistic effects of management actions and sequencing actions for maximum benefit will be important aspects of implementing the estuary recovery plan module.

What about the lower ranking actions? In many ways, the lower ranking actions are the most difficult to characterize in terms of survival improvements and costs. Low ratings may be due more to a lack of scientific information than a lack of effectiveness. For example, basic changes to the food web in the estuary as a result of increased phytoplankton production or the introduction of aquatic invertebrates may have profound effects on the estuary, but the degree of impact is unknown. These threats must be more fully understood if their contribution to overall ecosystem health is to be determined with accuracy.

What planning tasks remain? The process of developing this estuary recovery plan module pointed to several areas where recovery planning for the estuary could be refined. Additional scientific information about juvenile mortality in the estuary would clarify the ecological significance of the estuary relative to tributaries and the middle and upper mainstem Columbia River. A finer scale analysis of limiting factors, threats, and the benefits of management actions would aid in prioritizing actions and focusing them in the geographical areas where they would be most beneficial. Testing the assumptions underlying the allocation of benefits across management actions would increase the value of survival improvement targets as a planning tool, as would further evaluation of the constraints to implementation of the management actions. Lastly, understanding the potential cumulative or synergistic effects of management actions could lead to implementation decisions that would enhance the benefits of actions. Obtaining more information about these topics—mortality in the estuary, biological effects at a finer level, potential benefits of management actions, and synergistic effects—could represent the next level of planning for salmon recovery in the estuary.

Implementation Issues

Implementation of the 23 actions in the module will require the efforts of a variety of Federal, state, and local agencies, organizations, private enterprises, and citizens. (Some potential implementers have been identified in Table 5-6.) While many of these entities have already been working to identify, prioritize, and implement salmon and steelhead recovery actions, effective implementation of all module actions will require additional coordination.

Goals of coordination include using existing processes, programs, and forums efficiently; ensuring the appropriate scale, scope, and sequencing of projects; coordinating funding; tracking and reporting on implementation progress; coordinating monitoring efforts; and providing data management. In addition, implementing the module will require further evaluation of the constraints associated with the 23 actions as well as consideration of potential cumulative and synergistic effects. Also, implementers of module actions will need to remain abreast of current scientific information and ensure that it is continually incorporated into implementation decisions. Although some elements of these larger processes are in place, additional organizational capacity is necessary if these needs are to be adequately addressed.

Table 5-6 includes a rudimentary schedule for implementing each of the 23 management actions described in Chapter 5, but this schedule will need to be refined as the considerations mentioned above are addressed. The first step in coordinated implementation of the module will be a conversation among all relevant entities and stakeholders to discuss near-term implementation priorities, with a goal of developing a 5-year implementation plan that provides specificity and certainty regarding near-term actions and that identifies lead entities for implementation of specific actions or projects. Given the complexities involved in implementing the full suite of module actions, this conversation also will be an opportunity to explore options for and recommend an organizational structure for coordinating and overseeing implementation of the module. The Lower Columbia River Estuary Partnership, a National Estuary Program established to bring about collaboration, would be an appropriate convener of this discussion.

Education and outreach are important aspects of module implementation. Threats to salmonids in the estuary are likely to continue unabated unless resource users in the Columbia River basin make different choices about consumption and development—choices that may be socially and politically challenging. In the face of social and political obstacles, education is one way of garnering support for implementation of the management actions; in fact, education about stewardship and the ecosystem benefits that implementation would provide is an essential component of the management actions in the module; to the extent possible, these education efforts should be coordinated to create efficiencies.

Relationship of the FCRPS BiOp to the Estuary Module

Drafts of this module were available during the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) remand collaborative process, which led to the 2008-2018 FCRPS Biological Opinion and Supplemental Comprehensive Analysis (National Marine Fisheries Service 2008a and 2008b). Among the provisions of the 2008 FCRPS Biological Opinion (2008 BiOp) were requirements for the Federal action agencies to implement habitat improvement and predation control actions in the estuary. Estimates of the survival benefits that would be gained from those actions were included in the 2008 BiOp, and those survival estimates were derived from the allocation of survival improvements among actions in this module.

In February 2010, NMFS issued the 2010 Supplemental BiOp for the FCRPS (National Marine Fisheries Service 2010), which integrated elements from the 2008 BiOp and Adaptive Management Implementation Plan (AMIP). The AMIP included accelerated and enhanced actions to protect Columbia Basin salmon and steelhead, including (1) commitments to additional estuary actions under an agreement with the state of Washington, and (2) efforts to control native predators and invasive species. The AMIP also included enhanced research and monitoring and incorporated specific biological triggers for contingencies linked to unexpected declines in the abundance of listed fish.

The 2010 Supplemental BiOp retained the estimates of survival improvements from estuary habitat and predation control actions that had been incorporated into the 2008 BiOp and that were based on a draft version of this estuary module. The 2010 Supplemental BiOp also summarized and assessed relevant new information that had become available since the 2008 BiOp was issued, including information on climate change, juvenile salmonid use of the estuary and plume, predation, toxics, and ecological interactions between hatchery- and natural-origin fish. The new information summarized in the 2010 BiOp will be useful in informing implementation decisions regarding actions in the module.

Actions in the 2008 BiOp and its 2010 Supplement that relate to estuarine habitat, predation, and flow will contribute to implementation of actions in this module. The module, however, identifies habitat, predation, and flow actions that are larger in scope than the actions that will be implemented under the 2008 BiOp and its 2010 Supplement. NMFS projects that the 2008 BiOp actions related to estuarine habitat, flow, and predation will yield only a portion of the total survival improvements that the estuary module hypothesizes are possible for actions in those categories. The intent of the estuary module was to lay out the full suite of limiting factors and threats affecting the estuary; to identify actions or assessments needed to address—or inform the potential to address—those limiting factors and threats; and to provide a basis for future discussions and societal decisions about recovery efforts in the Columbia River estuary.

Preparation for Decision Making

Chapter 7 is intended to help organize a much-needed conversation about recovery efforts in the estuary, plume, and other ecosystems that salmonids depend on to complete their life cycles. While there are many decisions to be made, perhaps the most important is what our level of effort and commitment will be to improving conditions in the estuary. This boils down to deciding how much we are willing to do to recover salmon and steelhead in the Columbia River basin and how comfortable we are with the sacrifices that will be necessary.

The planning exercises in Chapters 5 and 7 were based on the best available science pertaining to limiting factors and threats. However, although science can help inform the key analyses in these chapters (the identification of management actions, constraints evaluation, survival improvement targets, and cost estimates), it cannot tell us which management actions to implement. This is so partly because of the gaps in our understanding of the physical and biological world of the estuary but also because other decision-making processes come into play when we make choices about the future and what we most value. Ultimately, the degree to which the estuary module is implemented will be determined by the social and political will of the region, and what current and future residents of the basin are willing to pay for—or do without—in order to return salmon and steelhead to viable levels.

Perhaps the single most important conclusion that can be made about the prioritization of management actions is that threats remain threats to salmonids because tough choices have yet to be made—choices that are difficult because of the myriad conflicting goals of the various public, private, individual, and organizational interests within the Columbia River basin. The variety and extent of those interests are reflected in the high degree of constraint for each of the 23 management actions identified in the recovery plan module. The take-home message from this is that the estuary and plume are crucial to ocean- and stream-type salmonids and that achieving a meaningful boost in survival from these ecosystems will require a major investment and implementation of all 23 management actions, to the extent possible.

CHAPTER 8
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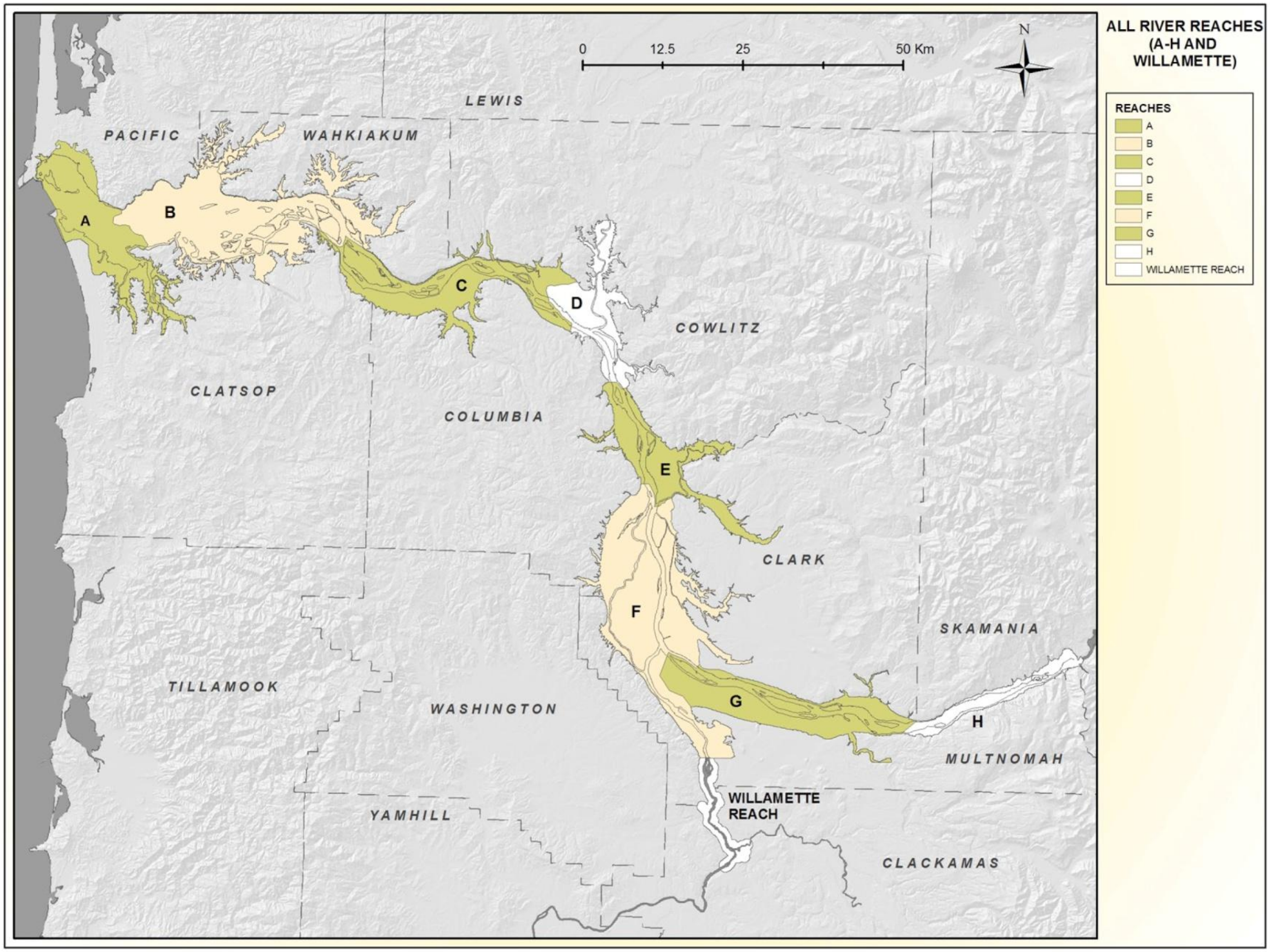
APPENDIX A

Selected Threats to Salmonids by Reach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CLARK
SKAMANIA
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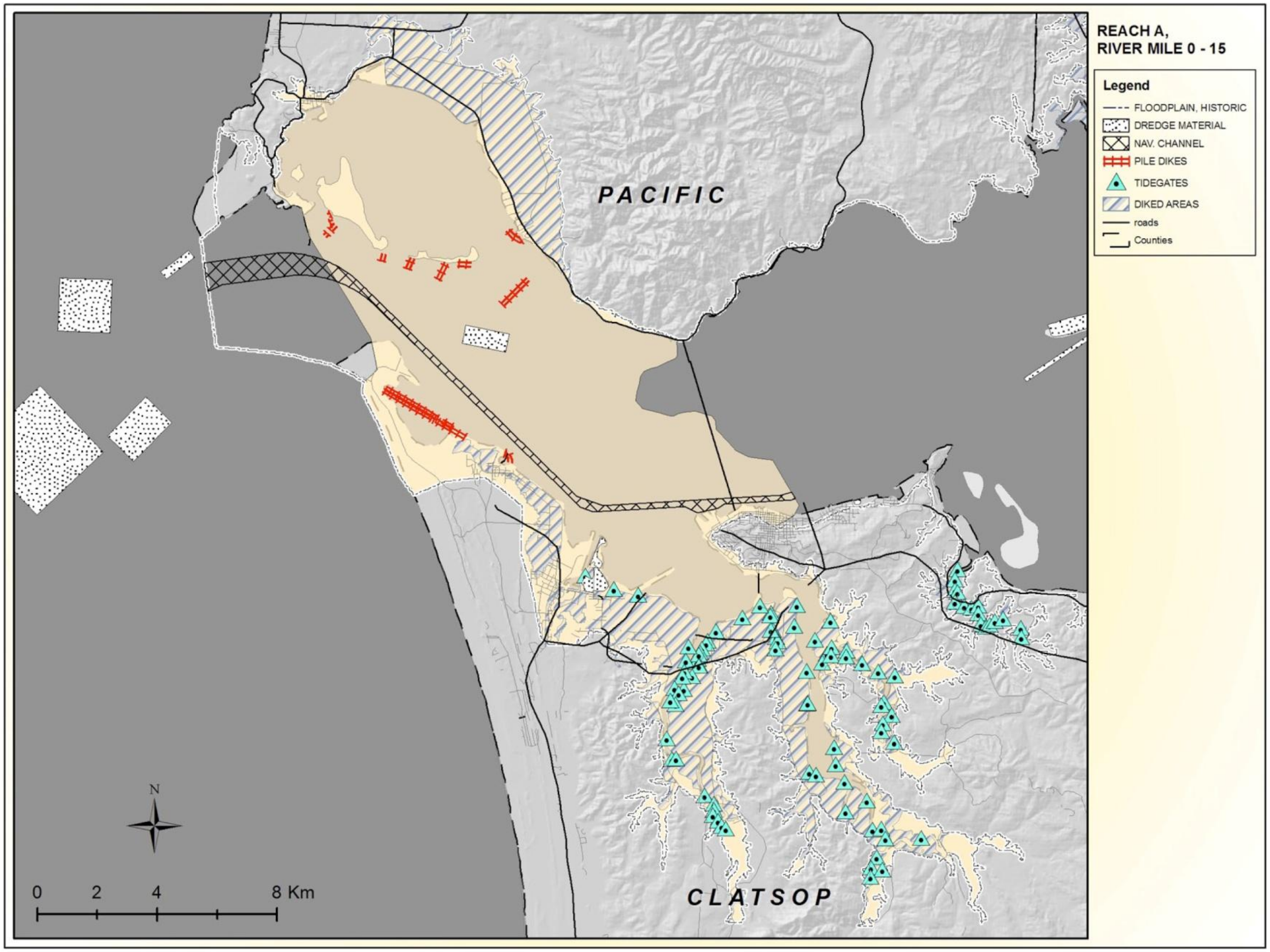
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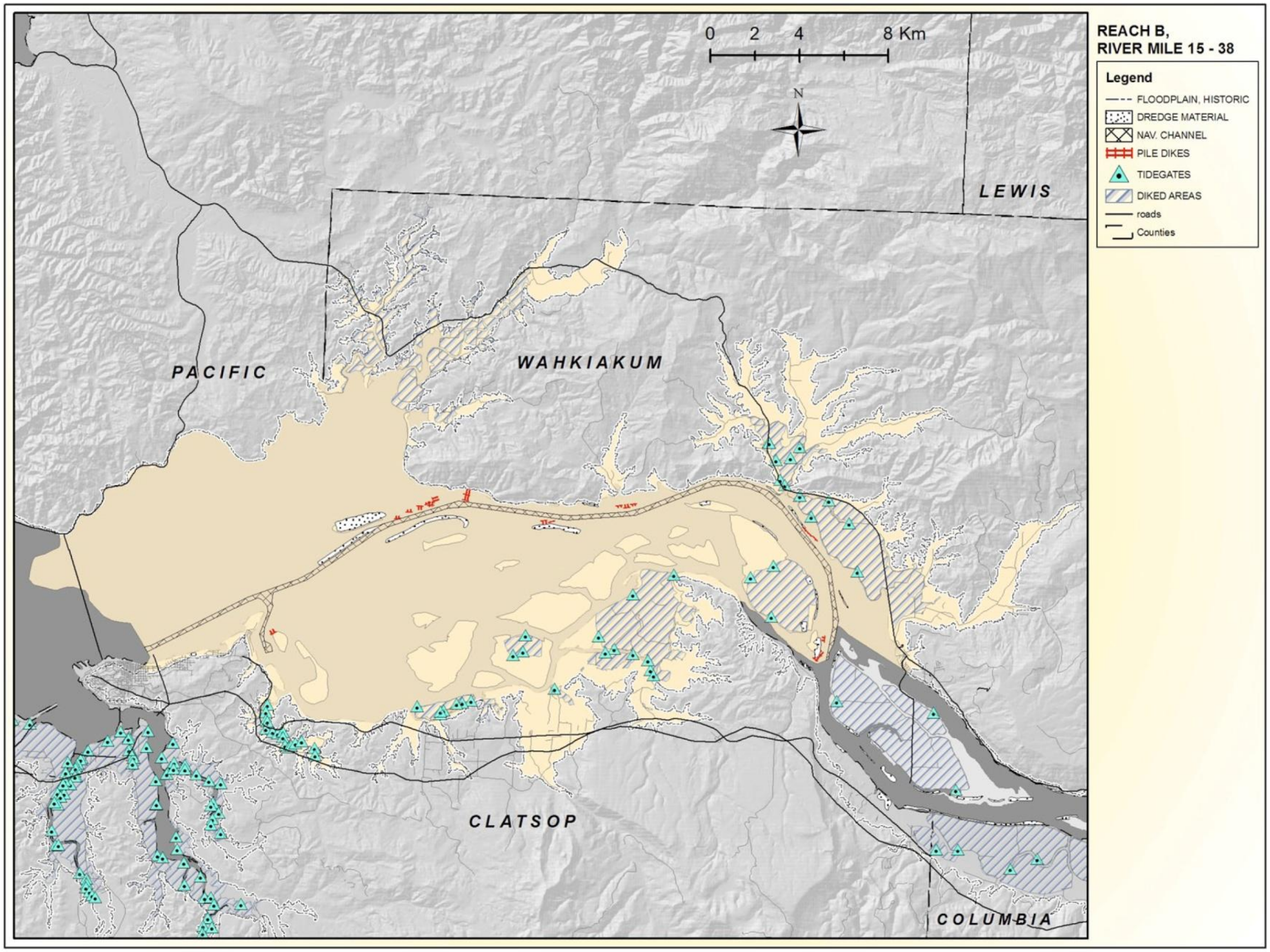
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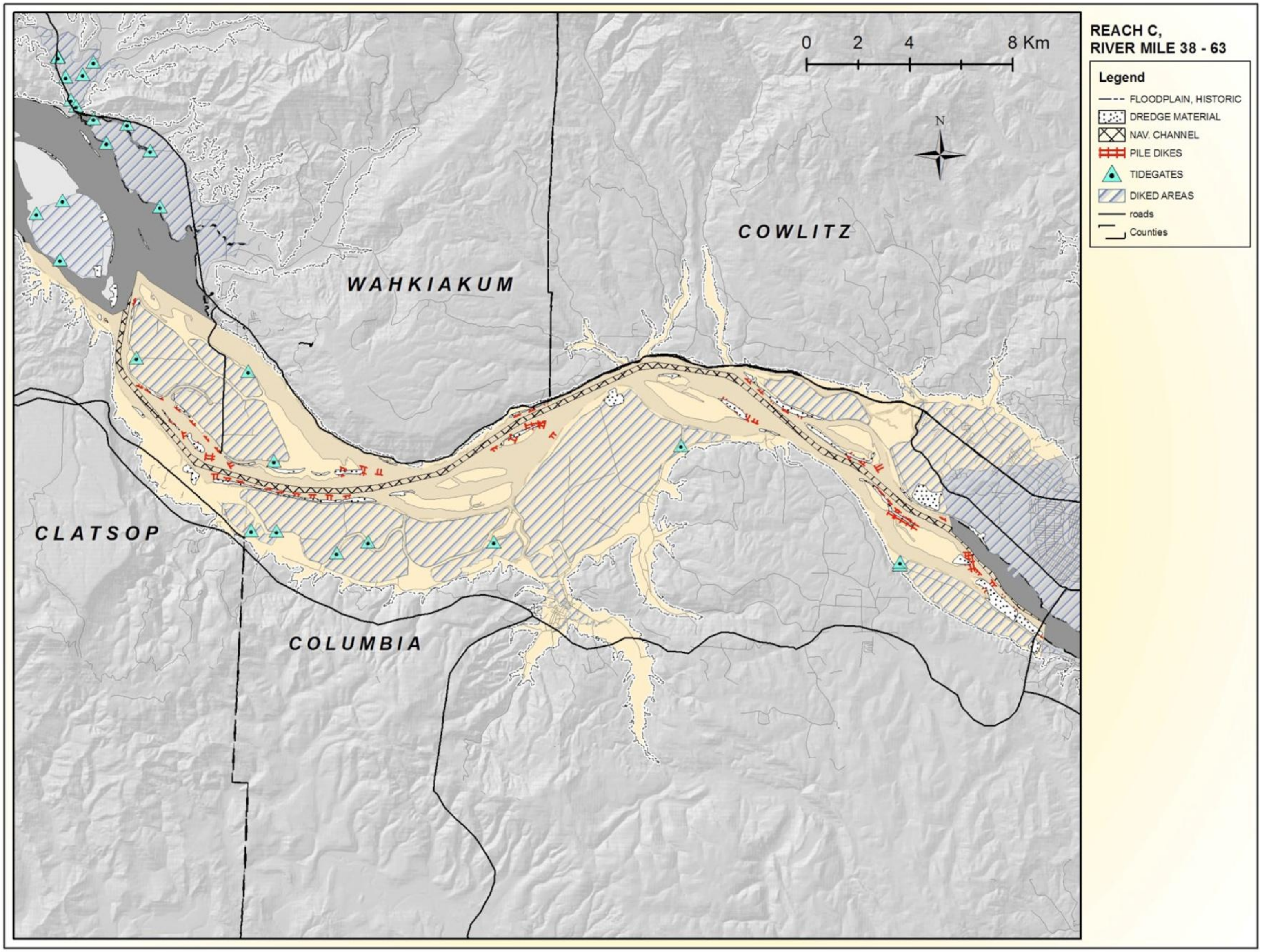
APPENDIX A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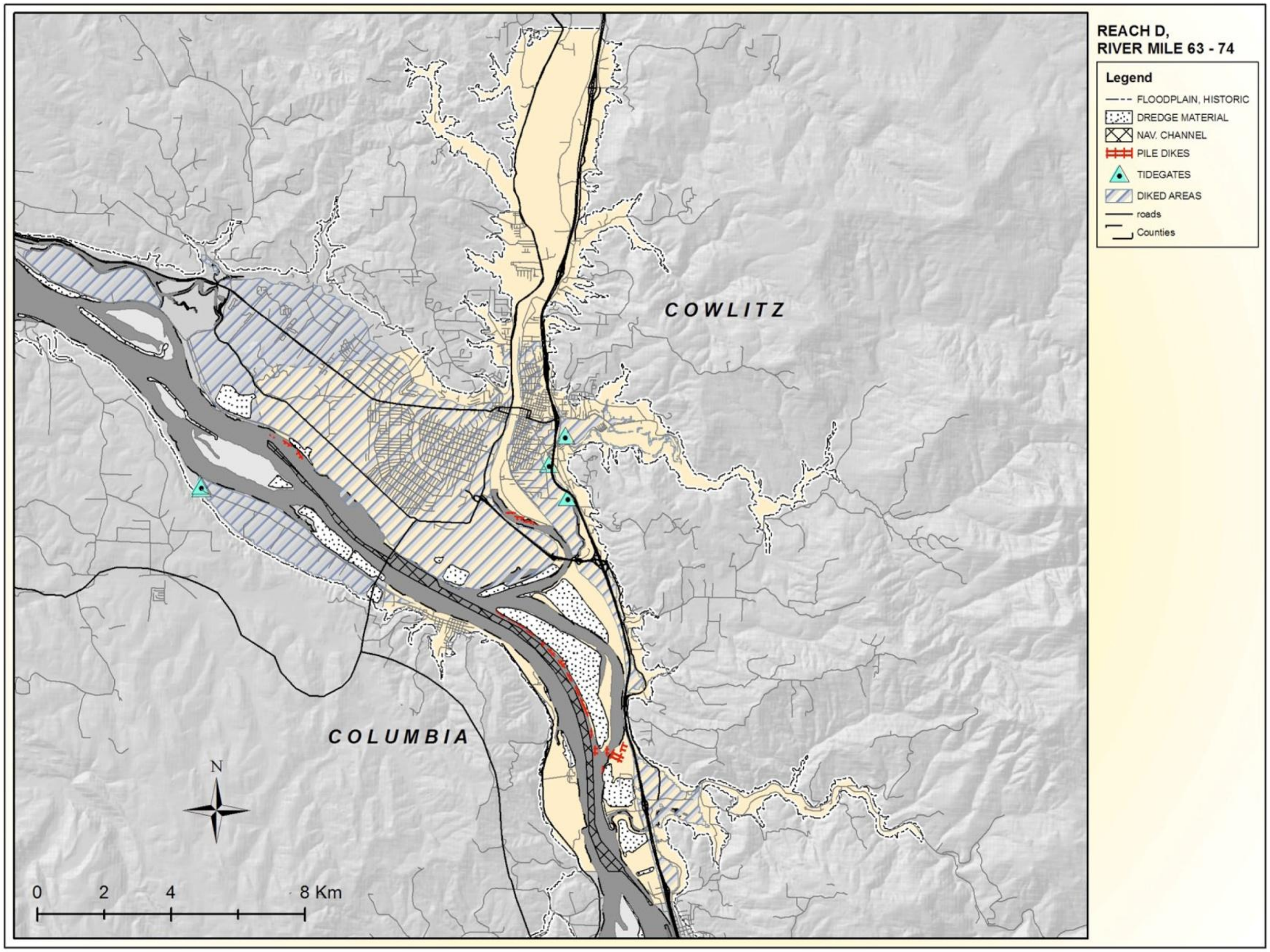
APPENDIX A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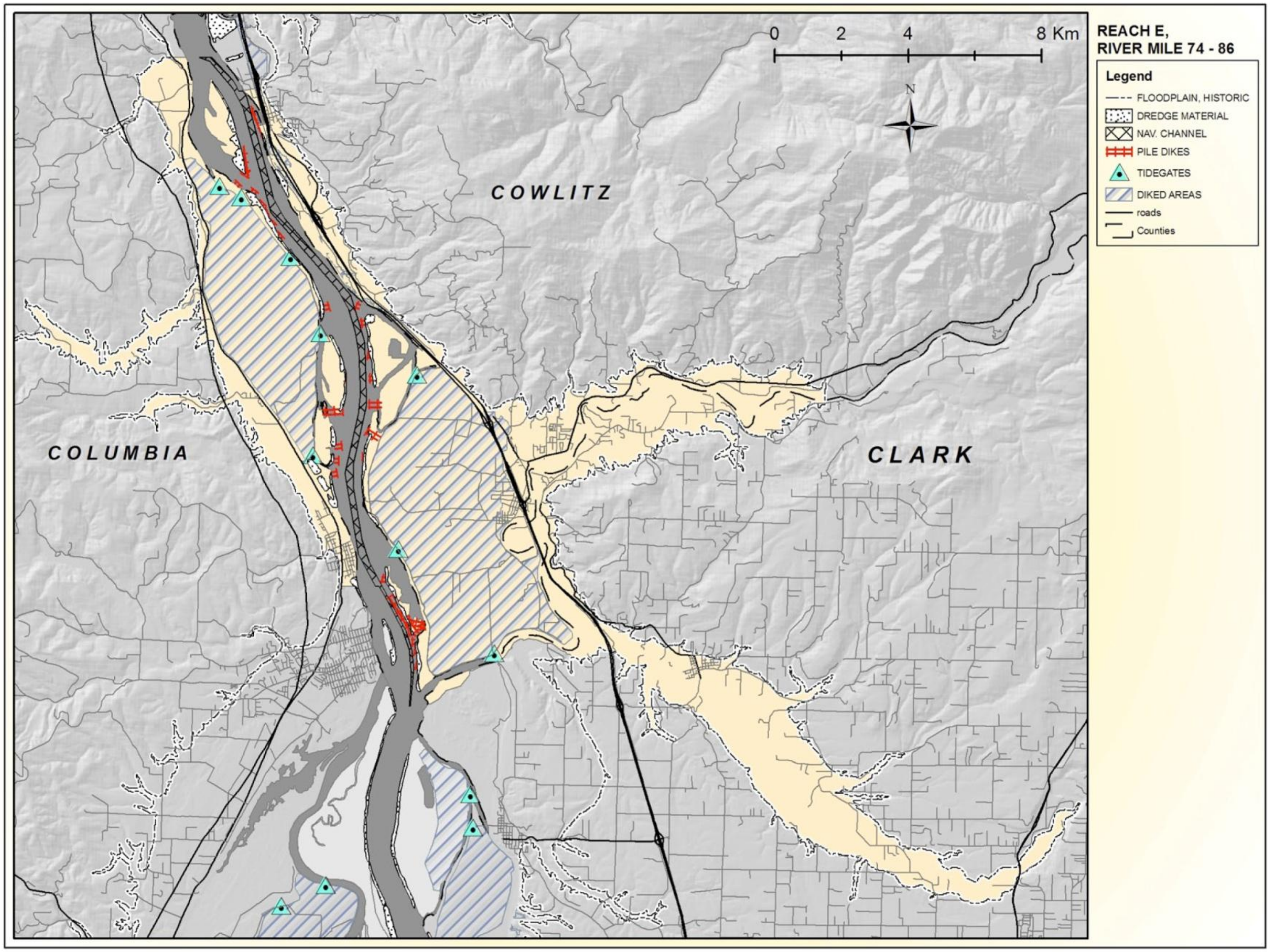
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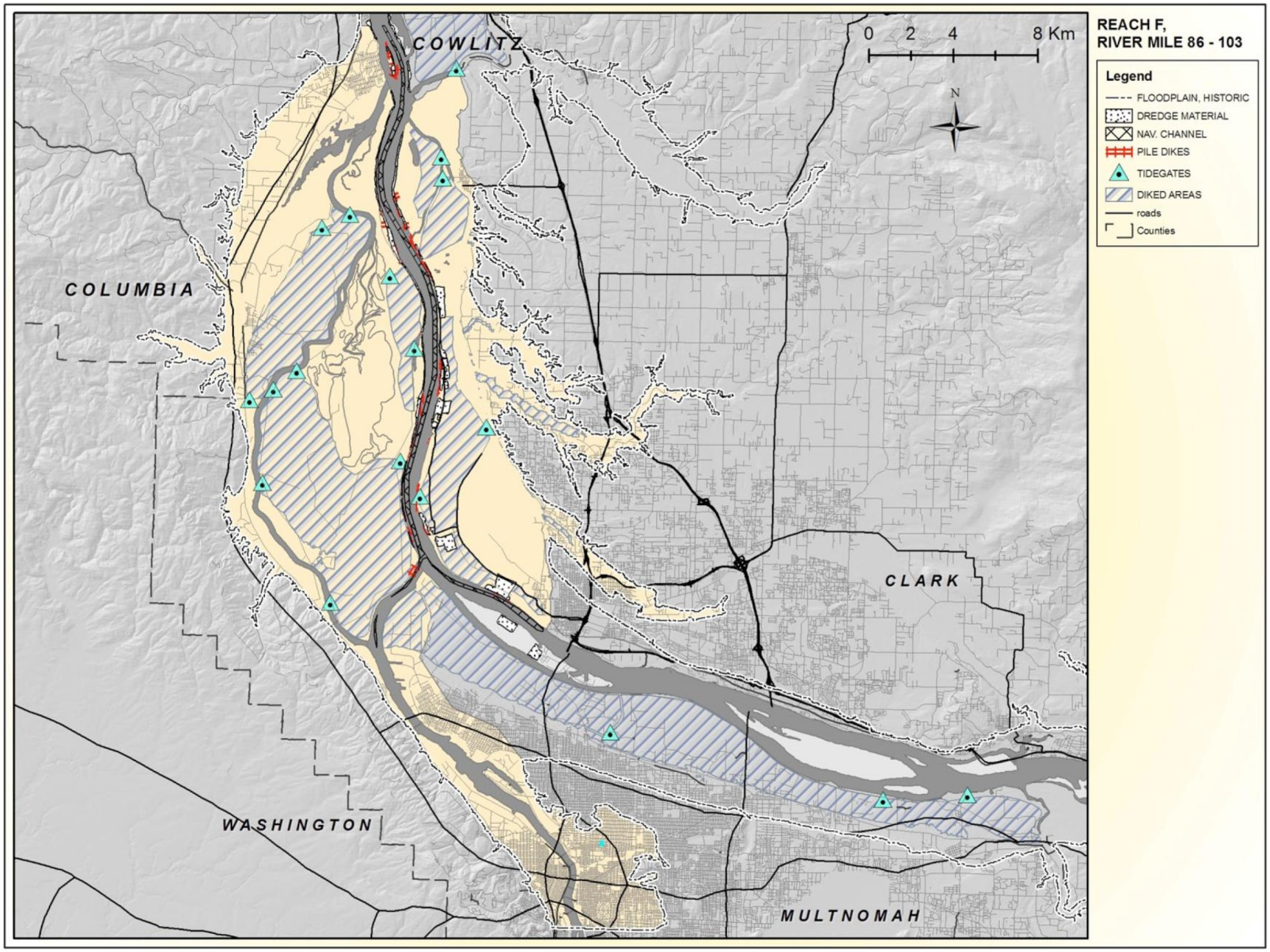
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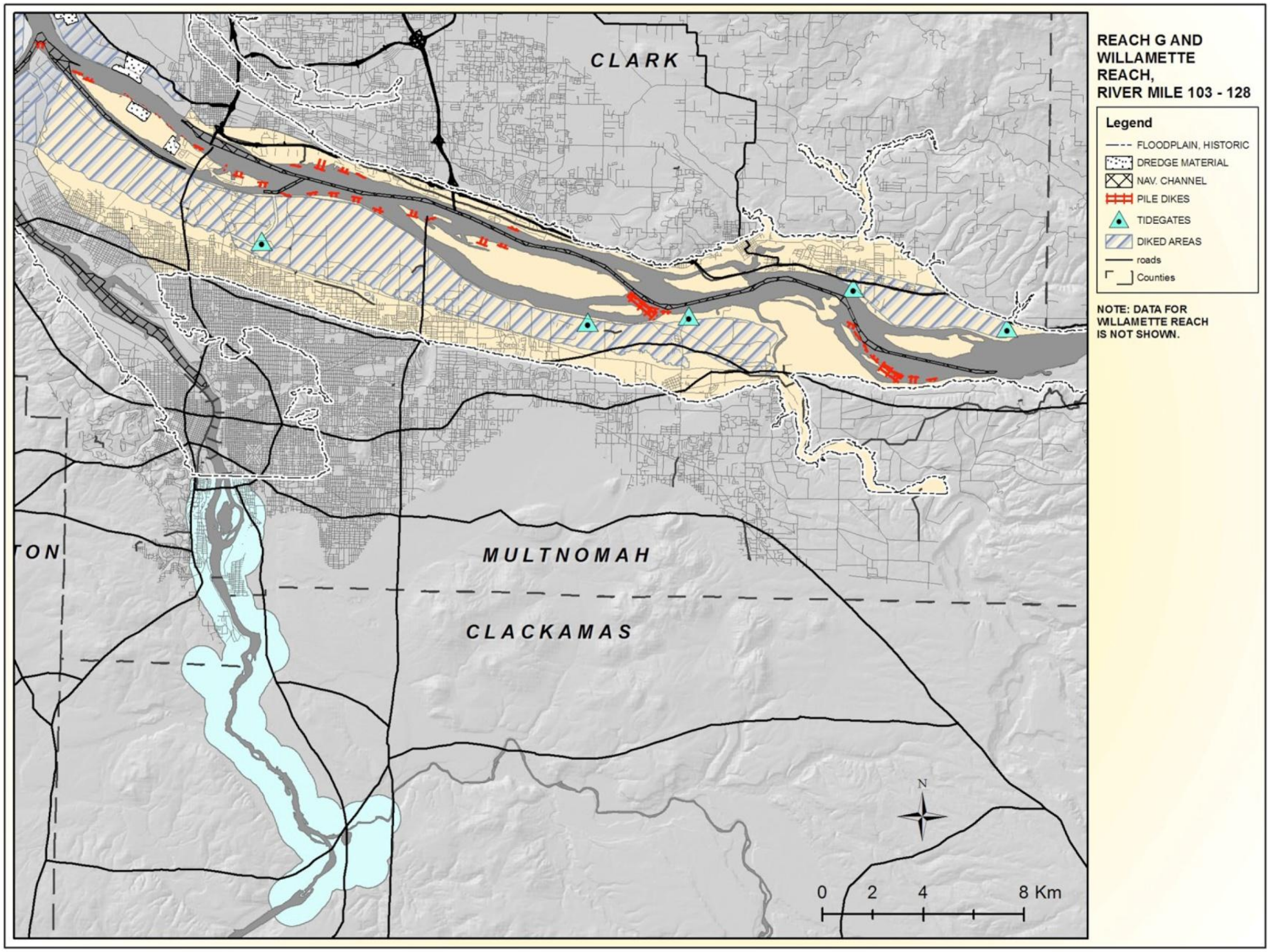
REACH G AND WILLAMETTE REACH, RIVER MILE 103 - 128
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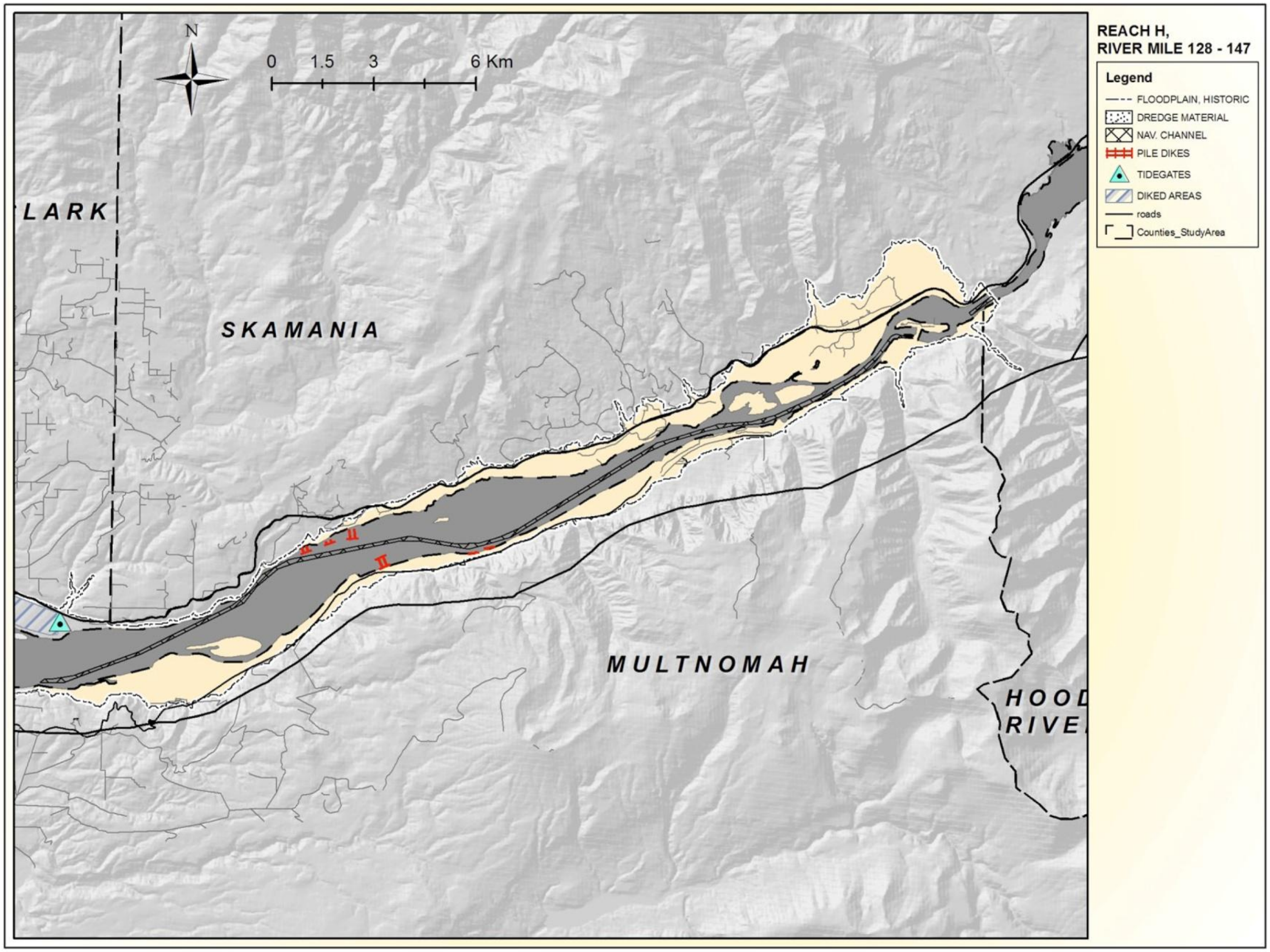

REACH H,
RIVER MILE 128 - 147
Legend
FLOODPLAIN, HISTORIC
DREDGE MATERIAL
NAV. CHANNEL
PILE DIKES
TIDEGATES
DIKED AREAS
roads
Counties_StudyArea
N
0 1.5 3 6 Km
LARK
SKAMANIA
MULTNOMAH
HOOD
RIVE

APPENDIX A

APPENDIX B

Development of Survival Improvement Targets

APPENDIX B

Development of Survival Improvement Targets

The survival improvement targets in Table 5-5 are a planning tool intended to help initiate a comprehensive discussion about salmonid mortality in the estuary and plume. This tool is an important first step in setting recovery targets for salmonids in the estuary and also for the Columbia River basin. PC Trask & Associates, Inc., developed the survival improvement targets because, in many cases, estimates of mortality resulting from individual limiting factors and of the effectiveness of management actions in reducing threats and limiting factors do not exist. On the other hand, there are reliable estimates of mortality resulting from several of the predators, ship wake stranding, and toxic contamination, and emerging acoustic wire tagging studies are helping to estimate the extent of mortality that juvenile salmonids experience during residency in the estuary.

PC Trask & Associates, Inc., took the following steps to develop the survival improvement targets:

1. Determined the abundance of wild, ESA-listed ocean- and stream-type juveniles entering the estuary using Ferguson (2006b), which estimated 25 million ocean-type juveniles and 14.3 million stream-type juveniles for 2006.
2. Assumed a 50 percent overall juvenile mortality rate for ocean-type salmonids in the estuary and a 40 percent mortality rate for stream-type juveniles. PC Trask & Associates, Inc., reached the 50 percent mortality estimate for ocean type juveniles by taking the 35 percent rate from 2005 micro-acoustic tagging results (Ferguson 2006b) and adding an additional 15 percent to account for smaller ocean-type juveniles not tracked by the study. PC Trask & Associates, Inc., reached the 40 percent mortality estimate for stream-type juveniles by taking the 25 percent rate from the same micro-acoustic tagging study and adding 15 percent to account for presumed deaths occurring in the plume. Continued annual study results will help refine these estimates over time.
3. Used a survival improvement target of 20 percent for both ocean- and stream-type juveniles. The 20 percent number is not scientifically based; instead, it represents a planning target that will require refinement as the extent to which actions are implemented and effective becomes clearer. Survival improvement numbers attempt to reflect wild, ESA-listed fish only. In most cases, known mortality to salmonids (such as from terns) does not break out wild fish from hatchery fish or ESA-listed fish from non-listed fish.
4. Allocated the two targets described above across 22 actions (CRE-14, "Reduce predation by pinnipeds," was treated separately for adult mortality), based on an extensive literature review and personal communication with various agency staff. PC Trask & Associates, Inc., evaluated each action using limiting factor information from Chapter 3, threat information from Chapter 4, and action evaluations from Chapter 5. As a result, the allocation takes into consideration a combination of factors, including the magnitude of the limiting factor, the degree of the associated threat(s), how well the action

addresses the threat, how constrained implementation of the action is likely to be, and the assumption that a considerable level of effort will be applied to implementing each action.

5. Assigned survival improvement targets on a relative scale across all of the actions. The reader should not view the survival improvement targets as an absolute numerical result for each action, but rather a relative indication of the importance of each action. In cases where the scientific community has determined the mortality associated with a particular limiting factor and developed a management plan with mortality reduction goals, such as with predation by Caspian terns, PC Trask & Associates, Inc., used these numbers to the degree possible.

Survival improvement targets are intended to be correlated with cost estimates presented in Table 5-6 for constrained implementation of the management actions. The resulting cost/survival estimates (see Table 7-5) are intended to initiate discussions about the validity of cost estimates and potential survival improvement targets; the cost/survival index values in Table 7-5 are highly uncertain because of the gross assumptions on both sides of the equation.

Disclaimer: Survival improvement numbers are for illustration only and are intended to demonstrate social choices in the face of significant uncertainty.
Literature sources generally do not prescribe actions, and relatively few actions have been specifically evaluated for associated survival estimates.

Table B-1
Notes on Development of Survival Improvement Targets

Action	Notes
CRE-1: Protect/restore riparian areas.	Estimate is unsupported in the literature. Estimate was assigned a high value in recognition of its importance relative to food sources and shoreline habitats. This is a protection action that is intended to reduce the potential for increased threat over time.
CRE-2: Operate the hydrosystem to reduce reservoir heating.	Estimate is unsupported in the literature. Estimate was assigned a relatively high value because temperatures commonly exceed 19 degrees Celsius and are doing so more frequently and for longer periods of time. (Nineteen degrees Celsius is considered the upper range of survival for salmonids). Estimate is based on a relatively large level of effort to reduce the threat. It is likely that mitigation will be required in tributaries to implement the action.
CRE-3: Protect/enhance instream flows influenced by withdrawals and other water management actions in tributaries.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. Estimate is closely aligned with CRE-4 and probably has overlapping benefits.

CRE-4: Adjust the timing, magnitude, and frequency of hydrosystem flows.	Estimate is unsupported in the literature. The action affects nearly every facet of estuary ecosystem health. Estimate is intended to demonstrate that changes to the hydrograph are possible and that small increments of change may produce a significant survival improvement. This action is worthy of further analysis that may help support a more defensible survival estimate.
CRE-5: Mitigate entrapment of fine sediment in reservoirs.	Estimate is unsupported in the literature. Estimate was assigned a low survival improvement because of the high degree of uncertainty about its potential to improve salmonid survival. Entrapment of sediment may have significantly larger effects.
CRE-6: Use dredged materials beneficially.	Estimate is unsupported in the literature. Estimate was assigned a low survival improvement because of the high degree of uncertainty about its potential to improve salmonid survival. Currently, beneficial uses are most often associated with nearshore erosion management, and little is known about potential benefits to salmonids in the nearshore.
CRE-7: Reduce entrainment/ habitat effects of dredging and ballast.	Estimate is unsupported in the literature. Estimate is relatively low because of the uncertainty and lack of mortality documentation associated with entrainment.
CRE-8: Remove or modify pilings and pile dikes	Estimate is unsupported in the literature. Estimate is relatively high because of the number of pile dikes in the estuary and the suspected predation effects that result from the threat, including predation by cormorants, pikeminnow, bass, walleye, and catfish. Altered flow circulation and reduced juvenile access to low-velocity habitats may also be a threat.
CRE-9: Protect/restore high-quality off-channel habitat.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. The high estimate reflects the magnitude of importance that off-channel habitats represent to juveniles, especially ocean types. Because restoration activities are highly constrained, it is vital not to lose additional functioning habitats. Protection alone will only help preserve the status quo.
CRE-10: Breach, lower, or relocate dikes and levees.	Estimate is unsupported in the literature. Estimate is intended to demonstrate that dike or levee breaching is one of the top few actions that will increase ocean-type survival in the estuary. If substantial improvements for ocean-type life histories in the estuary are to occur, this is one of a handful of actions that must be implemented. Estimate assumes a significantly higher level of implementation than what is currently occurring.
CRE-11: Reduce over-water structures.	Estimate is unsupported in the literature. Estimate is relatively high because of the number of over-water structures in the estuary and the suspected predation effects that result from the threat, including predation by cormorants, pikeminnow, bass, walleye, and catfish. Other effects, such as decreased light penetration, are not well understood.

CRE-12: Reduce vessel wake stranding.	Mortality estimates for test sites have demonstrated a wide range of confirmed mortality. In Bauersfeld (1977), an assessment of five test sites estimated approximately 150,000 stranded juveniles (on those sites). No estuary-wide estimates have been developed. The emerging availability of LIDAR imagery for the estuary may provide for analysis to extrapolate confirmed site-specific information to estuary-wide predictions. Estimate is relatively high within the range of study estimates.
CRE-13: Manage pikeminnow and other piscivorous fish.	Estimate is unsupported in the literature. Some information exists about predation rates. The threat does not currently appear to be on the increase. Estimate is relatively high based upon conjecture by the NMFS Northwest Fisheries Science Center regarding pikeminnow predation rates, but the threat should be studied further and monitored over time.
CRE-14: Reduce predation by pinnipeds.	An estuary-wide mortality estimate is unsupported in the literature. Estimates are for adults only. Annual counts at Bonneville Dam indicate between 0.4 percent and 3.4 percent mortality of spring Chinook and winter steelhead. A 500-pound Stellar sea lion consumes about 40 to 60 pounds of fish each day. An unsubstantiated estimate of all pinniped predation in the estuary of approximately 10 percent of spring Chinook and winter steelhead is probably reasonable.
CRE-15: Reduce invasive plants.	Estimate is unsupported in the literature. Noxious weeds alter food webs and habitat and work at the ecosystem scale. Very little is understood about the connection between noxious weeds and juvenile salmonid survival. Estimate is relatively high for noxious weeds compared to other ecosystem-scale threats because, although associated actions are difficult, they have a greater likelihood of success than do actions to address other similar threats, such as invertebrate infestations.
CRE-16: Redistribute Caspian terns.	Estimate is supported by the literature. Recent successes in relocating terns have been documented. Efforts to implement the action are under consideration. Estimated mortality attributed to Caspian tern predation is approximately 3.6 million juveniles in 2005. Current planning calls for a two-thirds reduction in the East Sand Island nesting.

CRE-17: Redistribute cormorants.	Estimate is supported by the literature. Efforts to manage cormorants are not nearly as mature as efforts to manage terns. There is less certainty about implementation potential because cormorants have not responded to management efforts to the degree that terns have. Estimated mortality attributable to predation by double-crested cormorants is considered to be comparable to that of predation by terns. Assignment of the target survival improvement was lower than for terns because cormorants may be harder to manage than terns.
CRE-18: Reduce shad abundance.	Estimate is unsupported in literature. Estimate is low because of the high degree of uncertainty about the relationship between shad, salmonids, and ecosystem health. Estimate is also low because the literature does not identify potential actions to reduce shad abundance levels.
CRE-19: Prevent aquatic invertebrate introductions.	Estimate is unsupported in the literature. Extent of the threat is well-documented; however, invertebrate infestations occur at the ecosystem scale, and the degree of mortality that occurs because of food web changes at this scale is unknown. Estimate is relatively low because of the uncertainty of the threat and the inherent challenges of reducing the threat.
CRE-20: Implement pesticide/fertilizer BMPs.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 1.5 percent to 9 percent, depending on the amount of time juveniles spend in the estuary. Estimates for CRE-21, CRE-22, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-21: Identify and reduce sources of pollutants.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 1.5 percent to 9 percent. Estimates for CRE-20, CRE-22, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-22: Restore or mitigate contaminated sites.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 1.5 percent to 9 percent. Estimates for actions CRE-20, CRE-21, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-23: Implement stormwater BMPs.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. This action does not assume retrofitting of existing stormwater function.