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Mainstem/Systemwide Program Summary:

Estuary and Marine Survival

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Northwest Power Planning Council

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Mainstem/Systemwide Program: Estuary and Marine Survival

Table of Contents

Program Description 1
Purpose of Program 1
Scope of Program - Estuary Habitat from Bonneville Dam into the Ocean 3
Estuary 3
Plume 4
Northeast Pacific Coastal Shelf 5
Salmonid Species Affected/Benefited 6
Accomplishments/Results 8
Adaptive Management Implications 8
Historic Management Perspective of the Lower Columbia River and Estuary 8
Factors of Decline for Salmon in the Lower Columbia River and Estuary 9
Benefits to Fish and Wildlife 13
Current Management Perspective of the Lower Columbia River and Estuary 13
Project Funding to Date 19
Reports and Technical Papers 20
III. Relationship of Program to USFWS and NMFS Biological Opinions 21
Future Needs 26
Project Recommendations 26
Themes addressed - Targeted research, Flow Regulation, Monitoring and Adaptive Management, Integration Across All Themes 28
Themes addressed - Targeted research, Flow Regulation, Monitoring and Adaptive Management, Habitat Conservation and Restoration 28
Themes addressed - Targeted Research, Monitoring and Adaptive Management, Integration Across All Themes 29
Future Needs 31
References 34

List of Figures

Figure 1. The Lower Columbia River estuary 3

Mainstem/Systemwide Program Summary: Estuary and Marine Survival

Program Description

Purpose of Program

Recent evidence suggests that improvement in survival of the estuarine and ocean life history phase of Columbia River salmon, particularly the early ocean period, may be critical to recovery of endangered stocks (Kareiva et al. 2000). Moreover, current evidence reveals that some salmon habitats occupied during these phases (for example, habitats within Columbia River estuary and the plume) have been highly modified due to river modifications (e.g. altered channel morphology) and modified flows as a result of the Federal Columbia River Hydropower System (FCRPS). In addition, the impacts of global climate change in modifying habitat important to salmon needs to be considered. This expands the spatial scale of consideration to the Northeast Pacific Ocean. In order to evaluate the potential for achievable improvement in salmon survival from changes in current management practices, it will be important to understand the relationship between survival (and mortality) among freshwater and the estuarine and ocean phases of the life history of salmonids. This in turn will require a better understanding of the processes that limit and/or enhance salmon survival in these habitats. These processes, though better characterized in the freshwater environment, are poorly characterized in the estuarine, plume, and marine environment (Casillas 1999, Bottom et al. 2001).

An emphasis on survival of salmon in the estuarine and marine environment is warranted because approximately half of all preadult (egg through juvenile stage) salmon mortality occurs in the estuarine and marine environment (Bradford 1995). Variability in ocean salmon survival is very high, with annual and seasonal mortality ranging over three orders of magnitude Pacific Fishery Management Council (PFMC 2000). Abiotic and biotic ocean conditions are highly variable as well, and undoubtedly account for the large range of juvenile salmon ocean survival. Long-term regime shifts in climatic processes and El Niño and La Niña events affect oceanic structure and can produce abrupt differences in salmon marine survival and returns (Francis and Hare 1994). The latest recognized regime shift occurred in the late 1970s and may be a factor in reduced ocean survival of salmon in the Pacific Northwest and increased survival in Alaska (Mantua et al. 1997) during this period. Recent changes in ocean conditions, which began in late-1998 and continue to present, provide evidence of a possible new regime shift (Peterson and Mackas 2001, Peterson and Schwing in prep) that appear to be favorable to salmon survival.

Characterizing features affecting mortality of salmon through their entire marine life history phase (smolt through adult) may be most desirable, however, assessing factors during the early marine period is likely to be most beneficial (Kareiva 2001). Beamish and Mahnken (2001) support this contention by delineating the "critical size-critical period" hypothesis for salmon survival. They put forth a paradigm suggesting that achieving a critical size and surviving the first period of winter in the marine environment (i.e., the early ocean life history phase) is the period were recruitment success is largely established. This is consistent with the relationship between growth and mortality rates, which have been shown to scale through allometric (length-weight) relationships (Peterson and Wroblewski 1984, McGurk 1996, Lorenzen 1996) and decline through time. Pearcy (1992) has also indicated that the first few weeks-to-months of ocean life are a critical life history phase for recruitment success of salmonids. Several lines of additional evidence support this contention. Peterman et al. (1998) and Pyper et al. (1999) assessed variation in survival rates, length-at-age 4, and age-at-maturity for nine stocks of Bristol Bay sockeye salmon from northern Alaska, and 16 stocks of Fraser River sockeye salmon in southern British Columbia. Mueter et al. (2001) did the same for 120 stocks of pink, chum and sockeye. They concluded that much of the difference in survival rates between Fraser River, Bristol Bay, British Columbia and Washington State stocks is attributable to conditions in the first summer in the marine habitat. They stated that local marine environmental conditions where salmon stocks originate greatly affected survival.

The first summer at sea being a critical period for salmonid is also derived from the positive relationship between abundance of coho salmon jacks (precocious males) and adult survival rates (Pearcy 1992). Precociousness is a function of environmental conditions; higher growth rates (as a function of good ocean conditions) translate to increased proportion of jacks (Friedland and Haas 1996). Because coho salmon jacks, for instance, return to spawn after only 3-4 months in the ocean, they cannot have migrated far from their rivers of origin. This finding suggests again that the local marine environmental conditions greatly affect survival and year-class success for outmigrating stocks of juvenile salmon.

A comprehensive program to rebuild anadromous salmon runs must focus on all life history stages and all opportunities to increase salmonid survival National Research Council (NRC 1996). However, efforts to date have been limited largely to the freshwater life stages, with attempts to rehabilitate and mitigate for losses occurring in the riverine environment. Many fisheries managers believe that salmon populations cannot be rebuilt by just improving freshwater habitats and/or improved hatchery practices. A better understanding of the ecology of salmonids in estuarine and nearshore ocean research is critical to effectively manage Pacific salmon populations (Emmett and Schiewe 1997). If the marine environment affects recruitment success in a predictable manner, then measuring, predicting, and reducing salmonid losses in the marine environment may be possible. This information would strongly complement freshwater-related salmonid restoration efforts.

Finally, all proposed freshwater habitat rehabilitation and restoration efforts will operate within the context of uncertainty associated with environmental variability and environmental change. The NRC (1996) report stated that variations in ocean conditions powerfully influence salmon abundance. Throughout most of the 1980□s and 1990□s, ocean conditions in the Pacific Northwest region were poor, and the low ocean survival might well explain the limited success to date of habitat restoration efforts. We are just now beginning to understand what happens to salmon during the major part of their lives □. the years spent at sea. New insights already demonstrate that variations in salmon abundance are linked to phenomena on spatial and temporal scales that biologists and managers have not previously taken into account (the entire North Pacific Basin and decadal time scales). Thus, understanding local marine conditions and their influence on survival and health of outmigrating juvenile salmon will help in identifying important features that benefit or suppress growth, recovery, and resilience of specific salmon stocks.

This systemwide summary covers the mainstem Columbia region from Bonneville Dam out the mouth of the Columbia River, through the plume and to the marine environment of the coastal shelf and of the Northeast Pacific and Gulf of Alaska. It addresses this environment in the context of salmonids that use this portion of the system. Upland habitats and issues affecting coastal cuthtroat trout are addressed in the mainstem habitat systemwide summary.

Scope of Program - Estuary Habitat from Bonneville Dam into the Ocean

Estuary

With a watershed of roughly 660,500 km^2, encompassing seven states, two Canadian provinces, and two major continental mountain ranges (Cascades and Rockies), the Columbia River is the second largest river in the United States.

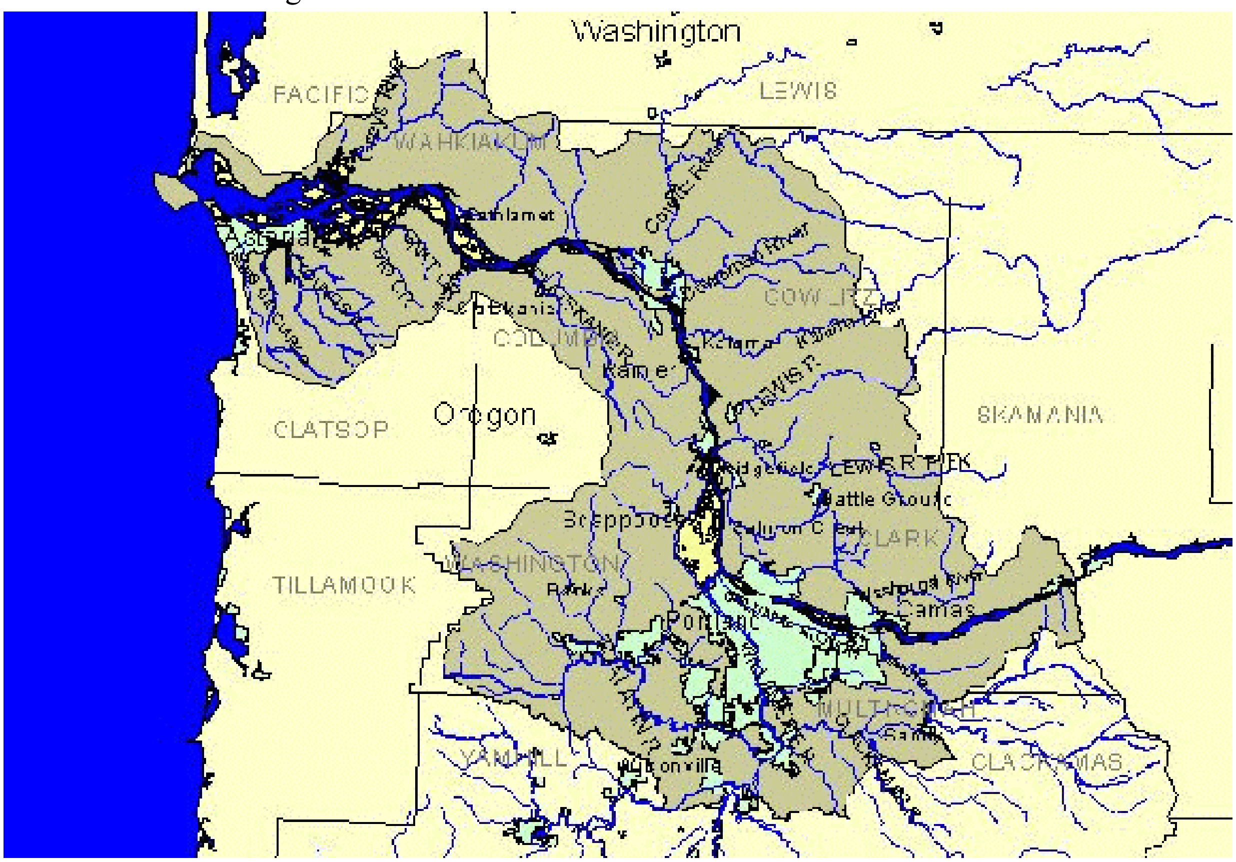

Figure 1. The Lower Columbia River estuary

The river and estuary are dominant features in the circulation of the Northeast Pacific Ocean as well, with a mean annual discharge at the mouth of ~5,500 m^{3}s^{-1}. We define the Columbia River estuary (Fig. 1) to include the free-flowing waters that are influenced by oceanic tides: a reach spanning 240 km from the river's ocean entrance to the base of Bonneville Dam. Relative to juvenile salmon migration along the estuarine gradient, this system includes three physiographic subsystems:

- The tidal freshwater portion (or "fluvial region;" Simenstad et al. 1990b) from Bonneville Dam to the maximum upstream extent of salinity intrusion (~55 km from the entrance);
- The brackish-oligohaline region above the open expanse of the main estuary (upstream from ~30 to 55 km from the entrance); and
- The broad, euryhaline region in the lower 30 km of the estuary. Ecological studies in the estuary during the early 1980s further partitioned the euryhaline region into seven subareas: (1) entrance, (2) Trestle and Baker Bays, (3) Youngs Bay, (4) estuarine channels (5) mid-estuary shoals of the "estuarine mixing zone," (6) Grays Bay, and (7) Cathlamet Bay (Simenstad et al. 1990b).

This lower "estuarine" area encompasses a complex network of main, tributary, and dendritic tidal channels, unvegetated shoals, emergent and forested wetlands, and extensive mudflats in peripheral bays. Approximately 26,550 ha (about 71.2%) of the 37,289 ha of this estuarine region is composed of shallow-water habitats (6 m or less relative to mean lower low water). Except in peripheral bays, where silt and clay sediments dominate, most of the estuary's sediments are composed of sand. More detailed descriptions of the river flow and sediment transported through the estuary appear in following chapters.

Plume

Freshwater from the Columbia River dilutes the coastal waters of the northeast Pacific Ocean at 46 E 15 N in a plume delimited by the 32.5 isopleth (Pruter and Alverson 1972). Historically, the detectable effluent plume extends over a latitude range of 40E to 49E N about 1000 km, and seaward to a maximum distance approaching 600 km. Areal extent and location of the plume are controlled by seasonal climatic regimes that influence river discharge and the prevailing northerly winds in summer and southerly winds of generally greater speed in winter. Plume water moves in response to wind and current, and plume volume increases with accumulated runoff and entrainment of ambient seawater. Two prominent seasonal patterns of effluent distribution prevail. One lies north of the river mouth and inshore during the southerly winds of winter and the other south and offshore during the northerly summer winds. The period when the plume distribution shifts is called the spring and fall transitions.

The shape and extent of the Columbia River plume is controlled largely by the amount of freshwater flowing out of the Columbia River. The timing and amount of flow affects the amount of sediment (and turbidity), as well as the amount of nutrients which fuel estuarine and oceanic productivity. Flow regulation, water withdrawal and climate change have reduced the average flow and altered the seasonality of Columbia River flows, changing the estuarine ecosystem (NRC 1996; Sherwood et al. 1990; Simenstad et al. 1990, 1992, Weitkamp et al. 1995, Bottom et al. 2001). Annual spring freshet flows through the Columbia River estuary are ~50% of the traditional levels that flushed the estuary and total sediment discharge is ~1/3 of 19th Century levels. Decreased spring flows and sediment discharges have also reduced the extent, speed of movement, thickness, and turbidity of the plume that once extended far out and south into the Pacific Ocean during the spring and summer (Barnes et al. 1972; Cudaback and Jay 1996, Hickey et al. 1998). Pearcy (1992) suggested that low river inflow is unfavorable for juvenile salmonid survival because of: a) reduced turbidity in the plume (leading to increased foraging efficiency of birds and fish predators), b) increased residence time of the fish in the estuary and near the coast where predation is high, c) decreased incidence of fronts with concentrated food resources for juvenile salmonids, and d) reduced overall total secondary productivity resulting in reductions in concentration of prey items preferred by salmonids.

Northeast Pacific Coastal Shelf

Once salmon make the transition from freshwater to a saltwater, a significant portion of Columbia River basin stocks inhabit, for extended periods of time, the Northeast Pacific coastal shelf habitat. The position and productivity of is affected by transport in the California Current and by coastal upwelling (Hickey 1998). The California Current is a broad, slow, meandering, equatorward-moving flow that extends from the northern tip of Vancouver Island (50E N) to the southern tip of Baja California (25E N). Offshore waters flow southward all year; however, over the continental shelf, southward flows occur only in spring, summer, and fall. During winter months, flow over the shelf reverses, and water moves northward as the Davidson Current. The transitions between northward and southward flows on the shelf bear the terms “spring transition” and “fall transition,” because they occur typically in March/April and October/November, respectively.

Coastal upwelling is the dominant physical force affecting production in local continental shelf waters off Washington and Oregon, occurring primarily during the months of April-September (Huyer 1977). Production is seasonal with periods of high and low productivity bounded by the spring and fall transition points. Highest biomass of both phytoplankton and zooplankton occurs in July and August (Peterson and Miller 1977). Coastal upwelling is not a continuous process, rather, it is characterized by a series of discrete events of upwelling-favorable northerly winds which blow for periods of 1-2 weeks, interspersed by periods of calm or wind reversals. It is the intermittent nature of upwelling that leads to highest productivity, thus the overall level of production during any given year is highly variable (Peterson and Miller 1975). Any process that leads to a reduction in the frequency and duration of northerly winds will result in decreased productivity. The most extreme of these processes is El Niño.

Variability in productivity of the California Current also occurs at decadal time scales. The North Pacific experiences dramatic shifts in climate at a frequency of 30-40 years, caused by eastward-westward jumps in the position and intensity of the Aleutian Low in winter. Shifts occurred in the 1920s, 1940s, and most recently in the winter of 1976/1977. One dramatic effect of the 1976 shift was a large increase in biological productivity in the Subarctic Pacific/Gulf of Alaska and a decrease in the California Current (Roemmich and McGowan 1995). During the post-1976 regime (known as a “warm regime”), zooplankton biomass inthe California Current declined five-fold whereas zooplankton biomass in the Subarctic Pacific increased at least two-fold (Brodeur and Ware 1992). Salmonid abundance was never higher in the Subarctic Pacific and never lower in the California Current. In contrast, during the past (cool) regime which extended from the 1940s through the mid-1970s, salmonid stocks were low in the subarctic and high in the California Current (Francis and Hare, 1994; Francis et al. 1998).

Recent work in the plume and adjacent coastal zone has now shown that the northern California Current may have experienced another regime shift, beginning in late 1998. Due in large part to increases in the length of the upwelling season in 1999, zooplankton biomass has doubled in the coastal waters off Oregon, community composition has shifted to a dominance of cold water species, and salmon survival has increased five-fold (Peterson and Schwing, in prep). Therefore, it is important to keep in mind that the coastal dynamics (including habitats influenced by the Columbia River plume) are modulated by climate influences at decadal scales as well as inter-annual, seasonal and daily scales depending upon the strength of the upwelling process.

The known ocean distribution of North American chinook salmon extends far beyond the coasts of Washington and Oregon to include part of the Bering Sea and the offshore North Pacific. Recent research has caught rapidly migrating Columbia River chinook salmon in Canadian and Alaskan coastal waters that were moving along the continental shelf at speeds of up to 2.2 body-lengths/sec. Such speeds brought these animals at least as far as the northern tip of Vancouver Island by June 3rd, and into SE Alaskan waters by late June. Thus, a component of Columbia River salmon (including Snake River chinook) undergo rapid and highly directed migrations that move them quickly out of the Columbia River plume and the Northeast Pacific coastal shelf and into the Gulf of Alaska.

Salmonid Species Affected/Benefited

All salmonid species, in both their juvenile and adult phases, use the Lower Columbia River and estuary, plume and marine environment, particularly the coastal shelf, as a migratory corridor and as rearing habitats. The estuarine and plume habitat are particularly important as they are subject to significant anthropogenic modification. In particular, estuarine habitats in the Lower Columbia River provide important nursery and rearing areas for young salmon and steelhead, and adults use them as temporary holding areas during their return migration from the ocean to upstream spawning areas (Myers et al. 1998, Busby et al. 1996, Johnson et al. 1997). Estuaries are considered important to rearing of juvenile salmon and represent an integral component of the continuum of habitats that salmon occupy for significant periods of time.

The estuary is this region is particularly important to endangered stocks of salmon that exhibit an ocean-type life history pattern. Juvenile salmon that emulate an ocean-type pattern migrate to the estuary as sub-yearlings and rear in the lower river and estuary for extended periods of time (months). Endangered salmon Evolutionary Significant Units (ESU) with this life history pattern include Snake River Fall Chinook Salmon, Upper Willamette River Chinook Salmon, Lower Columbia River Chinook Salmon, and Columbia River Chum Salmon (Myers et al. 1998, Johnson et al. 1997). Important habitat attributes include not only adequate food resources but also shallow water, low velocity habitats that serve as refuge areas for juveniles to rear, avoid predators, and grow.

Unfortunately, overall populations of the basin's anadromous fish stocks are estimated at less than 10 percent of their historic size, despite major hatchery programs. Artificial production now accounts for about 75 percent of all fish returning to the Columbia River system. Wild stocks of salmon, steelhead and sea-run cutthroat trout are virtually gone in some areas. The Columbia River basin's historically large chum salmon stocks have declined to less than one percent of their original level.

Due to a number of factors resulting in the decline of these species, 12 ESUs of salmon identified in the FCRPS Hydropower Biological Opinion pass through and/or spawn in the Lower Columbia River. The 12 ESU are:

- Snake River Spring/Summer Chinook
- Snake River Fall Chinook Salmon
- Upper Columbia River Spring-run Chinook Salmon
- Upper Willamette River Chinook Salmon
- Lower Columbia River Chinook Salmon
- Snake River Steelhead
- Middle Columbia River Steelhead
- Upper Willamette River Steelhead
- Lower Columbia River Steelhead
- Columbia River Chum Salmon
- Snake River Sockeye Salmon
- Upper Columbia River Steelhead

For more specific information on each ESU, the FCRPS Hydropower Biological Opinion provides geographical boundaries, historical, habitat, hatchery influence, and population trends and risks information in its sections 4.1 and 4.2.

Accomplishments/Results

Adaptive Management Implications

This section provides an historic overview of management of the Lower Columbia River and estuary. That retrospective perspective is then followed by a summarization of the main management themes that are currently occurring in the Lower Columbia River and estuary, including specific examples of those management actions. Neither of these sections is meant to be an exhaustive review of the subject of management of the Lower Columbia River. Instead, this section will highlight the traditional versus current perspectives of how this ecosystem functions to support the life history strategies of the salmonids that use it. In contrast, consideration of marine conditions (Columbia River plume, nearshore coastal regions, NE Pacific Ocean) as a factor in management of Columbia River basin stocks has received little attention to date (Bisbal and McConnaha 1998). The paucity of accomplishments and results with regard to understanding and managing marine survival of salmon reflects the lack of focus on this region rather than neglect to include information regarding the marine environment.

Historic Management Perspective of the Lower Columbia River and Estuary

Although in recent years, the traditional assumptions of fisheries management have received increased scrutiny (McEvoy 1986, Finlayson 1994, Lichatowich 1999, Independent Scientific Group 2000), the impact of these ideas on salmon research and management in estuaries has not been examined specifically. Lack of research interest in Northwest estuaries stems, in part, from long-held assumptions that populations are regulated by "density-dependent" interactions-biological factors like predation, disease, or food competition during the earliest and presumably most vulnerable stages of salmon life. These ideas coincided with the freshwater habitats where salmon are most easily observed and where the sources of mortality can be controlled.

Salmon hatcheries, for example, developed from the assumption that adult abundance is limited by freshwater mortality, and that abundance increases in direct proportion to the number of additional eggs that survive when they are reared in a controlled environment (Lichatowich 1999). Theoretical models in population ecology and the concept of "maximum sustained yield" similarly assumed density-dependent control of salmon and developed equations to describe the apparent relationship between population size and the resulting number of recruits (e.g., Ricker 1948, Larkin 1977).

Salmon hatcheries and harvest models have had widespread appeal. They reinforced the fundamental economic view of fishery management (Bottom 1995, 1997). They also met new standards of scientific legitimacy, as modern ecology actively shunned historical and descriptive explanations for the reductionist and predictive methods of the physical sciences (Kingsland 1995). Both achieved this predictability by simply eliminating natural variation: hatcheries through technological control of the only (fresh-water) variations assumed to be important, and harvest models by averaging the apparent relationship between population size and recruitment over the period of observation. In both cases, the assumption that populations are regulated by a predictable, freshwater struggle for existence allowed fishery management to avoid the messier stages of the salmon life cycle that were more difficult to understand and much more difficult to control.

Thus, a common theme of production thinking in salmon management is the notion that estuaries, like rivers (Lichatowich 1999), are hazardous places. A primary goal of production-oriented research is to identify, eliminate, or simply avoid apparent ecological constraints, particularly any obvious predators or competitors in the estuary. This approach emphasizes the need to reduce estuarine mortality of juvenile salmon regardless of their geographic origins or life histories or whether any of the additional survivors would be destined to return as adults. Most importantly, because it focuses on presumed threats to salmon, production thinking provides little or no information about the estuarine habitats and conditions that salmon actually *need*. Instead, the estuary is seen as a corridor through which a single, large, and undifferentiated mass of fish must run a gauntlet of predators before they can escape to the ocean. Among the many assumptions inherent to this view are the following:

- The factors that limit salmon production in estuaries are separable from conditions experienced during other life stages and can be treated independently.
- Estuaries have significant excess carrying capacity to accommodate large releases of hatchery fish.
- Estuarine abundance of juvenile salmon is regulated “top-down” by predators (or sometimes “bottom-up” by competitors) through density-dependent processes.
- The number of adult salmon produced each year is a function of the rate of predation (or competition) that occurs in the estuary.
- To avoid predators or competitors and improve survival rates, salmon must move rapidly through the estuarine corridor; and
- Adult returns will increase in proportion to the number of estuarine predators or competitors that are removed or otherwise prevented from interacting with salmon.

Factors of Decline for Salmon in the Lower Columbia River and Estuary

Multiple factors both upriver and within the estuary have simultaneously contributed to Columbia River salmon declines since the middle of the 19th century. These include effects of harvest; loss and degradation of spawning, rearing, and migratory habitat; hatchery production; large-scale changes in the hydrology of the river and estuary; and natural climatic variability (NRC 1996).

Salmon Harvest

Fisheries for Columbia River salmon became well established within four decades after Bruno de Heceta’s 1775 discovery of the river’s outlet to the Pacific Ocean. Over a similar period of fishing activity, targeted salmon stocks (i.e., spring chinook) were already showing signs of depression. Commercial harvest of adult salmon began about

1818 with packing of salmon as a salted or pickled product, but increased dramatically with the advent of commercial canning in 1866.

In response to canner demand, harvest intensity increased rapidly starting in 1866 over an 8-year period (Lichatowich et al. 1999). Commercial fishermen initially targeted spring-run chinook, considered the superior canning variety. By 1890, the concentrated harvest of these fish in the estuary and lower river was blamed for the dramatic reduction in the number of adults returning to spawn in the Snake River Basin (Evermann 1895). Salmon populations had declined throughout the Columbia River system by 1911.

Changes in Freshwater Habitat

Although irrigation in the basin began about the same time as the development of industrial salmon fisheries, it did not increase substantially until after implementation of the Reclamation Act of 1902, which stimulated expansion of irrigated lands from 2,000 km^2 to nearly 40 x 10^6 km^2 today, based on work of the Northwest Power Planning Council (NPPC) and others (NPPC 1986, NRC 1996). Yet surface water withdrawal did not accelerate until after World War II, principally in the mid-1960s, with technological advances and the availability of inexpensive electrical power. Irrigation not only decreased stream flow but also became a sink for migrating juvenile salmon that were diverted into irrigation canals and stranded in farmers□ fields. As early as 1890, state fish commissioners reported substantial losses of juvenile salmon in irrigation networks in eastern Oregon (Oregon State Board of Fish Commissioners 1890).

Extensive streambed and water modifications began to eliminate upriver spawning, rearing, and migratory habitats for salmon by the late 1800s. As early as 1894, mining in the Snake River watershed destroyed chinook spawning beds and was credited with the collapse of a popular Indian fishing site (Taylor 1999). Habitat loss due to logging and other intensive land uses such as cattle grazing increased after the turn of the century. Yet even before 1900, some practices damaging to salmon spawning and rearing habitat were prevalent, including removal of large woody debris from streams and the operation of splash dams (Sedell and Luchessa 1982, NRC 1996).

Construction of dams throughout the Columbia River Basin also has taken a heavy toll on salmon populations and accounts for much of the present-day reduction in historic salmon distribution. Chinook salmon populations from the upper Columbia River Basin in British Columbia and Alberta, middle Snake River Basin and above, and the greater part of the Deschutes River Basin have been extinct for at least 40 years due to dams built without fish passage capabilities. Today, 23 major hydropower and flood control dams exist on the mainstem Columbia and Snake Rivers, and over 300 smaller dams are distributed on tributaries throughout the U.S. portion of the watershed.

Salmon Hatcheries

Resource managers responded to declining Columbia River harvests in the mid-1890s by building salmon hatcheries. At first, hatcheries were promoted as a means to boost salmon production, to avoid the need for harvest regulations, and to generally improve on nature by using efficient technology to increase freshwater survival (Baird 1875, NRC

1996, Taylor 1999). Despite poor accounting for their performance and a general decline in support for hatcheries in the 1930s and 1940s, hatchery production expanded substantially in later years, stimulated by a new promise that artificial production could mitigate for the deleterious effects of dams and irrigation development (NRC 1996). Ultimately, more than 80 hatcheries were constructed in the basin. Hatchery adults now comprise more than 95% of the coho, 70% of the spring chinook, about 80% of the summer chinook, more than 50% of the fall chinook, and about 70% of the steelhead returning to the Columbia River (Columbia Basin Fish & Wildlife Authority 1990, Genovese and Emmett 1997).

Hatchery influence on chinook populations is now greatest for fall chinook in the middle and lower Columbia River sub-basins (>85% of total juvenile salmon production (Genovese and Emmett 1997)), and for spring and summer chinook in the Snake and Salmon River sub-basins (90 to 100% of the total production). More than 75% of the chinook salmon in the upper Columbia River, Deschutes, and John Day River sub-basins still results from natural production. On average, most hatchery fall chinook are released as fed fry and fingerlings, whereas releases of spring and summer chinook are more equally divided between sub-yearlings and yearling smolts.

Significant natural production of coho salmon (~30% of the total) now occurs only in the lower Columbia River subbasin. Hatchery-reared coho are released both as subyearling fry and fingerlings and as yearling smolts but releases of unfed fry are rare except in the lower and middle Columbia River sub-basins (Genovese and Emmett 1997). Between 50 and 70% of the chum salmon now produced in the lower Columbia River sub-basin are released from hatcheries as fed fry or fingerlings.

Intensive hatchery programs have had multiple effects on natural salmon production in the Columbia River Basin and on the recovery potential of at-risk populations (NRC 1996). Among these effects are reduced genetic diversity, competition between hatchery and naturally produced salmon, and depletion of wild populations in mixed stock fisheries. Loss of genetic and life-history diversity through large-scale hatchery production (Reisenbichler 1997) could be an important factor determining patterns of estuarine habitat use and the overall performance of juvenile salmon in the estuary.

Habitat Changes in the Estuary

Most loss and degradation of habitat within the Columbia River estuary occurred after the 1880s. Following a century of diking and filling activity, only 35% of the former area of marsh and swamp habitat remained in the estuary in 1980 (Thomas 1983). However, this is a gross estimate of the total habitat loss based on historical surveys. Other qualitative changes in physical conditions also may have had important effects on the salmon rearing capacity of the estuary.

Shoreline armoring and construction of over-water structures, channel dredging and removal of large woody debris, channelization by pile dikes and other structures, and discharge of pollutants have all significantly modified estuarine habitats. Unfortunately, the effects of such alterations on either juvenile or adult salmon rarely have been assessed.

While early channel dredging and hatchery production began to alter estuarine conditions in the second half of the 19th century, it wasnt until well into the 20th century that channelization and filling removed considerable amounts of estuarine habitat, and hydropower and irrigation developments significantly altered river flows. By this time, salmon harvest was already in an obvious state of decline (Taylor 1999). Although there were at least 174 dams in the basin by 1936, many of the mainstem dams that would ultimately comprise the Columbia River hydropower system were not completed until the 1950s. Accordingly, significant, coordinated flow modifications did not occur until the late 1960s (Sherwood et al. 1984).

Although the estuary has historically and currently experience low industrial development and relatively high flushing, water quality would conceivably not be considered a major concern for the Columbia basin as a factor affecting survival of salmon in the estuarine and marine environment (ISAB 2000). However, considering upstream developments (dams, urbanization, agriculture, habitat destruction), and the potential for global climate change recognized as a reality, water quality should be assessed as a factor affecting survival of salmon. For example, water temperature and toxins are important abiotic features affecting growth and survival of salmon. Recent evidence of accumulation of toxins in juvenile salmon in the Columbia River estuary and the warming of the river due to impoundment by dams reveal additional factors that need thorough evaluation as factors likely to affect survival of salmon and their evaluation should be incorporated in the Columbia River systemwide management plans. For more information, we refer you to the systemwide summary for water quality.

Climate Variability

Development activities in the Columbia River watershed and estuary were superimposed on a background of natural environmental changes, including substantial variations in climate, precipitation, and river flow. Often climatic fluctuations accounted for a greater degree of variation than those resulting from human interventions. Prior to 1910, spring freshets recorded at The Dalles often exceeded 20 x 10^3 m^3 s^{-1}, and winter flood flows in the Willamette River exceeded 5 x 10^3 m^3 s^{-1} (18 of 60 years). Both spring and winter peaks decreased dramatically thereafter, especially during the drought years of the 1930s (Sherwood et al. 1984).

Although the magnitudes of these changes are often impressive and suggest major shifts in riverine and estuarine disturbance regimes, Columbia River salmon stocks have withstood such disturbances for millennia (e.g., Chatters et al. 1995). Long-term productivity and the resilience of salmon species are the result of diverse life-history strategies that have evolved in a highly variable environment (Healey 1991, Healey and Prince 1995). A primary concern of recent salmon declines is whether habitat changes and reduced salmon diversity in the Columbia River Basin have severely undermined the capacity of populations to withstand large fluctuations, particularly major changes in long-established patterns of precipitation, temperature, and stream flow that some predictions suggest could accompany future global warming (Mantua et al. 1997).

Therefore, the cumulative effects of upstream developments on salmon rearing conditions in the estuary are poorly understood. Yet the combined influences of river flow regulation and industrial hatchery production are particularly noteworthy because of their direct impacts on salmon life histories or on the disturbance processes to which those life histories have adapted. Hydroelectric development now largely regulates the timing and magnitude of river flows, with potential effects on salmon migrations and on circulation processes and habitat conditions in the estuary. Hatchery programs now regulate the size, time of arrival, distribution, and rearing periods of most salmonids in the estuary. Thus, upriver controls placed on water and on fish have fundamental linkages to salmon production in the estuary.

Benefits to Fish and Wildlife

Current Management Perspective of the Lower Columbia River and Estuary

On September 12, 1996, Congress amended the Pacific Northwest Electric Power Planning and Conservation Act of 1980 to include a new section that requires the NPPC to "consider the impact of ocean conditions on fish and wildlife populations" when recommending hydropower mitigation projects for the Columbia River Basin.

This new amendment to the Power Act applies directly to anadromous fish populations, particularly Pacific salmon and steelhead, which have continued their precipitous decline despite decades of effort to mitigate effects of harvest and hydroelectric development in the basin. This legislation also focused new attention on the estuary, which provides important rearing habitat for juvenile salmon during their seaward migration and is directly impacted both by ocean conditions at the mouth and the effects of upstream hydropower development.

Concerns about the estuary and ocean represent a significant departure from previous management policy in the Columbia River Basin. Until now, restoration has focused almost exclusively on the freshwater phase of the salmon life cycle, even though salmon spend most of their lives at sea. Recent research has shown that decades-long shifts in climatic and oceanic conditions can produce fluctuations in salmon production across the entire North Pacific Ocean (Francis and Sibley 1991, Beamish and Bouillon 1993, Mantua et al. 1997). Such natural variability must be taken into account to develop appropriate recovery goals, actions, and expectations for Columbia River salmon.

Legislation that requires resource managers to look beyond fresh water thus recognizes that marine, estuarine, and riverine environments are each components of an extended salmonid ecosystem and cannot be treated independently (ISG 2000, Bisbal and McConnaha 1998). While clearly it is not possible to control fluctuations in the North Pacific Ocean, hydroelectric development and other upriver alterations directly affect the estuarine and nearshore coastal habitats of salmon as well as the health and diversity of salmonids that enter the ocean. Ultimately, these factors may decide whether salmon from the Columbia Basin can realize the full productive potential of the ocean under any particular set of environmental conditions.

In response to the legislative mandate to consider the ocean, the NPPC thus recommended two management strategies:

- improve estuarine and nearshore habitat conditions, which have been adversely affected by local habitat changes and upriver management activities; and
- preserve the diversity of life-history characteristics in salmon, which allows populations to withstand environmental fluctuations (NPPC 1997).

The NPPC further recommended several research initiatives to improve understanding of ocean effects on fish and wildlife management activities, including "a synthesis of what is known about the impacts of the construction and operation of the Columbia River hydroelectric system on the hydrology, habitats, and ecology of the Columbia River estuary and river plume and opportunities for management actions related to this understanding (NPPC 1998)."

Based on a review of existing studies and activities currently occurring in the Lower Columbia River, estuary, nearshore ocean, and plume environments, there are a number of key themes that current management in actions the Lower Columbia River and estuary share:

1) Protection of Existing Stocks - Actions that protect existing salmonid stocks through the continuum of estuarine and ocean habitats they occupy.
2) Habitat Conservation and Restoration - Protect, conserve, and restore habitats that are important to supporting and enhancing life history strategies of salmonids and overall ecosystem of the Lower Columbia River and estuary.
3) Monitoring and Adaptive Management - Conduct short and long-term monitoring of parameters important to salmonid life strategies and the overall ecosystem of the Lower Columbia River and estuary. The monitoring would include individual projects and as well as a system-wide assessment of the overall ecosystem of the Lower Columbia River and estuary. Both monitoring types could be built into an adaptive management approach to aid future management of the Lower Columbia River and ecosystem.
4) Targeted Research - Conduct research that advances the basic understanding of the ecology of the Lower Columbia River and estuary, and allows for the incorporation of that information into its current and future management.
5) Flow Regulation - Analyze and recommend flows as they relate to life history needs of salmon throughout their life cycle and life history diversity needs.
6) Integration Across All Themes - Management actions that support all the above themes and set the tone for future management of the Lower Columbia River and estuary.
7) Building Public Awareness and Participation - Involve decision-makers and the public in a dialogue about salmonid protection, conservation, and management.

There are number of current actions/activities that can be used to illustrate the above described themes. While not meant to be an exhaustive list, the following projects and programs provide examples that demonstrate the various types of actions currently occurring in the Lower Columbia River and estuary.

Theme 1 - Protection of Existing Stocks

Evaluation of live capture selective harvest methods for commercial fisheries on the Columbia River, Oregon and Washington Departments of Fish and Wildlife, 2001

The primary goal of this project is to develop, evaluate, and implement commercial live capture, selective harvest methods in the Lower Columbia River. The states' intent is for commercial fishers to contribute to the conservation of depressed or listed species by selectively harvesting fish from strong stocks, while releasing those from weak stocks live and unharmed to continue their upstream migration. This method of fishing requires developing and evaluating new gears and fishing methods that allow live capture of target and non-target species.

Theme 2 - Habitat Conservation and Restoration

Lower Columbia Fish Recovery Board Interim Regional Habitat Strategy, 2001

The Lower Columbia Fish Recovery Board (LCFRB) was established by RCW 77.85.200 to coordinate fish recovery activities in the lower Columbia region of Washington State. State law directs the Board to:

- Participate in the development of a regional fish recovery plan, particularly habitat recovery measures. In doing so, the Board is to coordinate with local governments, the State and the National Marine Fisheries Service (NMFS).
- Assess the factors for decline of salmon and steelhead on a "stream-by-stream" basis; and
- Implement the local government responsibilities for habitat restoration and preservation, including prioritizing and approving projects and programs, and receiving and disbursing funds.

The LCFRB's key activities include recovery planning, watershed planning and habitat restoration and protection. It is the overall habitat goal of the Lower Columbia Fish Recovery Board to provide the habitat necessary to support healthy, harvestable populations of Endangered Species Act (ESA)-listed fish species in the lower Columbia region of Washington. The LCFRB has developed an Interim Regional Habitat Strategy that outlines the goals and strategies the Board and its Technical Advisory Committee will use to identify and rank habitat restoration and protection needs and evaluate and rank habitat project proposals.

Specific goals for fish recovery and habitat restoration and protection are:

- Support recovery of ESA-listed stocks.
- Support biodiversity through recovery of native wild stocks.
- Restore or sustain geographic distribution of stocks.
- Maintain healthy stocks of a listed species.
- Support recovery of critical stocks of listed species.
- Restore access to habitat.

- Protect existing properly functioning habitat conditions.
- Restore degraded watershed processes needed to sustain properly functioning habitat conditions.
- Support critical salmonid life-history stages; and
- Secure near- and long-term benefits.

Theme 3 - Monitoring and Adaptive Management

The Oregon Department of Environmental Quality (ODEQ)

The ODEQ has an extensive statewide network of water quality ambient monitoring sites. In addition to three sites on the mainstem Columbia River, ODEQ maintains sites on many of the lower Columbia River tributaries. ODEQ supports additional monitoring which will help support agency programs. However, the current program is fiscally limited as it tries to meet the requirements of assessing Total Maximum Daily Load (TMDL) requirements compliance statewide and the additional monitoring commitments of the Oregon Plan for Salmon and Steelhead.

The Washington Department of Ecology (WDOE)

The WDOE currently has ambient monitoring sites on the major tributaries on the Washington side of the lower Columbia and the upper Columbia. There are no sites on the mainstem. Like ODEQ, WDOE is required to meet TMDL requirements statewide and address declining salmon and steelhead populations. The WDOE supports monitoring efforts on the lower Columbia River which help meet agency needs regarding these two issues.

Theme 4 - Targeted Research

Estuarine Habitat and Juvenile Salmon - Current and Historic Linkages in the Lower Columbia River and Estuary, NMFS and U.S. Army Corps of Engineers (Corps)

In a study with the Corps, the NMFS proposes as an overall goal to develop an understanding of how the estuary currently and historically benefited juvenile salmon by determining where salmon are (presence/absence and abundance) and their performance in relation to specific attributes of a variety of habitats in the tidally influenced lower river and estuary. Regions include shallow water areas either adjacent to peripheral forests and wetlands or centrally located in the river, dendritic and channel margins, and backwater sloughs. The NMFS also recognizes the need to place the salmon habitat associations in a historical context by evaluating river discharges and sediment inputs into the estuary for the past 100 years and reconstructing past and present availability of salmon habitat through the lower Columbia River and estuary using GIS mapping. The NMFS recommends developing a regional 3-dimensional numerical model of the lower Columbia River and estuary that can be used to characterize the impact of physical processes (flow, bathymetry, salinity, temperature, etc.) on potential availability of juvenile salmon habitat.

Recommended objectives of the project are to:

- Compare trends in abundance and life histories of juvenile salmon at a landscape scale on representative transects of shallow-water habitat between Puget Island and the Columbia River mouth.
- Describe salmonid use and performance in selected emergent and forested wetlands and their relationship to local habitat features; and
- Characterize historical changes in flow and sediment input to the Columbia River estuary and change in habitat availability throughout the lower river and estuary.

Theme 5 - Flow Regulation

Evaluation of Spawning for Fall Chinook and Chum Salmon just below the four Lower most Columbia River Dams, Washington Department of Fish and Wildlife

The primary goal of this project is to restore, protect, and enhance the fall chinook and chum salmon populations that spawn downstream from the Columbia River mainstem dams. The objectives of this project are threefold:

- Document the existence of fall chinook and/or chum salmon populations spawning downstream from Bonneville, The Dalles, John Day, and McNary dams and estimate the size of the populations;
- Profile the stocks for important population characteristics including spawning time, genetic make-up, emergence timing, emigration size and timing, and juvenile to adult survival rates and relate these population characteristics to river flows and water temperatures; and
- Determine physical habitat use and preference for fall chinook and chum salmon, and describe the relationship between streamflow/backwater effects and the quantity, quality, and location of physical habitat.

A fundamental strategy towards realizing the goal of this project is to develop the information necessary to make recommendations for hydrosystem operations and water management that are required for fall chinook and chum salmon to successfully carry out their life cycles by providing mainstem spawning and rearing habitat in the Columbia River.

Theme 6 - Integration Across All Themes

Lower Columbia River Estuary Partnership - Comprehensive Conservation and Management Plan (CCMP)

The Lower Columbia River Estuary Partnership became one of 28 programs in the National Estuary Program (NEP) in 1995. The Estuary Program□s fundamental goal is to achieve a high level of biological integrity for the lower Columbia River and estuary.

A management committee of stakeholders carefully reviewed the technical studies conducted under the Bi-State Water Program from 1990-96. Those studies provide the background for the technical elements of this plan. Using the technical data based on this assessment and supplementary information, the Management Committee identified seven priority issues of concern to the Lower Columbia River Estuary:

- Biological Integrity
- Impacts of Human Activity and Growth
- Habitat Loss and Modification
- Conventional Pollutants
- Toxic Contaminants
- Institutional Constraints
- Public Awareness and Stewardship

Based on the seven priority issues identified above, LCREP□s CCMP includes 43 actions that address the following broad categories of importance to management of the Lower Columbia River:

- Habitat and Land Use
- Education and Management
- Conventional and Toxic Pollutants

Wy-Kan-Ush-Mi Wa-Kish-Wit Spirit of the Salmon The Columbia River Anadromous Fish Restoration Plan of the Nez Perce, Umatilla, Warm Springs, and Yakama Tribes, Nez Perce, Umatilla, Warm Springs, and Yakama Tribes, 1995

The Spirit of the Salmon provides a framework to restore the Columbia River salmon which is, simply stated: put the fish back into the rivers. According to Spirit of the Salmon, past attempts to maintain or restore declining salmon numbers all assumed that technology alone could □fix□ the damage caused by disregard for the underlying, interconnected processes of nature which gave rise to and sustained the great salmon runs of the Columbia basin. Simple solutions could not replace the complexity of nature; naturally these attempts failed. The goals of the Spirit of the Salmon report are:

- Restore anadromous fish to the rivers and streams that support the historical, cultural and economic practices of the tribes.
- Emphasize strategies that rely on natural production and healthy river systems to achieve this goal.
- Protect tribal sovereignty and treaty rights; and
- Reclaim the anadromous fish resource and the environment on which it depends for future generations.

Theme 7 - Building Public Awareness and Participation

The Conservation Partnership in Oregon and Washington

The Conservation Partnership in Oregon and Washington is a unique coalition of local, tribal, state and federal groups that mobilizes staff and program funding to help people and communities address natural resource conservation issues. Relying on the mixed expertise, authority and common sense that each member organization brings to the table, the partnership strives to realize a shared vision – local people making informed decisions for healthy and economically viable lands. These goals and objectives were derived from

Natural Resource Conservation Service state and basin strategic plans and from individual Soil and Water Conservation District (SWCD) work plans. The primary goals of the Partnership are to:

- View and manage functional aquatic, wetland, riparian and upland habitats that support diverse native fish and wildlife populations as essential components of healthy watersheds; and
- Manage quantity and quality of water in an efficient and sustainable manner, making sure it is acceptable for its intended uses.

The primary objectives of the Partnership are to:

- Focus fish and wildlife restoration efforts on the connectivity between uplands, riparian areas and wetlands within a watershed.
- Furnish the technical and financial assistance needed by landowners to meet local, state and federal goals for fish and wildlife and water quality.
- Utilize a cooperative approach between local groups (i.e., SWCDs and watershed councils), state and federal agencies with fish, wildlife and water quality responsibilities to provide technical assistance, implementation funding and environmental certainty to private landowners.
- Develop partnerships to ensure participation through outreach and education of all interested parties.
- Conserve private land through voluntary, locally-led approaches.
- Work together to carry out the Oregon Plan through watershed management; and
- Promote public awareness, interest and participation in natural resource protection program.

Project Funding to Date

This section provides an overview of Bonneville Power Administration (BPA) funding since program inception. Funding in this region has been very limited, and thus the number of projects directly addressing survival are few. This summary, moreover, is not meant to be an exhaustive listing of all projects that address estuarine and marine survival of Columbia River basin salmon in any manner, but focuses on those projects that provide some of the basic understanding and tools that can be used to assess the extent and variation of estuarine and marine survival experienced by Columbia River basin salmon.

- 8740100 Travel time and survival smolt physiology - Provides information on smoltification and disease in juvenile salmonids for smolt monitoring program. $365K/yr
- 8910700 Epidemiological survival method - Improve monitoring and evaluation capabilities by developing better measurement tools to estimate juvenile and adult survival. $151K/yr
- 9202200 Wild smolt behavior/physiology (ESA) - Using findings developed on the physiological development of wild spring chinook salmon as a template, testing

the physiological aspects of wild fish that may be used to improve migration behavior and smolt-to-adult survival of hatchery-reared salmonids. 350K/yr

- 9207300 An automated fish marking and tagging system - Develop an automated mass-marking technique for juvenile salmonids that removes the adipose fin and/or applies coded-wire tags needed to assess smolt-to-adult returns. $382K/yr
- 9403300 Fish passage center - Provides regional resource to assemble information from various agencies to assess, in part, smolt-to-adult returns. $712K/yr
- 9702400 Avian predation on juvenile salmonids in the lower Columbia River - Estimates the number of juvenile salmonids consumed by colonial waterbirds in the lower Columbia River, identifies condition and locales where avian predation is most prevalent, provide recommendations to reduce avian predation on salmonids, and evaluated the efficacy of control measures that are implemented. $300K/yr
- 9702600 Ecology of marine predatory fishes: Influence on salmonid ocean survival - Assess the role of marine piscine predators on survival of juvenile salmon as they enter and occupy the nearshore marine environment off the mouth of the Columbia River. $180K/year
- 9801400 Ocean survival of salmonids relative to migrational timing, fish health, predation and oceanographic conditions in the Columbia River plume and adjacent coastal waters - Assesses the role of the Columbia River plume on growth and survival of juvenile salmon as they first enter the ocean environment. $845K/year
- Development of a Conceptual Model to Assess Estuarine Influence on Recovery and Resilience of Salmon Populations in the Columbia River (1999-2000) - Provided a compilation of what is currently known regarding the role of the Columbia River estuary to growth and survival of juvenile salmon and data gaps needed to be filled to assess the impact of the FCRPS on habitat opportunity in the lower river and estuary. 150K

Reports and Technical Papers

This section provides an overview of reports and papers as a result of funding from BPA funding since program inception. As stated previously, funding in this region has been very limited, and thus the number of reports directly addressing survival are few.

- Ocean Carrying Capacity: Recovery Issues for Threatened and Endangered Snake River Salmon. 1993. Report to the BPA prepared by Jim Lichatowich, Project 93-013. 25 pp.
- Cruise Reports - Ocean survival of juvenile salmonids in the Columbia River plume 1998-2000 (Available from BPA or NMFS)
- Ecology of marine predatory and prey fishes off the Columbia River, 1998 and 1999. NOAA Tech. Memo. NMFS-NWFSC-51. 108 pp.
- Salmon at River's End: The role of the estuary in the decline and recovery of Columbia River salmon. 2001. Draft Report submitted to the BPA by Bottom et al.

III. Relationship of Program to USFWS[1] and NMFS Biological Opinions

According to the FCRPS Hydropower Biological Opinion, estuarine protection and restoration must play vital roles in rebuilding the productivity of listed salmon and steelhead throughout the Columbia River basin. The states of Oregon and Washington, with congressional authorization under the Clean Water Act (CWA), have developed a Comprehensive Conservation and Management Plan through the Lower Columbia River Estuary Program (LCREP). The Federal agencies strongly support the actions of this plan that contribute to salmon recovery and seek to expand on them.

The following action items call on the Action Agencies, primarily the Corps and BPA, to play an important role in estuary restoration efforts. The Corps is meant to playa lead role, with BPA primarily providing cost-share funding. The Corps and BPA actions are not meant to hinge on LCREP approval, but they are meant to be fully coordinated with the LCREP.

The following are the action items in the FCRPS Hydropower Biological Opinion related to the mainstem estuary and near-shore ocean environments:

Action 158 - During 2001, the Corps and BPA shall seek funding and develop an action plan to rapidly inventory estuarine habitat, model physical and biological features of the historical lower river and estuary , identify limiting biological and physical factors in the estuary , identify impacts of the FCRPS system on habitat and listed salmon in the estuary relative to other factors, and develop criteria for estuarine habitat restoration. A good deal is unknown about the ecology of the Columbia River estuary insofar as it affects listed species. It is important to develop a better understanding of historic salmon rearing patterns in the estuary; historic changes in the distribution, amounts, and classes of estuarine and floodplain habitat available to juvenile salmonids; variability in salinity, temperature, water depth, velocity, dissolved oxygen, and turbidity; habitat-salmon associations; sedimentation rates; salmon and habitat conditions in the transition zone; long-term variability and trends in the size, timing, and abundance of hatchery and wild outmigrants from the Columbia River; and the relative effects of inflow from upriver, changes in bathymetry due to the navigation channel, and changes in habitat due to other forms of development. Under this action item, the Corps and BPA are expected to develop programs to build an understanding of these matters and, in the relatively short term, to develop criteria for estuary habitat restoration on the basis of the best available information.

Action 159 - BPA and the Corps, working with LCREP and NMFS, shall develop a plan addressing the habitat needs of salmon and steelhead in the estuary.

BPA and the Corps, working with LCREP and NMFS, will develop specific plans for salmon and steelhead habitat protection and enhancement. These plans should contain clear goals for listed salmon conservation in the estuary, identify habitats with the

[1] The USFWS Biological Opinion for mainstem habitat describing estuarine and marine survival is discussed in the Mainstem Habitat Systemwide Summary

characteristics and diversity to support salmon productivity, identify potential performance measures, identify flow requirements to support estuarine habitat requirements for salmon, and develop a program of research, monitoring, and evaluation. The plans should be completed by 2003.

Action 160 - The Corps and BPA, working with LCREP, shall develop and implement an estuary restoration program with a goal of protecting and enhancing 10,000 acres of tidal wetlands and other key habitats over 10 years, beginning in 2001, to rebuild productivity for listed populations in the lower 46 river miles of the Columbia River. The Corps shall seek funds for the Federal share of the program, and BPA shall provide funding for the non-Federal share. The Action Agencies shall provide planning and engineering expertise to implement the non-Federal share of on-the-ground habitat improvement efforts identified in LCREP, Action 2.

Much of the complexity of the estuary's historic shallow-water habitat and much of the estuary's saltwater wetlands have been lost due to the effects of local, navigational, and hydropower development. LCREP proposes a 10-year program to protect and enhance high-quality habitat on both sides of the river to support salmon rebuilding. A high priority should be put on tidal wetlands and other key habitats to rebuild productivity in the lower 46 river miles. Federal agencies will provide technical and financial support for this program and for efforts to implement on-the-ground activities identified in planning.

As more information is gained from inventory and analytical work, the 10,000-acre goal may be modified to ensure that habitats that are determined to be important to the survival and recovery of anadromous fish are addressed. Examples of acceptable estuary habitat improvement work include the following:

- Acquiring rights to diked lands.
- Improving wetlands and aquatic plant communities.
- Enhancing moist soil and wooded wetland via better management of river flows.
- Reestablishing flow patterns that have been altered by causeways.
- Supplementing the nutrient base by importing nutrient-rich sediments and large woody debris into the estuary.
- Modifying abundance and distribution of predators by altering their habitat.
- Creating wetland habitats in sand flats between the north and south channels.
- Creating shallow channels in inter-tidal areas; and
- Enhancing connections between lakes, sloughs, side channels, and the main channel.

The Corps and BPA will put high priority on improving access to and the quality of chum habitat, especially in the Grays River. The work outlined in this action is in addition to any habitat improvement work that may be connected to the Corps' Columbia River Channel Improvements Project.

Action 161 - Between 2001 and 2010, the Corps and BPA shall fund a monitoring and research program acceptable to NMFS and closely coordinated with the LCREP monitoring and research efforts (Management Plan Action 28) to address the estuary objectives of this biological opinion.

Action 162 - During 2000, BPA, working with NMFS, shall continue to develop a conceptual model of the relationship between estuarine conditions and salmon population structure and resilience. The model will highlight the relationship among hydropower, water management, estuarine conditions, and fish response. The work will enable the agencies to identify information gaps that have to be addressed to develop recommendations for FCRPS management and operations.

Action 163 - The Action Agencies and NMFS, in conjunction with the Habitat Coordination Team, will develop a compliance monitoring program for inclusion in the first land 5-year plans.

Compliance monitoring is necessary to determine how well management actions are implemented. From a regulatory perspective, compliance monitoring is necessary to ensure that agencies and individuals responsible for mitigation or restoration activities complete their responsibilities. From a biological perspective, NMFS must know how well a management action is implemented. If salmon do not respond, NMFS will be able to distinguish between management that did not work and management that was not implemented.

Some compliance monitoring will be conducted during the monitoring and evaluation program outlined in Section 9.6.5. of the FCRPS Hydropower Biological Opinion. However, not all sites will be checked at the appropriate intervals during this program. Therefore, the agency or party conducting each action will be responsible for keeping a log book of implementation, which is entered monthly into a web-based data archive. The NMFS will randomly send out field staff to check on the log books and validate their entries.

An important, but often overlooked, aspect of the biology of Columbia River basin salmonids is the effect of the FCRPS on their use of estuarine and ocean (plume and nearshore) environments. The FCRPS can have a direct and substantial impact on conditions in these habitats through its alteration of the hydrograph, water quality , and other impacts. Regional analyses have identified these environments as critical to population growth potential and, thus, as appropriate for mitigation actions.

Unfortunately, little is known about salmonid use of these habitats. Of primary importance are the following:

- The contribution of juvenile survival during the estuary/early ocean phase to overall ocean survival.
- Cause-and-effect links between estuary/early ocean resources and juvenile survival.
- Cause-and-effect links between estuary/ocean resources and adult survival.
- The spatial distribution of each stock in the estuary/ocean and the temporal contribution to survival; and
- The influence of natural variation versus that of humanly caused changes in environmental conditions affecting juvenile and adult survival in the estuary/ocean phase.

The distribution of each stock in the estuary/early ocean, survival rates, and natural variation in those rates will largely be addressed through tier 2 population and environmental status monitoring. However, tier 3 studies will be necessary to determine causal links between FCRPS alterations of the estuarine and nearshore ocean environments and salmon population response. In addition, several important studies addressing the following are also needed:

- Enhance and benchmark plume modeling; establish a long-term plume monitoring station.

- Partition the role of the estuary habitat from that of the nearshore ocean in juvenile survival.
- Identify and differentiate physical/chemical versus biological factors that cause mortality.
- Evaluate the influence of altering volume and timing of the historical hydrograph, hydrosystem operations, and the physical condition (bathymetry and structure) of the lower Columbia River and the estuary, as well as the effect on juveniles of the size, shape, and beneficial use of the Columbia River plume in the nearshore ocean environment; and
- Determine the extent of indirect, humanly caused mortality in these environments; for example, assess how tern and comorant populations are affected by hatchery and hydrosystem operations.

To address these critical needs, the following ongoing activities will be conducted:

Action 194 - The Action Agencies and NMFS shall work within the annual planning and congressional appropriation processes to establish and provide the appropriate level of FCRPS funding for studies to develop a physical model of the lower Columbia River and plume. This model will characterize potential changes to estuarine habitat associated with modified hydrosystem flows and the effects of altered flows where they meet the California Current to form the Columbia River plume.

Physical characteristics of the estuary such as river flow, hydrograph, velocity, bathymety, salinity intrusion, and circulation patterns define estuarine conditions. It is, therefore, important to characterize the physical aspects of the estuary and to compare existing and future physical attributes with historical conditions to assess the potential effect of hydro system flow regimes on estuarine habitat. Physical changes to the estuary will affect its ecology and, potentially, how salmonids use the estuary for migration, growth, and development. The plume habitat as an extension of the estuary, or as a unique habitat important to Columbia River salmon, will be similarly affected by actions of the FCRPS. Characterization of these effects to assess the importance of historical and current conditions will help facilitate the recovery of all salmon stocks.

Action 195 - The Action Agencies shall investigate and partition the causes of mortality below Bonneville Dam after juvenile salmonid passage through the FCRPS .

A long-term research, monitoring, and evaluation plan should be developed to measure mortality that may occur after smolts have passed through Bonneville Dam. The plan will include post Bonneville mortality that may be associated with passage of smolts through the Federal hydro system and the extent of delayed mortality, which is uncertain and central to decisions about hydro system configuration and the role of juvenile salmonid transportation. These evaluations should attempt to establish how much of the post-Bonneville mortality is natural and how much is related to other factors, such as hydro system passage and fitness.

Action 196 - The Action Agencies and NMFS shall work within the annual planning and congressional appropriation processes to establish and provide the appropriate level of FCRPS funding for studies to develop an understanding of juvenile and adult salmon use of the Columbia River estuary .These studies support the actions to develop criteria for estuarine restoration (Action 158), restoration planning (Action 159), and implementation (Action 160) in Section 9.6.2.2. of the FCRPS Hydropower Biological Opinion.

Estuary use potentially has a major effect on salmonid survival to adulthood. The estuarine ecology of salmon in general and the use of Columbia River estuarine habitat in particular are poorly understood. Juvenile distributions relative to habitat type, food habits, prey preferences, and the growth and physiological condition of juveniles entering and leaving the estuary are important aspects of salmonid ecology in the estuary. Information on these aspects of all salmonid life histories is needed to develop an understanding of salmonid estuary use and any influences of the hydro system on flows, turbidity, and nutrient delivery that might, in turn, affect salmonid ecology in the estuary .

Action 197 - The Action Agencies and NMFS shall work within the annual planning and congressional appropriation processes to establish and provide the appropriate level of FCRPS funding for studies to develop an understanding of juvenile and adult salmon use of the Columbia River plume.

Plume dynamics and interaction with the California Current can potentially have a major effect on salmonid survival to adulthood. The plume ecology of salmon and use of the plume habitat are poorly understood. Juvenile distribution in terms of food availability, predators, and performance (fitness, growth, and health) must be assessed in relation to plume dynamics. Information on all salmonid life histories is needed to develop an understanding of salmonid use of the plume and any influences of the hydrosystem on turbidity, nutrient delivery, and habitat attributes that might affect salmonid ecology and survival in the plume.

Evaluating juvenile and adult use of the estuarine and nearshore environments will require monitoring techniques still in the early phases of development. In particular, use of acoustic (sonic) tags with fixed, towed, or buoyed detector arrays is recommended, as is the continued development of existing technologies such as PIT -tag detector flow through trawl surveys. The immediate value of a concerted sampling effort in the estuary and nearshore regions will be development of cause-and-effect relationships between FCRPS flow management and physical conditions (e.g., bathymetry, suspended particulate matter, and temperature) that affect the availability of suitable habitat for juvenile salmonids. The NMFS will use this information to recommend changes in flow management operations to improve juvenile survival.

Future Needs

Project Recommendations

The Mainstem/Systemwide program for Estuary and Marine Survival does not have a specific program/project requirements in the same manner as more established and upstream systemwide programs do. Therefore, BPA, in coordination with the Corps, should fund programs and projects that result in a coordinated understanding of the factors affecting mortality of salmon through the estuary, plume and nearshore ocean environment. Those projects and programs should reflect the spirit and intent of the action items described in the FCRPS Hydropower Biological Opinion and listed in Section III. of this report.

As an Action Agency responsible for much of the major dam operation in the FCRPS, the Corps has responsibility to mitigate for the impact of the dam structures and passage of salmon and to understand the role of channel modification on salmon habitat and survival. They have funded efforts to understand the role of “delayed mortality” and “extra mortality” of salmon, a postulated impact of transportation and dam passage manifested in the estuary, plume, or nearshore ocean environment and to understand the role of the estuary to salmon survival.

It is recommended that projects funded through the Corps be supplemented and integrated with funding and projects from BPA to develop an understanding of the role of the estuary, plume, and nearshore environments and the impact of modifications upriver thru the ocean on survival of salmon. Those projects that receive funding from the Corps and BPA over the next three years should accommodate and/or complement the themes articulated in the Section II. A, Adaptive Management Implications portion of this document. Emphasis should be placed on conservation and restoration projects and reflect the needs to salmonids and overall ecosystem restoration, and can be used to support and complement on-going and needed future research action over the next three years and beyond.

The FCRPS Hydropower Biological Opinion action items listed in Section III. of this report are cross-referenced against the themes to indicate their relationship to one another. Please also note that the Action Agencies, as required by the FCRPS Hydropower Biological Opinion, prepared a 2002 Implementation Plan for the FCRPS. The Implementation Plan (page 21) identifies a number of actions that the Action agencies will conduct to support recovery of estuarine, nearshore ocean, and plume environment for the benefit of listed salmonids. The themes identified earlier and restated below with modifications to include the plume and ocean environments support the actions described in the Implementation Plan.

The themes are as follows:

1) Protection of Existing Stocks - Actions that protect existing salmonid stocks through the continuum of estuarine and ocean habitats they occupy (Related to FCRPS Action

Item 159).

2) Habitat Conservation and Restoration - Protect, conserve, and restore habitats that are important to supporting and enhancing life history strategies of salmonids and overall ecosystem of the Lower Columbia River and estuary, plume and ocean (Related to FCRPS Action Items 159, 160, and 196).
3) Monitoring and Adaptive Management - Conduct short and long-term monitoring of parameters important to salmonid life strategies and the overall ecosystem of the Lower Columbia River and estuary, plume, and ocean. The monitoring would include individual projects and as well as a system-wide assessment of the overall ecosystem of the Lower Columbia River and estuary, plume, and ocean. Both monitoring types could be built into an adaptive management approach to aid future management of the Lower Columbia River and related ecosystem (Related to FCRPS Action Items 159, 161, 162, 163, 196).
4) Targeted Research - Conduct research that advances the basic understanding of the ecology of the Lower Columbia River and estuary, plume, and ocean, and allows for the incorporation of that information into its current and future management (Related to FCRPS Action Items 158, 162, 163, 194, 195, 196, 197).
5) Flow Regulation - Analyze and recommend flows as they relate to life history needs of salmon throughout their life cycle and life history diversity needs (related to FCRPS Action Items 195).
6) Integration Across All Themes - Management actions that support all the above themes and set the tone for future management of the Lower Columbia River and estuary and plume (Related to FCRPS Action Items 158, 159).
7) Building Public Awareness and Participation - Involve decision-makers and the public in a dialogue about salmonid protection, conservation, and management (Related to FCRPS Action Item159).

As stated previously, a coordinated understanding of the factors affecting mortality of salmon through the estuary, plume and nearshore ocean environment has not been a long-term focus of the action agencies until recently. As a consequence, program needs to address this element are in their infancy. Many of the themes identified above are not yet covered in the existing efforts and require proposed dedicated or integrated projects. Those projects and programs that are recommended should, again, reflect the spirit and intent of the action items described in the FCRPS Hydropower Biological Opinion and listed in Section III. There are few current actions/activities that address several of the themes and can be used to illustrate projects that require additional BPA funding. It should be noted that the examples we use are for illustrative purposes and reflect activities that are most familiar to us, however, there are few activities directed at estuary and ocean survival of salmon from which to draw upon. These include, with themes they address:

Themes addressed - Targeted research, Flow Regulation, Monitoring and Adaptive Management, Integration Across All Themes

Ocean Survival Of Juvenile Salmonids In The Columbia River Plume, NMFS, Oregon State University and Oregon Graduate Institute, 1998 to present (Funding derived from the BPA; continued funding recommended). - A study by NMFS, Oregon State University, and the Oregon Graduate Institute has been ongoing since 1998 to evaluate the role of the Columbia River plume on growth and survival of juvenile salmon. Inter-annual variation in ocean recruitment of salmon is high and thought to be associated with variation in nearshore ocean conditions. The nearshore ocean environment, particularly that associated with the Columbia River plume, is a critical habitat to outmigrating juvenile salmon. Several investigators have already suggested that survival during the first year of ocean life is a key to establishing year-class strength. However, the factors and processes associated with the plume environment that enable or alter survival potential is largely unknown. Moreover, hydropower generation in the Columbia River has altered the amount and timing of water delivered to the plume, potentially affecting the beneficial features of the plume environment to juvenile salmon. In the case of salmonids originating in the Columbia River Basin, survival success likely hinges on the complex interaction of smolt quality and the abiotic and biotic ocean conditions at the time of entry and during their first year of ocean existence.

This study focuses on the hypothesis that variation in the physical and biological conditions of the nearshore environment, particularly that associated with the Columbia River plume, affects overall survival of Columbia River stocks. Primary factors being evaluated include (a) food availability and habits, (b) time of entry, smolt quality, and growth and bioenergetic status at the time of entry and during the first growing season in the ocean, and (c) predation. (A companion study on predation on juvenile salmon is ongoing.) The study proposes to characterize, over a 10-year period, the physical and biological features of the nearshore ocean environment with real-time and modeling projections of the Columbia River plume as it interacts with the coastal circulation regime, and to relate these features, both spatially and temporally, to variation in salmon health, condition, and survival.

Themes addressed - Targeted research, Flow Regulation, Monitoring and Adaptive Management, Habitat Conservation and Restoration

Estuarine habitat and juvenile salmon - Current and historic linkages in the lower Columbia River and estuary (Funding derived from the Corps, supplemental funding by BPA recommended) -

A study by NMFS, Corps, University of Washington, Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, and the Oregon Graduate Institute to identify important estuarine habitats and to evaluate the role of the Columbia River estuary to juvenile salmon was begun in 2000. Estuaries are considered important to rearing of juvenile salmon and represent an integral component of the continuum of habitats that salmon occupy for significant periods of time.

There is, however, a general lack of science-based information concerning attributes of these tidal freshwater and oligohaline transition zones needed to support juvenile salmon, particularly in the Columbia River estuary. The need to develop effective restoration strategies drove the researchers to propose empirically identifying the benefit of these habitats to juvenile salmon by evaluating habitat-salmon linkages in the lower Columbia River and estuary. They propose a monitoring approach to identify associations between salmon and habitat in the lower Columbia River and estuary. They further propose a historic reconstruction of flow and sediment input in the system and historic reconstruction of critical salmon habitat using GIS for comparison to present day conditions and to gauge loss and factors associated with loss of critical habitats and to identify areas for future restoration.

The approach will be to: 1) determine the relationship between habitat and the presence, use, and benefit to juvenile salmon, with an emphasis on subyearling chinook salmon, in the lower Columbia River and estuary and 2) understand change in flow, sediment input, and availability of habitat in the lower Columbia River and estuary. To be successful, this approach requires that we both establish relevant empirical associations between habitat variables and juvenile salmon and accurately model physical changes in the lower Columbia River and estuary.

During later years of this proposed study, a modeling effort to evaluate the impact of physical change (natural and anthropogenically-induced variability) on the availability of critical salmon habitat is planned. To accomplish this objective, they plan to use the CORIE numerical modeling system for the lower Columbia River and estuary. This modeling system is being independently developed and validated. It will be used here to evaluate availability of habitat affected by variation imposed by both natural processes and anthropogenic manipulation of the system and further, to a limited extent, associations between salmon use and habitat type.

Additional efforts in continuing years include: 1) an effort to better characterize life histories of juvenile salmon among different habitats using scale and otolith analyses, 2) use of light traps to achieve diurnal resolution of juvenile salmon use and abundance of estuarine habitats and to validate beach seining estimates of juvenile salmon abundance, 3) refine and evaluate methodologies to estimate in continuum habitat opportunity for juvenile salmon in Cathlamet Bay, and 4) develop methods for evaluating the amount of fine and coarse sediment inputs to the Columbia River estuary.

Themes addressed - Targeted Research, Monitoring and Adaptive Management, Integration Across All Themes

Developing tools and estimating survival of salmon through the Columbia River estuary (Funding derived from the Corps, supplemental funding by BPA recommended) - The NMFS has determined through evaluation of additional needs derived from the FCRPS, that the following efforts need to be supported; 1) a statement on the need to estimate survival of various stocks migrating through the Lower Columbia River estuary and 2) a statement on the need to develop the tools and methodologies that will enable survival to be estimated and the monitoring of habitats salmon are selecting and occupying, and their spatial and temporal distributions within these habitats. To make these types of observations, new tools and techniques will have to be developed, especially to be able to monitor the survival and movements of smaller subyearling chinook salmon. Listed below are research studies that address these types of information needs that will require additional BPA funding:

A study to estimate salmonid survival through the Columbia River estuary using acoustic tags - There is a need to develop an acoustic tag and concomitant detection array to estimate survival, residence behavior, and ocean-entry timing of both stream- and ocean-type juvenile salmonids through the Columbia River estuary to explore passage behavior through the estuary, characterize how salmonids utilize estuarine habitats, and evaluate the affect from physical changes to the estuary (flow and habitat) on the recovery of listed salmon stocks. PIT-tagged juvenile salmon from known ESUs and rearing histories (hatchery versus wild) could be diverted at the Bonneville Dam smolt monitoring facility using the select-by-code system or from local, lower river hatcheries and habitat types and implanted with acoustic tags. A key study element would be development of a small acoustic tag for use in subyearling fall chinook salmon (*Oncorhynchus tshawytscha*). By downsizing existing tag hardware, a variety of targeted groups and life histories can be evaluated to develop a broader understanding of the relationship between estuarine residence and survival, growth, and perhaps survival in the near-shore marine environment.

The study should: 1) develop an acoustic tag small enough for subyearling chinook salmon, 2) develop the detection array required to receive signals from these new tags in the acoustically complex environment at the mouth of the Columbia River, 3) integrate the statistical requirements of a single-release survival model and experimental parameters used during full-scale implementation (sample size, detection probability, and differences in survival between various treatment groups such as species, ESU, rearing history, and migration history) into the development of the tag and detection array, 4) assess potential biological effects of the acoustic tag on salmon, and 5) make estimates of survival, behavior, and ocean-entry timing.

Evaluate the migration behavior of PIT-tagged juvenile salmonids in the Columbia River estuary - Development of a small-boat PIT trawl deployment to is needed to sample PIT-tagged fish in areas currently inaccessible to the pair-trawl, for use in determining estuarine utilization and habitat preferences by juvenile salmonids. The small trawl might also be utilized at Jones Beach during July and August to monitor the downstream migration timing of subyearling chinook salmon from ESUs located above Jones Beach.

PIT-tag interrogation data from the estuary will eventually provide the ability to partition juvenile salmonid survival between river and ocean environments. With a more complete understanding of relative survival and timing differences between stocks, we may be able to identify periods or locations of increased or decreased survival. This knowledge may allow management alterations such as changing the proportions of transported versus river migrating fish in association with river conditions or date and altering release timing for hatchery fish and barged-fish release schedules or locations to manipulate the migration and ocean entry dates to increase overall survival. Estuarine interrogation data of PIT-tagged fish previously detected at Bonneville Dam provide a means for evaluating comparative survival rates of inriver migrants from a release site to Bonneville Dam. Additional sampling in the brackish water portion of the estuary will provide important timing and residency assessments for juvenile salmonids previously unavailable.

Future Needs

Although BPA has recently focused on the impact of the FCRPS on downstream impacts and the role of the estuary and ocean on survival of salmon, there have been a number of significant, on-going activities outlining needs pertinent to future research and conservation of habitats in the Lower Columbia estuary and ocean. For instance, the LCREP has developed a plan to monitor and restore habitat in the Columbia River estuary that is in the process of being implemented. The ISAB conducted a recent review of needs in understanding the role of the Columbia River estuary and provided recommendations for future research. A team of estuarine scientists, headed by NMFS, with funding from the BPA, evaluated with currently available information, the role of the estuary and the impact of the FCRPS on salmon, providing recommendations for future research. And finally, a team of NMFS scientists recently published a review of needed ocean research to help guide efforts in recovery of diminished salmon stocks.

Specific recommendations from these assessments and studies can be obtained directly from the reports or publications. Collectively, the results of this body of work provide direction for future research needs to assist identifying the role of the estuary and ocean on survival of salmon and recovery of suppressed salmon stocks. Moreover, synthesis of their recommendations highlight additional thematic areas that are needed to address estuarine, plume and ocean research not yet directed. These include:

1) Adopt an ecologically-based framework for estuarine, plume, and ocean management and habitat restoration/conservation
2) Focus on all life history stages and all opportunities to increase salmonid survival
3) Develop tools for forecasting salmonid survival
4) Develop the necessary tools to house, manage, and disseminate the data and information collected for use by decision-makers and the public

Future programmatic efforts that address specific questions needed to fulfill the thematic areas identified in Section IV.A and B include the following proposal areas:

- <u>Distribution and Movement Patterns of Salmon in the Ocean</u> - Despite the research described previously, we still have an incomplete understanding of distribution and ecology of juvenile salmon in nearshore and coastal environments. We know little about small-scale diel movement patterns, residence times, and habitat preferences of salmon once they enter salt water. This information, which is a critical input to Individual Based Models or life history models, can only be attained by systematic sampling for several years, especially during the first few months that salmon spend at sea. Similarly, we lack information on the oceanic distribution and habitat utilization of adult salmonids, especially during the winter, which may be a critical period in their existence. Although general information about where a species is found at what time is useful, detailed stock-specific information is necessary to protect endangered stocks.

- Health and Condition of Hatchery and Wild Fish in Estuarine and Ocean Survival - Hatchery fish do not survive as well as wild fish in estuaries and coastal ocean areas and fish from different hatcheries do not have equal survival rates, suggesting that differences in the condition of released fish or in hatchery release practices vary greatly. Technology is available now to mass-mark all individuals from a particular hatchery using thermal otolith tags so their movements and survival can be followed through time. New methods for mass marking wild fish should be developed so that direct comparisons between wild and hatchery stocks can be made in estuarine and ocean environments.
- Trophic Dynamics and Food Webs Leading to and from Salmon - It is unclear whether bottom-up or top-down processes, or some combination of both, limit salmon production in estuarine and nearshore coastal environments. This is one of the most challenging areas in salmon research, and one that will require a concerted effort to make substantial gains. Accurate estimates of food consumption and growth potential will require a combination of field and laboratory studies, thus providing useful inputs to spatially explicit bioenergetic models. Measurement of production rates of the lower trophic levels used by salmon are also lacking and, presently such rates can be approximated only by using models. Comparisons should be made of estuarine dynamics, diet, and food consumption for the same salmon species in estuaries along a latitudinal gradient. In coastal environments, the importance of meso-scale features such as riverine plumes, eddies, and coastal jets, relative to the coastal ocean as a whole needs to be assessed. This will require detailed comparisons of the distribution patterns and growth of juvenile salmon, their predators, and prey between these features and at reference sites.
- Atmospheric and Oceanographic Processes that affect Salmon Production and Survival - Variability in atmospheric and oceanographic processes is clearly important in the interannual and inter-decadal differences observed in salmon id survival and production These processes operate at several scales, but our ability to detect the dynamic relationships is hindered mainly by the dearth of appropriate biological information. Environmental data useful for fisheries research and management is readily available and their relationships to salmon survival need to be extended to include new populations and additional potential explanatory variables as more biological data become available. Relationships using only one physical variable often degenerate over time and we need to go beyond correlations to determine how the environment affects salmon through impacts on food resources or predator distributions. The variables examined should be at the appropriate scale and affect the relevant phases of salmon life history.
- The role of toxics and water quality in salmon health and survival - Accumulation of toxics and altered water quality(eg. temperature) in the lower Columbia River and estuary is now being recognized a major source of concern. Characterizing the impact of altered water quality will likely be important in understanding survival of salmon in the estuarine, plume and ocean habitats. Efforts to monitor contaminants in salmon and their prey should be pursued with complimentary studies on biological effects of contaminants.

- Assess the role of disease in estuarine, plume, and ocean survival - Among the critical uncertainties in the life cycle of salmon is our lack of information on the impacts that pathogens have on the survival of fish during their transition to saltwater and of their role in the delayed mortality that occurs in the ocean. Pathogens of special concern in the Columbia River Basin the agent causing bacterial kidney disease, furunculosis, the virus that causes infectious pancreatic necrosis, and the agents that cause whirling disease Infection by these pathogens likely affect the ability of fish to physiologically adapt to sea water, and decreases their resistance to a common, ubiquitous saltwater pathogen, *Vibrio anguillarum*. Such studies would also provide critical information to understand the role of disease in affecting survival and for models developed to analyze survival of populations in the ocean.

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