Technical Report 2006-06

Juvenile Pacific Salmon in Puget Sound

Prepared in support of the Puget Sound Nearshore Partnership

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Valued Ecosystem Components Report Series

Puget Sound Nearshore Partnership

Restoring our ecosystem health

The Puget Sound Nearshore Partnership (PSNP) has developed a list of valued ecosystem components (VECs). The list of VECs is meant to represent a cross-section of organisms and physical structures that occupy and interact with the physical processes found in the nearshore. The VECs will help PSNP frame the symptoms of declining Puget Sound nearshore ecosystem integrity, explain how ecosystem processes are linked to ecosystem outputs, and describe the potential benefits of proposed actions in terms that make sense to the broader community. A series of "white papers" was developed that describes each of the VECs. Following is the list of published papers in the series. All papers are available at *www.pugetsoundnearshore.org.*

Brennan, J.S. 2007. Marine Riparian Vegetation Communities of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-02. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Buchanan, J.B. 2006. Nearshore Birds in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Eissinger, A.M. 2007. Great Blue Herons in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Leschine, T.M. and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Front cover: Juvenile Chinook salmon (courtesy of University of Washington).

Back cover: Juvenile chum salmon, left (courtesy of Steve Schroder); juvenile Chinook salmon, right (courtesy of Roger Tabor).

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The Puget Sound Nearshore Partnership Steering Committee initiated the concept of this paper and the others in this series. The Nearshore Partnership Project Management Team (PMT) — Tim Smith, Bernie Hargrave, Curtis Tanner and Fred Goetz — oversaw production of the papers. The Nearshore Science Team (NST) played a number of roles: they helped develop conceptual models for each valued ecosystem component (VEC), in collaboration with the authors; individual members were reviewers for selected papers; and members were also authors, including Megan Dethier, Tom Mumford, Tom Leschine and Kurt Fresh. Other NST members involved were Si Simenstad, Hugh Shipman, Doug Myers, Miles Logsdon, Randy Shuman, Curtis Tanner and Fred Goetz.

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Executive Summary

Puget Sound salmon (genus *Oncorhynchus*) spawn in freshwater and feed, grow and mature in marine waters. During their transition from freshwater to saltwater, juvenile salmon occupy nearshore ecosystems in Puget Sound. This period of nearshore residence is critical to the viability, persistence and abundance of Puget Sound salmon. Thus, restoring and protecting nearshore habitats important to juvenile salmon must be a part of efforts to rebuild depleted salmon runs throughout this region. The primary objective of this report is to summarize what we know about salmon use of nearshore habitats to help protect and restore these habitats.

Five species of Pacific salmon spawn and rear in Puget Sound. Use of nearshore ecosystems varies considerably between and within species. The concept that not all salmon use nearshore ecosystems in the same way is fundamental to the planning, implementation and monitoring of protection and restoration actions directed at salmon. This report focuses on naturally produced juvenile Chinook salmon and juvenile chum salmon, because these two species make the most extensive use of nearshore habitats.

For each species of salmon, use of nearshore habitats varies with scale. Two important scales of variation in habitat use are population (i.e., within species) and life history strategy (i.e., within population). Populations are subspecies units that refer to geographically discrete, semi-isolated breeding units of salmon. Populations differ in their use of nearshore habitats because of the specific conditions (e.g., differences in flow regimes, temperature regimes and migration distances) each encounters.

Populations are aggregated by the National Oceanic and Atmospheric Administration (NOAA) Fisheries into groups called Evolutionarily Significant Units (ESUs) that are used to make decisions about status under the Endangered Species Act (ESA). Two groups of Puget Sound salmon populations were listed as threatened under the ESA. The 22 populations of Chinook salmon spawning within Puget Sound east of the Elwha River were grouped into one ESU and listed as threatened in 1999. In addition, two populations (consisting of eight sub-populations) of chum salmon spawning in Hood Canal and the eastern Strait of Juan de Fuca during the summer and early fall (termed summer chum) were also grouped into an ESU and listed as threatened in 1999.

The second scale of variability important to understanding juvenile salmon use of nearshore ecosystems is the life history strategy of the fish. Individuals within a population vary in habitat use, based upon such factors as where they come from within the watershed, spawning timing, climate and abundance. Although life history variation occurs along a continuum, individuals within a salmon population can be aggregated into a more discrete number of life history strategies. In Puget Sound, juvenile Chinook salmon have been aggregated into four general life history strategies, referred to as migrant fry, delta fry migrants, parr migrants, and yearlings, based upon when the fish leave freshwater and their size at this time.

The first juvenile Chinook salmon to arrive in estuaries are fry (< 50 mm fork length [FL]), which enter natal deltas between December and April. Some of the fry pass quickly through the natal delta (the migrant fry strategy) and enter Puget Sound, spending only days in natal deltas. Other fry (the delta fry strategy) remain in natal deltas for extended periods of up to 120 days, where they make extensive use of small (1st or 2nd order), dendritic tidal channels (channels that end in the upper end of the marsh) and sloughs in tidal wetlands.

During the late spring, fish associated with two other life history strategies (parr migrant and yearling) leave freshwater rearing habitats and migrate downstream to the estuary. Most parr migrants and yearlings arrive in the delta from May to mid-July. Residence time and migration timing from the natal delta into Puget Sound habitats are a function of a number of factors. In particular, with the exception of the migrant fry strategy, fish size at the time the fish arrive in the delta and residence time in the delta tend to be inversely related. Environmental conditions, especially increasing water temperatures, may also be an important determinant of when juvenile Chinook salmon leave delta habitats.

Once juvenile Chinook salmon leave estuarine/delta habitats and enter Puget Sound, they distribute widely throughout nearshore ecosystems. Their abundance in shoreline areas of Puget Sound typically peaks in June and July, although some are still present in shoreline habitats through at least October. As the fish increase in size, the depth of the water and diversity of habitats they use change. Optimal conditions for smaller juvenile Chinook salmon (< 70 mm) in estuarine areas appear to be low gradient, shallow water, fine-grained substrates (silts and mud), low salinity, and low wave energy. As they grow, juvenile Chinook salmon use a greater diversity of Puget Sound habitats including deeper, more offshore habitats, and eventually, most fish leave for North Pacific Ocean feeding grounds.

Within Puget Sound watersheds, we have not yet identified discrete life history strategies for chum salmon populations. Most chum salmon fry leave freshwater within one or two days of emergence, which can occur as early as December. These early emerging fish are likely summer run chum salmon, with later emerging members belonging to other races. Most available information on chum salmon does not distinguish use based upon race (i.e., it is not specific to summer chum salmon). The timing of when chum salmon enter nearshore ecosystems should affect some aspects of habitat use such as diet, residence time, growth rates and so on, simply because the condition of nearshore ecosystems is not the same for early and late migrants.

Chum salmon fry can either pass directly through natal estuaries into Puget Sound, or they can rear for weeks in estuarine habitats before moving into shoreline areas. Juvenile chum salmon often occur in non-natal estuaries. Migration rates of chum salmon in nearshore areas depend upon such factors as fish size, foraging success and environmental conditions (currents). Habitat use appears to be strongly size dependent. Small chum salmon fry (< 50-60 mm) tend to migrate along the shoreline in shallow water, < 2 meters in depth. As chum salmon fry increase in size to more than 60 mm, they expand the habitats they use to include nearshore surface waters. Chum salmon abundance in nearshore areas peaks in May and June. Abundance after June declines significantly as chum salmon move farther offshore and migrate out of Puget Sound, although some are still found in nearshore areas through October.

The ability of nearshore ecosystems to support or promote salmon population viability is a function of the biological, physical and chemical characteristics of the habitats used by juvenile salmon. Habitat function depends upon both local attributes and the context of that habitat within the bigger picture of its surrounding larger ecological systems (referred to as landscape attributes); landscape attributes include the arrangement of habitats, habitat shape, location and connectivity. The ability of nearshore habitats to support salmon population viability is a function of how well the habitat supports: 1) feeding and growth, 2) avoidance of predators, 3) the physiological transition from freshwater to saltwater, and 4) migration to ocean feeding habitats. In general, our ability to quantitatively or conceptually link nearshore habitat characteristics to functions of that habitat for juvenile salmon (i.e., salmon performance) varies considerably with species and habitat type. This reflects the complexity of the salmon life cycle and the fact that the habitat requirements of salmon can vary broadly as a function of many factors, including specific location of the habitat, time of year, species, population, size of salmon, and life history strategy. For example, our ability to link nearshore habitat characteristics to functions that support juvenile Chinook salmon is strongest in natal deltas and weakest along shorelines.

Humans can impact the functioning of nearshore habitats for juvenile salmon in many ways. A Conceptual Model developed by the Nearshore Science Team (Simenstad et al. 2006) was used to explore the relationships between human actions (including restoration actions), ecosystem processes, habitat and function (in this case support of juvenile salmon). Lessons learned from applying this conceptual model to several scenarios involving juvenile salmon revealed that a scenario needs to be created that answers a number of questions:

1. What species, life history strategy, and size class is being considered?
2. What habitat type is being affected (e.g., eelgrass bed vs. tidal channel)?
3. Where in Puget Sound is the action occurring?
4. What type of action is being considered (e.g., dike breaching vs. armoring)?
5. What constraints, such as geomorphologic context, exist?

If such scenarios can be devised, then we can more directly explore how an action may affect salmon population viability, identify possible outcomes of an action, define key uncertainties, and help assess potential risks.

Preface

Of the many organisms that inhabit the Puget Sound, Pacific salmon are the species most identifiable with this region. They have been important to the culture, economy, commerce, and way of life of people of the region for thousands of years. As early as people walked this land, salmon was undoubtedly an important food source because of its abundance and wide distribution. The return of the salmon to streams was a cause of celebration and ceremony by native peoples, because it meant a major source of food had been renewed for yet another year. Salmon was also an important symbol that was regularly incorporated into regional art.

To the Europeans that settled in this area, salmon rapidly became important as a food source and a major economic force that was commercially and recreationally harvested. Puget Sound salmon were caught and continue to be caught by a plethora of commercial fisheries in all marine waters of the state. Salmon are commercially harvested by native peoples, and non-Indians as well. Commercial fisheries for salmon support many jobs involved in the catching, marketing, and sales of salmon and are a major source of income for many Native American tribes of the Pacific Northwest.

In addition to being good to eat, salmon are fun to catch with a hook and line. This has resulted in a robust recreational industry for salmon throughout Puget Sound and the Washington coast. People come from all over the world to catch Puget Sound salmon. For example, when the sockeye salmon fishery in Lake Washington is open, thousands of boats can be counted on the water of this one urban lake, all fishing for sockeye salmon. Like commercial fishing, recreational fishing has economic benefits that go beyond simply the angler. Fisherman must buy tackle, boats and other equipment, stay in hotels, and drive to where they will fish. Many communities, especially along the coast of Washington, have been largely supported by commercial and recreational salmon fishing.

Other, non-consumptive uses of salmon have developed as well. For example, many people simply enjoy viewing salmon as they migrate through such places as the Ballard Locks and spawn in the Cedar River near Seattle. In the Skagit River, people boat the river simply to watch the eagles feed on the chum salmon that have returned to spawn. Salmon have become a vehicle to educate children about nature and the place they live.

As our commercial and recreational use of the salmon resource expanded, our need to learn more about this creature increased. We now know much about the ecological significance of salmon. Many scientists regard salmon as a keystone species and an indicator of the condition of many of our northwest ecosystems. At any one time, salmon occupy multiple trophic levels in the Puget Sound food web and are critical to the movement of nutrients and organic matter in and around Puget Sound. At the same time of year, some Chinook salmon are eating insects in a marsh, some are eating small fish in shoreline areas, and some are eating even larger fish. In addition, Chinook salmon are eaten by hundreds of other species that inhabit Puget Sound and its watersheds. For example, sub-adults and adults are eaten by orcas, and the condition of Chinook populations is critical to the status of some orca populations in this region (Kriete, 2007). In recent years, we have also discovered that salmon move nutrients from marine waters to freshwater, helping sustain these freshwater ecosystems. Salmon carcasses act as fertilizer for vegetation around streams and lakes and are used directly or indirectly as food by rearing juvenile salmon. Thus, the condition of succeeding generations of some salmon populations depends upon abundance levels of returning adults.

Introduction

Puget Sound salmon (genus *Oncorhynchus)* are anadromous, meaning that they spawn in freshwater and feed, grow, and mature in marine waters. Five species of Pacific salmon use the nearshore ecosystems of Puget Sound — Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), sockeye (*O. nerka*). Because Pacific salmon are anadromous, they occupy a landscape of thousands of square miles that ranges from the mountainous, snow-fed streams, where the fish spawn, to the vast, open Pacific Ocean, where they feed and grow.

Thus, the condition of salmon populations does not depend upon use of a single habitat type but rather upon the full range of habitats available to the fish during their entire life cycle (Bottom et al. 2005b), including habitats associated with nearshore ecosystems. A growing body of evidence demonstrates that the time salmon spend in nearshore ecosystems and the quantity and quality of nearshore habitats available are important to the viability of salmon populations (Carl and Healey 1984; MacDonald et al. 1988; Mortensen et al. 2000; Magnusson and Hilborn 2003; Greene and Beechie 2004; Bottom et al. 2005a, b; Greene et al. 2005).

Viability is a relatively new conceptual approach to Pacific salmon management that is being used by NOAA Fisheries to evaluate recovery of salmon populations. Viability refers to the ability of populations to persist over long time scales (McElhany et al. 2000) and is used to evaluate their status and condition. Viability is viewed from the perspective of extinction risk; viability increases as the risk of extinction declines. NOAA Fisheries identified four characteristics of populations that should be used to evaluate viability (McElhany et al. 2000): abundance, productivity, spatial structure and diversity. All four of these parameters are critical to the viability of salmon populations, all are interrelated, and levels of all four attributes in aggregate characterize extinction risk. For example, while the abundance levels of a population are still important, where that abundance is in space and time, and what the abundance is composed of (e.g., ages and sizes) are also important.

Along the west coast of North America, the abundance levels of many populations of Pacific salmon are at critically low levels (Nehlsen et al. 1991; Stouder et al. 1997; McClure et al. 2003). Large scale efforts to recover these populations are under way throughout the region. A growing body of evidence suggests that restoring and protecting nearshore habitats must be considered a part of efforts to rebuild salmon runs throughout this region (MacDonald et al. 1988; Magnusson and Hilborn 2003; Greene and Beechie 2004; Bottom et al. 2005b; Greene et al. 2005). The Puget Sound Technical Recovery Team recognized this body of evidence in providing technical guidance for watershed and nearshore recovery groups to develop recovery plans (available at: *www.nwfsc.noaa.gov/trt/puget/pstrtwatershedguidance.pdf*). Recovery of nearshore ecosystems is also an explicit part of salmon recovery efforts identified in the recently completed salmon recovery plan for Puget Sound (e.g., Shared Salmon Strategy 2007, available at *www.sharedsalmonstrategy.org/plan/index.htm*).

Although nearshore ecosystems are important to recovery of salmon populations, it is clear that to successfully rebuild depressed salmon populations, we must consider how they use the entire landscape available to them, and we must address the full range of problems they face over this landscape. Thus, the condition of spawning areas, other freshwater and marine rearing areas, and migratory corridors must be addressed. Fish from spawning areas must have habitats available to occupy once they emerge from the gravel and begin their long journeys to the sea and back again. How to best restore and protect nearshore habitats to support salmon recovery is (and will continue to be) an evolving process. The intent of this report is to summarize what we know about salmon use of nearshore habitats, to help protect and restore nearshore habitats.

Habitat Use

Each salmon species employs a fundamentally different approach in how it uses freshwater, marine and nearshore landscapes. For example, juvenile sockeye salmon rear extensively in lakes, coho rear for at least one year in streams, and pink and chum salmon do not rear in freshwater. The concept that salmon vary in their use of habitats is fundamental to the planning, implementation, and monitoring of protection and restoration actions directed at salmon. This document will focus primarily on habitat use and nearshore requirements of juvenile Chinook and chum salmon, because these two species make the most extensive use of nearshore habitats.

While species-specific differences in salmon habitat use have long been appreciated, our understanding of the significance of variability in habitat use at other scales (e.g., within a species) is more recent. This report focuses on two scales of variability in nearshore habitat use by juvenile salmon. The first scale of variation is the population level. Populations are geographically discrete, self-perpetuating and semi-isolated (in terms of genetic exchange) reproductive or breeding units (Rich 1939). Each population exhibits a range of meristic characteristics, behaviors and inherent capabilities that are defined by the long-term legacy of the particular set of conditions the fish experience during their life histories, including climate, instream flow conditions, temperature regimes, stream size, substrate attributes and ocean conditions. In other words, populations adapt to more effectively utilize the long-term environmental regime they experience (Waples et al. 2001). Thus, during their life histories, each population encounters different conditions that can prompt different habitat use (e.g., when the fish arrive at a particular habitat type, size at arrival, the specific habitats used, and how long they reside in a habitat). For example, juvenile salmon entering Puget Sound from the Nisqually River encounter different environmental conditions, predators, and food items than fish entering from the Nooksack River.

Groups of populations can also be aggregated or grouped into larger clusters. One approach has been to group populations into what are referred to as metapopulations, which are groups in which significant genetic exchange is occurring (Hanski and Gilpin 1996). NOAA Fisheries has used the concept of metapopulations to develop an approach for applying the Endangered Species Act (ESA) to salmon. Their approach aggregates populations into ESUs (Evolutionarily Significant Units) (Waples 1995) that are the basic units of assessment used to implement the ESA. The loss or endangerment of an ESU is considered significant to the evolutionary persistence of a species.

Another scale of variability in nearshore habitat use is the sub-population level. Variability within populations is reflected as variability or diversity in a wide variety of traits, including body size, fecundity, timing of life history events, location of spawning, residence time in various habitats, size at age, age at maturity, ocean distribution, and physiological characteristics (Healey and Heard 1984; Levings et al. 1986; Taylor 1990; Quinn and Unwin 1993; NRC 1996; Miller and Sadro 2003). Some of these traits are genetically based, others result from a combination of genetic and environmental factors, and others can result from genetic drift (Hansen and Jonsson 1991; Stearns 1992; Gharrett and Smoker 1993; Quinn et al. 2000; Waples et al. 2004; Beechie et al. 2006). Diversity can be affected by a variety of natural and anthropogenic factors, including habitat changes, harvest practices and hatchery practices (NRC 1996; Quinn et al. 2000; Cucherousset et al. 2005; Beechie et al. 2006).

Although life history variation occurs along a continuum, it is convenient from an analytical perspective to define a more limited number of discrete life history strategies (Reimers 1973; Carl and Healey 1984; Wissmar and Simenstad 1998; Beamer et al. 2005). For this report, I have adopted Beamer et al.'s (2005) life history classification scheme for Skagit River Chinook salmon, which distinguishes four strategies based upon the size of the fish at the time they emigrate from freshwater, when the fish leave freshwater, and how they rear in freshwater and nearshore habitats:

1. Fry migrants — generally spend a short time in freshwater (1-10 days) after hatching and then rapidly migrate through the natal estuary/delta into Puget Sound. As a result, these fish are less than 50 mm at the time they leave their natal freshwater system. Fry migrants rear in a diversity of habitats in the nearshore regions of Puget Sound.
2. Delta fry migrants — similar freshwater residency to fry migrants except delta fry remain in natal delta habitats to rear for extended periods (weeks to months). This life history type is also small (<50 mm) when entering the natal estuary.
3. Parr migrants — remain in freshwater and rear for up to six months before migrating to the estuary. Fish of this life history type are larger (generally > 70 mm) at the time they enter their natal estuary.
4. Yearlings — rear in freshwater for at least one year before migrating to Puget Sound. Fish from this life history type spend only a short period of time in natal deltas and are larger than other life history strategies at the time they leave freshwater.

While all life history strategies appear to occur in all Puget Sound Chinook salmon populations (see Shared Strategy Salmon Recovery Plan (2007) chapters for individual watersheds), the mix or relative proportion of these strategies varies between populations and between years within populations. Most Puget Sound Chinook salmon populations are composed (on average) of the parr migrant and delta fry strategies, although several populations are predominantly yearlings. The distribution of life history strategies reflects variability in the relative survivals between the ocean (fry and parr) and stream type (yearlings) components within the population. Although chum salmon populations can be disaggregated into different life history strategies, such an analysis has not been conducted. Accordingly, discussions of nearshore habitat use by juvenile chum salmon will focus on the racial and ESU scales.

The focus of this report is on use of the nearshore ecosystems by naturally produced juvenile Chinook and chum salmon. Our understanding of how these two species use nearshore ecosystems has been shaped by two important factors. First, hatchery fish have been used for more than 100 years to supplement and enhance native populations and mitigate for habitat loss. In addition to being a cause of the decline of some populations, hatchery-produced fish likely differ from natural fish in how they use nearshore ecosystems (Fresh 1997). Because our ability to distinguish naturally-produced and hatchery-produced fish in the field has been limited until recently, much of what we have learned about salmon may apply primarily to hatchery fish and not wild fish. Second, our understanding of salmon habitat use has been shaped by the condition of the habitats we are studying and the populations that use them. For example, the distribution and quality of habitats that can potentially be used will be a major factor affecting the number and type of life history strategies present within a population (NRC 1996). If the habitats do not exist or have been significantly altered because of either natural or anthropogenic factors, then population members cannot use them, and distinct life history strategies can potentially be eliminated from the population (Bottom et al. 2005b).

Chinook Salmon

The time and size of migration from freshwater primarily determines the different ways in which each life history strategy uses nearshore habitats. Chinook salmon emerge from incubation gravels from approximately December to April. Upon emergence, fry can vary widely in how long they stay in freshwater and where they are found. Juvenile Chinook salmon enter natal deltas from December to at least September. The timing of estuarine entry depends upon such factors as population of origin, life history strategy, where spawning occurred (e.g., a headwater stream versus a mainstem stream), when the eggs were deposited, flow levels, oxygen levels, and water temperature.

The first juveniles that arrive in the natal estuary are fry (< 50 mm). Fry can adopt one of two general behaviors. First, some pass directly through the natal delta (the migrant fry strategy) and enter Puget Sound, spending only days in natal deltas. These fish then rear throughout the nearshore regions of Puget Sound before leaving Puget Sound. One of the habitats that migrant fry use are the connected lagoons and small stream mouths along the shore of Puget Sound. These types of systems are referred to as "pocket estuaries" (Beamer et al. 2003). Densities of migrant fry in pocket estuaries in winter and early spring are typically greater than in adjacent nearshore intertidal habitats, suggesting that these habitats are important to this life history strategy (Beamer et al. 2005). Wind and tidal currents probably play a major role in distributing fry migrants from the natal delta to shoreline areas where they can encounter pocket estuaries.

Second, some fry remain in natal deltas (the delta fry strategy) where they rear for extended periods of up to 120 days (e.g., Simenstad et al. 1982; Beamer et al. 2005). Fry are distributed within deltas by a combination of tidal and fluvial processes, which depend upon the fundamental form and geomorphology of each system and such factors as river outflow and tidal prism. Small (1st or 2nd order), dendritic tidal channels (channels that end in the upper end of the marsh) found in wetland areas and sloughs in all zones of the estuary are important rearing habitats for Chinook salmon fry (Healey 1980; Congleton et al. 1981; Levy and Northcote 1982; Levings et al. 1986, 1991; MacDonald et al. 1987; Shreffler et al. 1990; Miller and Simenstad 1997; Gray et al. 2002; Beamer et al. 2005). However, because many of these tidal channel networks dewater at lower tides, availability and characteristics of low tide refuges are also important factors for these fish in deltas.

During the late spring, parr migrants and yearlings leave freshwater rearing habitats and migrate downstream to the estuary. Arrival of parr migrants in the delta generally is from May to mid-July, although small numbers of parr can be found migrating downstream throughout most of the summer in some years (D. Seiler, Washington State Department of Fish and Wildlife, pers. comm.). In the estuary, migrant parr and yearlings mix with delta fry. Residence time of juvenile Chinook salmon in natal deltas, and when the fish leave these systems, is a function of a number of factors. In particular, fish size at the time they arrive in the delta and residence time in the delta are inversely related (Healey 1980, 1982). Thus, the delta fry strategy has the longest residence time in the delta, and yearlings the shortest. Environmental conditions, especially water temperatures, may also be an important determinant of how long Chinook salmon stay in delta habitats. Water temperatures in delta habitats, especially the shallow water areas associated with the dendritic channel systems, will eventually warm to more than 15° C in most years. As temperatures increase beyond this level, they become increasingly stressful to the fish and affect habitat use (e.g., fish may avoid use of the tidal marsh systems and instead use deeper refuge areas in larger channels or leave the delta altogether).

Once juvenile Chinook salmon leave estuarine/delta habitats and enter Puget Sound, they distribute widely and probably can be found along all stretches of shoreline at some point during the year. Recent data from coded wire tag recoveries of hatchery juvenile Chinook salmon (Brennan et al. 2004; Fresh et al. 2006) suggest that some fish from each population may distribute broadly within Puget Sound before leaving. Juvenile Chinook salmon abundance in shoreline areas of Puget Sound typically peaks in June and July (Stober and Salo 1973; Fresh et al. 1979), although some are present in shoreline habitats through October (Stober and Salo 1973; Fresh 1979; Fresh et al. 2006). Once in Puget Sound, different life history strategies and populations mix. At this time, we do not know if habitat use in Puget Sound differs among life history strategies (other than pocket estuary use by migrant fry). It is probable that Chinook salmon juveniles of a similar size occurring in the same place at the same time use the available habitat in the same way and have similar growth rates and diet, regardless of their origin or life history strategy.

As juvenile Chinook salmon grow and increase in size, the depth of the water and diversity of habitats they use expand (Healey 1980, 1982; Levy and Northcote 1982; Simenstad et al. 1982; Levings et al. 1986; Duffy 2003; Miller and Sadro 2003). Optimal conditions for smaller juvenile Chinook salmon (< 70 mm) in estuarine areas appear to be low gradient, shallow water, fine-grained substrates (silts and mud), low salinity, and low wave energy (Healey 1980; Levings et al. 1986; Simenstad 2000). With increasing size, juvenile Chinook salmon move into deeper, more offshore habitats. It is not clear whether they change habitats abruptly (e.g., at a transitional size) or more gradually (e.g., they simply increase the amount of time they spend in a broader array of habitats).

Chum Salmon

Within Puget Sound watersheds, most chum salmon fry leave fresh water within one or two days of emergence, so emergence timing provides an accurate estimate of timing of estuarine entry (Salo 1991). Chum salmon fry begin emerging in December. Early emerging chum salmon are likely summer-run fish (adults enter freshwater in summer and early fall), with later emerging members belonging to other races (fall and winter), although the division between emergence of summer and fall chum salmon fry is still unclear. Although we know a lot about use of Hood Canal nearshore habitats by juvenile chum salmon, most available information does not distinguish use based upon race (i.e., it is not specific to summer chum salmon). We should expect the timing of chum salmon entry into nearshore ecosystems to affect some aspects of habitat use, such as diet, residence time, and growth rates, because the condition of nearshore ecosystems is not the same for early and late migrants (Simenstad et al. 1980).

Studies in Hood Canal and elsewhere (e.g., Snohomish River estuary) demonstrate that chum salmon fry either pass directly through natal estuaries into Puget Sound or rear for weeks in estuarine habitats before moving into shoreline areas (Stober and Salo 1973; Healey 1979; Salo et al. 1980; Levy and Northcote 1982; Simenstad et al. 1982). Dispersal of fish from natal estuaries probably depends upon a number of factors such as geomorphology of the estuary, freshwater outflow, and water circulation patterns within the receiving environment (e.g., Hood Canal). As with Chinook salmon, juvenile chum salmon can distribute widely from natal estuaries (Bax 1983) and occupy non-natal estuaries during their migration from Puget Sound (E. Beamer, pers. comm., Skagit River System Cooperative). For example, Bax (1983) found that at least 25 percent of hatchery chum salmon juveniles that were released north of the Skokomish River moved back onto the Skokomish delta and were still present there four days after release.

Migration rates of chum salmon in nearshore areas are variable and depend upon fish size, foraging success, and environmental conditions (currents and prevailing winds). Small chum salmon fry (< 50-60 mm) appear to migrate primarily along the shoreline in shallow water less than 2 meters in depth (Healey 1979; Simenstad et al. 1982). Use of shallow water habitats relates to predator avoidance and prey availability. When present in shallow water habitats, juvenile chum salmon less than 60 mm consume primarily epibenthic invertebrates, particularly harpacticoid copepods and gammarid amphipods. These epibenthic prey are primarily associated with protected, fine-grained substrates and often eelgrass (Healey 1979; Simenstad et al. 1982) and are especially abundant early in the year in some locations (e.g.; Thom et al. 1989). This suggests that these habitat types are especially important to small, early migrating chum salmon, some of which are presumably summer chum salmon. As chum salmon fry increase in size to more than 60 mm, their habitat use expands to include neritic or nearshore surface waters, possibly to take advantage of alternate prey resources found in these habitats (e.g., Healey 1979; Healey 1982; Simenstad et al. 1982; Simenstad and Wissmar 1985).

Chum salmon abundance in nearshore areas peaks in May and June, when chum salmon juveniles can be found distributed widely throughout Puget Sound (e.g., Fresh et al. 1979; Salo et al. 1980; Duffy 2003; Brennan et al. 2004; Fresh et al. 2006). Abundance after June declines significantly as chum salmon move further offshore and migrate out of Puget Sound. Small numbers of juvenile chum salmon are, however, still found in nearshore areas until at least October (Fresh et al. 2006).

Nearshore Habitat Requirements of Juvenile Salmon

The ability of nearshore ecosystems to support or promote salmon population viability is a function of the biological, physical and chemical characteristics of the habitats used by the juvenile salmon. These habitat characteristics or attributes can be evaluated at multiple spatial and temporal scales. Historically, nearshore habitats have been viewed primarily at site or patch scales (e.g., area of a marsh, substrate composition, and channel depth). In recent years, the concepts of landscape ecology (e.g., Turner 1989) have been increasingly applied to evaluating salmon habitat (Simenstad 2000; Simenstad et al. 2000; Hood 2002). A landscape view proposes that the function of any unit of habitat depends upon both its local attributes and its context within the bigger picture of the surrounding habitat, including such things as the arrangement of habitats and habitat shape, location, and connectivity to other habitats. An example of the effect of one landscape factor is connectivity. Beamer et al. (2005) suggested that connectivity of habitat, or the length, condition and complexity of pathways fish followed among habitats, affected their importance to juvenile Chinook salmon. For instance, juvenile Chinook salmon were less abundant in dendritic tidal channel systems as distance from the main distributary channels increased.

Fundamentally, the level of habitat function depends upon the accessibility and quality of the habitat. Accessibility of habitat relates to the ability of the fish to find and then use it. Simenstad (2000) and Simenstad and Cordell (2000) used the term "opportunity" to refer to habitat attributes that affect the ability of juvenile salmon to access habitat. Examples of opportunity attributes include tidal elevation, hydrodynamic processes that disperse fish, and temperature (Bottom et al. 2005a) (Table 1). Habitat quality, or what Simenstad (2000) and Simenstad and Cordell (2000) refer to as habitat "capacity", refers to attributes that affect the ability of the habitat to support fish once they have accessed it (Simenstad and Cordell 2000). Examples of capacity attributes include predator population sizes, prey production and prey availability (Table 1). In simple terms, opportunity attributes affect whether the capacity attributes of the habitats (e.g., food) are available to the fish. The concepts of opportunity and capacity are useful to consider, since they can help guide decisions about what types of restoration are needed (e.g., fixing access, increasing capacity, or both). Table 1 lists some of the characteristics of habitat that I believe are important in recovery planning, the scale at which they operate, and whether they affect capacity, opportunity or both. For example, high temperatures can prevent juvenile salmon from occupying a particular habitat (opportunity), while more moderate temperatures affect bioenergetics of the fish (capacity).

The function of any unit of habitat for juvenile salmon reflects how well all the attributes associated with that habitat affect population viability. From the perspective of an individual fish, the ultimate measure of function is how well occupation of that habitat helps the fish survive and successfully pass on its genetic material (i.e., fitness). Physiological and behavioral measures of how habitat is functioning are related to how well the habitat supports: 1) feeding and growth, 2) avoidance of predators, 3) the physiological transition from freshwater-to-saltwater, and 4) migration to ocean feeding habitats (Simenstad et al. 1982; Simenstad and Cordell 2000).

Feeding and Growth

Juvenile salmon feed in all habitats that they occupy and use prey that originate from a wide diversity of sources including pelagic, benthic, and terrestrial sources (Fresh et al. 1981; Healey 1982; Simenstad et al. 1982; Brennan et al. 2004; Duffy et al. 2005). This abundant and diverse prey base helps supports high growth rates during use of nearshore ecosystems (Simenstad et al. 1982). Prey originate from a complex series of interactions that involve the acquisition, processing and conversion of organic matter and nutrients into prey that can be eaten by juvenile salmon. Nearshore food webs are noteworthy in that they support abundant prey types that are especially important to small juvenile salmon and because they depend upon internally-derived (i.e., from nearshore habitats) sources of organic matter (e.g., eelgrass) (Sibert et al. 1977). A variety of factors affect feeding and growth, including habitat characteristics, fish size, temperature, turbidity, tidal convergence zones, time of year and climate (e.g., Simenstad et al. 1980; Fresh et al. 1981; Gregory 1994).

Refuge from Predation

Salmon are preyed on by a wide variety of fish, birds and mammals during their nearshore residence (Parker 1971; Fresh 1997). Simenstad et al. (1982) suggested that some features of nearshore ecosystems may help reduce predation on juvenile salmon. These include high levels of turbidity, presence of shallow water habitat, and abundant and diverse prey resources that sustain high growth rates and allow juvenile salmon to rapidly outgrow many of their predators. Several studies have found that turbidity can reduce visibility of salmon juveniles to predators (Gregory 1993; Gregory and Levings 1998).

Physiological Transition

As juvenile salmon leave freshwater, they must physiologically change from an animal adapted to freshwater (parr) to one that is adapted to seawater (smolt). This means the fish must be able to osmoregulate in saltwater, where conditions are clearly much different from what they left in freshwater. Smoltification is the term used to describe juvenile

Table 1. Nearshore habitat attributes important to juvenile salmon, the scale at which each attribute operates, and whether they affect capacity, opportunity, or both. The table is not intended to be comprehensive but rather to illustrate types of attributes important in recovery planning. Further, where data existed, or a strong conceptual linkage could be made, attributes were included that explicitly linked habitat to juvenile salmon performance.

Habitat		**Scale**		**Type of Attribute**	
Type	Attribute	Local	Landscape	Opportunity	Capacity
Water Characteristics					
	Temperature	●		●	●
	Salinity	●	●	●	
	River flow	●	●	●	
	Diss. Oxy	●		●	●
	Tidal Currents	●	●	●	
	Turbidity	●		●	●
Physical Characteristics					
	Sediment Comp.	●			●
	Sediment Depth	●			●
	Water Depth	●		●	
	Habitat Size		●		●
	Shape		●		●
	Connectivity	●	●		●
	Water Volume	●		●	
	Drainage Area		●	●	
	Vegetation Composition	●	●		●
	Vegetation Height	●			●
Biological Characteristics					
	Prey Abundance	●	●		●
	Prey Composition	●	●		●
	Predator Abundance	●			●
	Exotic Species	●			●

salmonids that are undergoing the various shifts in enzyme functions, behavior, appearance, and physiology as they transition to saltwater conditions (Wedemeyer et al. 1980; Clarke and Hirano 1995). Factors that influence the rate and timing of smoltification in salmon include species, fish size, photoperiod, lunar cycles, water temperature, and fish condition (Wedemeyer et al. 1980; Clarke and Hirano 1995; DeVries et al. 2004).

Part of the smoltification process occurs in nearshore ecosystems. It is possible that habitat use in nearshore ecosystems is driven, at least in part, by physiological needs, especially salinity regimes. Because salinity patterns are most complex in estuary/delta habitats, it seems reasonable to hypothesize that these habitats are critical for the physiological transition of some salmon species and life history strategies (Schroder and Fresh 1992). However, the importance of particular habitats to smoltification will vary with species, size and life history strategy. For example, chum salmon fry are able to adjust almost immediately to saltwater, regardless of when and where they leave freshwater (Iwata 1982). The broad range in size and timing of estuarine entry by juvenile Chinook salmon suggests that there are differences in how each life history strategy smolts. In the case of migrant fry, smoltification and osmoregulatory transition probably occur in nearshore areas of Puget Sound, since the fish pass rapidly through natal deltas. For yearlings, on the other hand, much of the parr-to-smolt transformation occurs in freshwater and Puget Sound, because their residence time in the natal delta is very short.

Migratory Pathway

Except for a few landlocked populations, salmon are a migratory animal through their entire life history (i.e., they migrate virtually continually from freshwater spawning areas to ocean feeding grounds and back again). Their survival depends upon their ability to occupy and move among freshwater, nearshore, and marine habitats. Thus, the integrity of nearshore habitats as a whole will have a profound effect upon the ability of salmon to journey to and from ocean feeding areas. Migratory behavior is complex (i.e., fish do not always take the most direct pathways) and varies among and within populations of the same species. For example, recovery of coded-wire-tagged hatchery juvenile Chinook salmon suggests that most fish using nearshore ecosystems of Puget Sound are from Puget Sound (Duffy 2003; Brennan et al. 2004; Fresh et al. 2006). In addition, fish from many populations distribute widely upon entering Puget Sound, and some fish from outside the region (e.g., from Canada) also enter Puget Sound (Duffy 2003; Brennan et al. 2004; Fresh et al. 2006). Simenstad (2000) suggested that salmon recovery should emphasize corridors and linkages (i.e., connectivity) among habitats at all scales.

Linking Salmon Performance and Habitat Characteristics

In general, our ability to quantitatively or conceptually link nearshore habitat characteristics to functions of that habitat for juvenile salmon (i.e., salmon performance) varies considerably with species and habitat type. This in part reflects the complexity of the salmon life cycle and the fact that the habitat requirements of salmon can vary broadly as a function of many factors, including specific location of that habitat, time of year, species, population, size of salmon and life history strategy. This is different from many of the other nearshore species that have fairly specific habitat requirements (e.g., substrate requirements for clams, kelps, and eelgrass). Thus, the substrate types needed by salmon fry in an estuary will be different from the substrate types needed by larger fingerling salmon associated with a shoreline area.

I believe our ability to link nearshore habitat characteristics to functions of that habitat to support juvenile salmon (i.e., salmon performance) is strongest in natal deltas. We know that variability in habitat attributes in deltas, especially a number of features of small tidal channels, can be directly related to viability of salmon populations (e.g., Beamer et al. 2005). For example, Beamer et al. (2005) provided evidence that tidal channel networks that had high connectivity (closest to main migratory routes) and were the most accessible throughout the greatest tidal range were used by the greatest number of juvenile Chinook salmon. In contrast to the natal deltas, we have a poor understanding of how juvenile Chinook salmon use littoral habitats along the shoreline. We lack very basic information about what shoreline habitats are used, how long fish are there, how they get there (the role of hydrodynamic processes versus fish behavior), differences in habitat use among populations, life history strategies, competition and predation, and other ecological issues. One exception is emerging information about the functions of pocket estuaries for Chinook salmon (Beamer et al. 2003; 2005). Pocket estuaries that are the most highly connected to the natal deltas (e.g., within one day's swim of the main delta) may be important habitats for the migrant fry strategy.

We also know much about the migration of juvenile chum salmon along shorelines, based primarily upon studies from Hood Canal (e.g., Salo et al. 1980; Bax 1983). We understand that there are strong linkages between juvenile chum salmon and specific prey communities associated with particular types of littoral habitats such as eelgrass beds (Simenstad and Wissmar 1985; Simenstad et al. 1988). As a result, the distribution and landscape configuration of eelgrass may have an important influence on performance of chum salmon fry. Similar to juvenile Chinook salmon, chum salmon also make extensive use of non-natal deltas (Bax 1983). In contrast to Chinook salmon, however, our understanding of how juvenile chum salmon use natal deltas (e.g., factors affecting retention, residence time) is limited to only a few systems (e.g., Nanaimo and Fraser rivers).

Distribution, Status and Trends

Distribution

Along the West Coast of North America, Chinook salmon spawn primarily in large river systems, such as the Sacramento, Columbia and Fraser rivers, from the Salinas River in California to the Canadian Arctic (Healey 1991). Within Puget Sound, most Chinook salmon spawn in the 12 largest watersheds, although spawning also occurs in smaller tributaries in some areas such as south Puget Sound (Myers et al. 1998).

Chum salmon spawn on both sides of the Pacific Ocean (Salo 1991) in river systems of all sizes, ranging from large mainstem rivers (e.g., Fraser and Skagit) to unnamed seasonal creeks; chum salmon occasionally spawn in tidally influenced portions of some streams. Within Puget Sound, chum salmon can be divided into three types (or clusters of populations) based upon timing of entry into freshwater and spawning. Although there is some overlap in spawning timing among the three groups, summer-run chum salmon spawn primarily in August and September, normal or fall-run chum spawn from October to December, and winter or late-run chum spawn from January to March. Fall populations represent the great majority of the chum salmon in Puget Sound.

Status and Trends

In 1991, Willa Nehlsen and colleagues published a comprehensive analysis of the status and trends of salmonid populations in the Pacific Northwest, including the Puget Sound region (Nehlsen et al. 1991). They concluded that more than 180 populations of salmon and steelhead had been extirpated in the Pacific Northwest (Washington, Oregon and Idaho), and that much of the decline was due to loss and degradation of habitat. Their work represents a milestone in salmon conservation, since it drew widespread attention to the condition of salmon populations and their habitats in this region.

Since that time, a number of assessments of the status and trends of salmon in Puget Sound have been produced (e.g., Stouder et al. 1997; Knudsen et al. 2000). Of these, the landmark Salmon and Steelhead Stock Inventories (SASSI) of 1992 and 2002 (available at *www.wdfw.wa.gov/SASSI*; WDFW 1993) were especially significant (Table 2). SASSI did not explicitly evaluate population viability but rather evaluated status, primarily using metrics of abundance (e.g., numbers of returning adults and trends in harvest). The SASSI process rated stocks (a unit of salmon management similar to population) according to whether they were in critical condition, depressed, healthy, unknown (a determination could not be made, reflecting either lack of appropriate information or disagreement among co-managers) or not rated. Within Puget Sound, 206 stocks of all species combined were identified in 1992 (note that an effort was not made to thoroughly identify extinct stocks). A new SASSI inventory for Washington state was published in 2003 (available at *www.wdfw.wa.gov/SASSI*) that altered a number of stock definitions and stock status ratings (Table 2). For example, in the 1992 inventory, about one-third of the Chinook salmon stocks were classified as critical or depressed, while nearly two-thirds were rated as critical or depressed in the 2002 inventory (Table 2). The overall conclusions from the SASSI inventory were that there were critical and depressed stocks spread among the six salmonid species, but that as a group, Chinook salmon were in the worst condition.

Another important assessment of the status and trends of Puget Sound salmon occurred as part of the federal government's process to decide whether some populations qualified for protection under the Endangered Species Act (ESA). Available information for each species was compiled and published in separate status review volumes: Chinook salmon (Myers et al. 1998); sockeye salmon (Gustafson et al. 1997); coho salmon (Weitkamp et al. 1995); chum salmon (Johnson et al. 1997); pink salmon (Hard et al. 1996), and steelhead trout (Busby et al. 1996). The 22 populations of Chinook salmon spawning within Puget Sound were grouped into one ESU and listed as threatened in 1999 under ESA (Table 3); one population of summer chum salmon spawning in Hood Canal and a second spawning in the eastern Strait of Juan de Fuca (comprising eight spawning aggregations) were also grouped into an ESU that qualified for federal protection under the ESA.

For each of these two threatened groups of salmon, additional information on population status is available in the recently released Salmon Recovery Plan (available at *www.sharedsalmonstrategy.org/plan/index.htm*). Also, Ruckelshaus et al. (2006) provide the assessment of the historical population structure of the Puget Sound Chinook salmon ESU that served as a technical basis for the recovery plan and describe the substantial losses of spawning aggregations and life history types that have occurred in Puget Sound. Finally, the Hood Canal Summer Chum Salmon Conservation Initiative (available at *http://wdfw.wa.gov/fish/chum/chum.htm*) provides additional technical information on the status of Hood Canal summer chum salmon. Depending upon the population, average numbers of naturally spawning Chinook salmon in the Puget Sound ESU for the last five years (Table 3) have ranged between 1 percent and 10 percent of historical levels. For the period 1994-1998, productivity, as measured by return-per-spawner was less than 1.0, or below replacement levels for one-third of the populations. For the Hood Canal summer chum salmon ESU, six of the eight extant stocks have exhibited decreasing long term trends in abundance, with returns well below replacement levels.

Table 2. Summary of the 1992 (WDFW 1993) and 2002 SASSI *(www.wdfw.wa.gov)* inventories of salmon and steelhead stocks in Puget Sound. Each value represents the number of stocks in that category. Steelhead trout are also included for comparison purposes.

Species	Assessment[1]	1992	2002
Chinook salmon	Total	29	27
	Critical	4	5
	Depressed	8	14
	Healthy	10	4
	Unknown	7	3
	Not Rated	0	1
	Extinct	0	0
Chum salmon- normal	Total	45	45
	Critical	0	0
	Depressed	0	2
	Healthy	31	30
	Unknown	14	13
	Not Rated	0	0
	Extinct	0	0
Chum salmon- summer	Total	20	20
	Critical	1	2
	Depressed	1	5
	Healthy	3	4
	Unknown	1	1
	Not Rated	13	0
	Extinct	1	8
Chum salmon- winter	Total	2	2
	Healthy	2	2
Coho salmon	Total	45	45
	Critical	1	2
	Depressed	15	6
	Healthy	20	26
	Unknown	9	11
	Not Rated	0	0
	Extinct	0	0
Sockeye salmon	Total	9	9
	Critical	1	0

Table 2 continued/

Species	Assessment[1]	1992	2002
	Depressed	4	4
	Healthy	3	4
	Unknown	1	1
	Not Rated	0	0
	Extinct	0	0
Pink salmon	Total	13	13
	Critical	2	2
	Depressed	2	4
	Healthy	8	6
	Unknown	1	1
	Not Rated	0	0
	Extinct	0	0
Steelhead trout	Total	60	60
(summer and winter)	Critical	1	1
	Depressed	14	19
	Healthy	16	8
	Unknown	29	31
	Not Rated	0	1
	Extinct	0	0

[1] Critical = Critical stocks are those that have declined to the point that the stocks are in danger of significant loss of genetic diversity or are at risk of extinction. Depressed = A depressed stock is one whose production is below expected levels, based on available habitat and natural variation in survival rates, but above where permanent damage is likely. Unknown = Insufficient information to rate stock.

Human Impacts on Juvenile Salmon in the Nearshore

Within Puget Sound, the abundance levels of many populations of Pacific salmon are at critically low levels (Nehlsen et al. 1991; Stouder et al. 1997; Knudsen et al. 2000). The concern about the downward trends in salmon populations coastwide led to status reviews, severe restrictions on harvest of salmon originating from Puget Sound, and listings of several Puget Sound ESUs as threatened. Large-scale efforts to recover these populations are now under way throughout the region. A growing body of evidence demonstrates that restoring and protecting nearshore habitats must be a part of efforts to rebuild salmon runs throughout this region (Magnusson and Hilborn 2003; Greene and Beechie 2004; Bottom et al. 2005b; Greene et al. 2005).

Humans impact the functioning of nearshore habitats used by juvenile salmon in many ways. A number of recent evaluations provide more detailed discussions of stressor effects on salmonids in nearshore ecosystems (e.g., Puget Sound Water Quality Authority [PSWQA] 2002; Puget Sound Action Team [PSAT] 2005, available at *www.psat.wa.gov/Programs/salmon_recovery/*; Shared Salmon Strategy Recovery Plan 2007). To help explore and understand how nearshore ecosystems of Puget Sound function, the Nearshore Science Team (NST) of Puget Sound Nearshore Ecosystem Restoration Project (PSNRP) developed a general conceptual model (Simenstad et al. 2006). The model can be used to explore how nearshore ecosystems respond to different types of anthropogenic actions. It can also help identify potential out-

Figure 1. General Nearshore Science Team Conceptual model applied to salmon.

Table 3. Summary of recent abundance levels of extant Puget Sound Chinook salmon populations from the Shared Strategy Salmon Recovery Plan (2007). Values are geometric mean escapements for each time period.

Population	1986-1990	2000-2004
North, Middle Fork Nooksack	140	4,252
South Fork Nooksack	243	303
Lower Skagit	2,732	2,597
Upper Skagit	8,020	12,116
Upper Cascade	226	355
Lower Sauk	888	825
Upper Sauk	720	413
Suiattle	687	409
N. Fork Stillaguamish	699	1,176
S. Fork Stillaguamish	257	205
Skykomish	3,204	4,759
Snoqualamie	907	2,446
Sammamish	388	243
Cedar	733	412
Green/Duwamish	7,966	13,172
White	73	1,417
Puyallup	1,509	1,353
Nisqually	602	1,295
Skokomish	1,630	1,479
Mid Hood Canal	87	202
Dungeness	185	532
Elwha Natural Spawners	2,055	847
Elwha Natural+Hatchery Spawners	3,887	2,384

comes of an action and key uncertainties, and assess potential risks. The model proposes that anthropogenic changes (either positive or negative) will alter ecosystem processes, which in turn will modify various attributes of habitat; changes in habitat will then have some effects on different ecosystem functions (e.g., capacity to support salmon, support of spawning by smelt and herring) (Figure 1). In the case of salmon, the functional responses of interest are growth and feeding, predator avoidance, physiological transition, and migration. How well nearshore habitats support these four functions will help define the ability of the habitat to support salmon population viability (i.e., abundance, productivity, spatial structure, and diversity), which is the ultimate consideration (Figure 1).

To apply the NST conceptual model to salmon, a scenario needs to be created that answers a number of questions including:

1. What species, life history strategy, and size class are considered?
2. What habitat type is being affected? At a minimum, this should involve asking whether a beach, embayment, delta, or rocky shore is affected.
3. Does the action affect opportunity, capacity or both?
4. Where in Puget Sound is the action occurring?
5. What type of action is being considered? This could be a restoration action or a development or a combination of actions.
6. What constraints, such as geomorphologic context, may exist?

The reason these questions need to be addressed is that the salmon response to any action affecting nearshore ecosystems will be spatially explicit, a function of the type of action, and a function of various characteristics of the fish (e.g., species and size). Table 4 summarizes some of the ways that ecosystem processes, salmon habitat, and habitat function can be affected by different types of actions.

To illustrate how the conceptual model can be used to examine impacts of an action on juvenile salmon, I applied the model to one case history example (Figure 2): how the loss of tidal marsh channels in natal deltas affects Chinook salmon. As documented by Bortelson et al. (1980) and Collins et al. (2003), all deltas associated with the major Chinook salmon spawning streams in Puget Sound have been heavily altered. Many changes have occurred in freshwater that can affect delta systems, such as alterations in hydrology due to dam construction (e.g., Skagit and Snohomish rivers), watershed changes due to loss of forest cover, and water quality changes due to urbanization. However, I only considered the effects of restoring tidal hydrology by dike breaching/removal (Figure 2). This action will affect several ecosystem processes, including tidal hydrology, sediment movements and cycling of organic matter. As a result of the dike breaching, new tidal channels will form, sediment will be deposited in the restoring marsh, and the development of a new plant community will make more organic matter and food items available. How new tidal channels develop (e.g., position, length and depth) will depend upon a number of factors, such as where and how much of the dike is removed, size of the new wetland, and where in the estuary the new wetland is located. A number of habitat attributes will change. For example, opportunity will increase by adding new habitat that was previously unavailable. This will be further influenced by connectivity of the new channels. Habitat capacity will also increase as a result of more prey (such as insects) being produced as new vegetation grows. Assuming the delta is at carrying capacity, the addition of new tidal habitat will increase the number of delta fry that can rear in the estuary, residence time of fish in the delta, and growth of fish associated with this life history strategy. Ultimately, the addition of the new tidal channels will increase population viability by altering the distribution and composition of life history strategies and increase spatial structure by creating new habitat, thereby spreading the population out in space and time. Productivity will also be strongly affected, because more salmon from one of the dominant life history strategies will survive, which in turn will affect abundance of returning adults (Beamer et al. 2005).

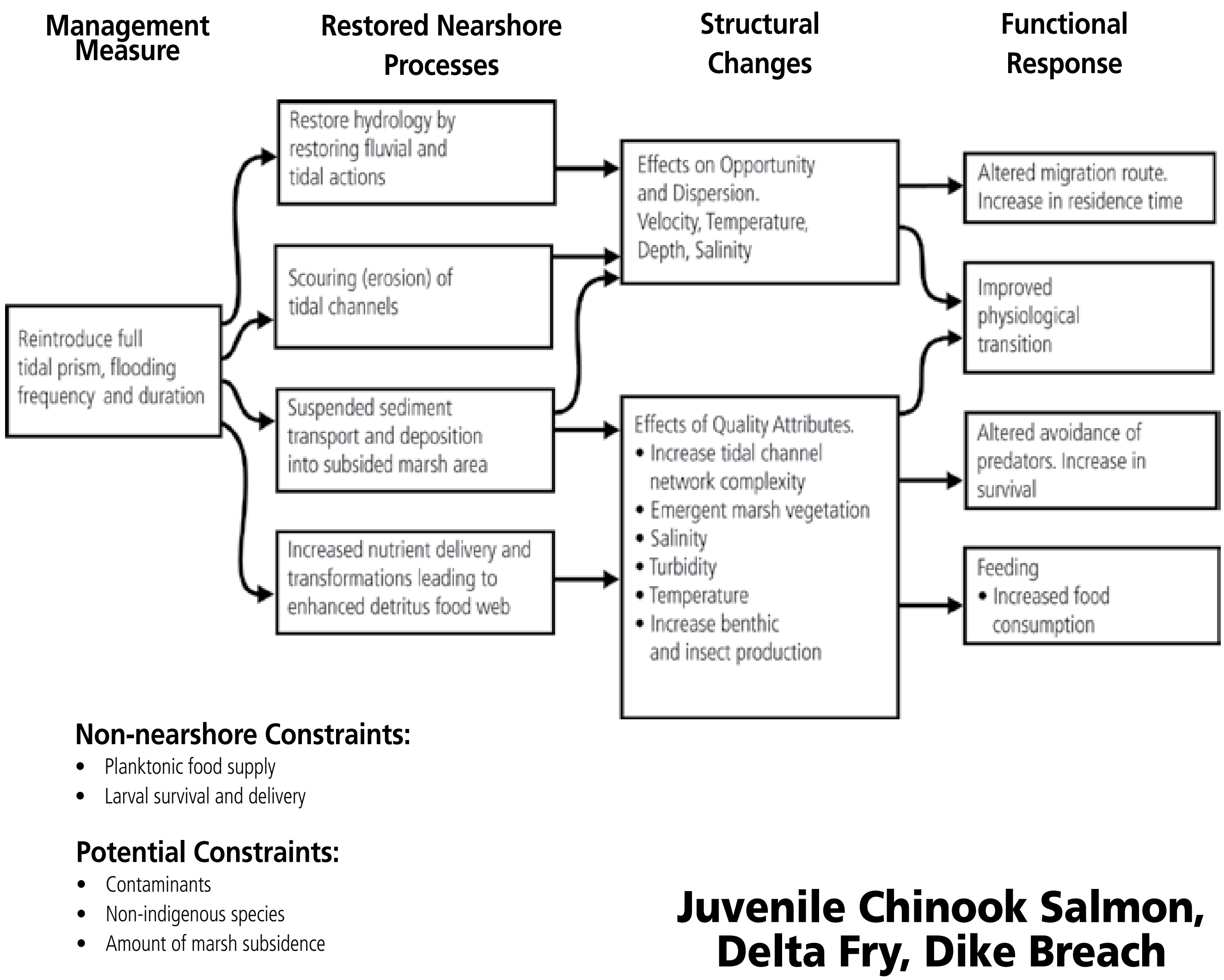

Figure 2. NST Conceptual Model applied to effects of a dike breach in a natal delta on juvenile Chinook salmon (delta fry strategy).

Table 4. Some functional responses of salmon to several types of actions in nearshore ecosystems.

Actions or Stressors	Habitats Affected (based on NST typology)	Processes Altered	Habitat Effects	Functional Response of Salmon
Shoreline Armoring (riprap, bulkheads)	Beaches	a. erosion/sediment transport	Physical/Chemical a. altered beach sediment size/type b. decreased sediment abundance c. increased wave energy Biological a. altered plant/animal assemblages (loss of eelgrass/copepods) b. beach scouring and/or lowering c. loss of shallow nearshore habitats d. loss of connectivity e. altered shoreline hydrodynamics/drift (groins, etc..)	a. reduced prey density b. increased predation and lower survival c. altered migration
Overwater Structures (stairs, docks, marinas)	Beaches, Embayments	a. erosion/sediment transport	Physical/Chemical a. altered beach sediment size/type b. light limitation/alteration Biological a. loss of eelgrass	a. reduced prey b. increased predation, loss of refuge habitat c. altered migration behavior
Stormwater/ Wastewater	Beaches, Embayments, Deltas, Rocky Shores	a. nutrient input b. freshwater input	Physical/Chemical a. low dissolved oxygen b. contaminant loading c. nutrient loading d. physical scouring from increased runoff e. increased shoreline erosion from poor stormwater conveyance/ maintenance f. alteration of beach hydrodynamics Biological a. altered plant/animal assemblages (including macroalgae blooms) b. eelgrass loss. c. forcing of habitat shifts by animals due to blooms (slowing of water, accumulation of nutrients, etc)	a. increased injury risk (lesions, tumors) b. reduced prey c. reduced habitat

Landfill (below the high water line)	Beaches, Embayments, Deltas	a. tidal exchange b. erosion/sediment transport	<u>Physical/Chemical</u> a. delta and lagoon loss b. altered beach sediment size/type c. decreased sediment abundance d. increased wave energy <u>Biological</u> a. altered plant/animal assemblages b. loss of shallow nearshore corridor c. loss of riparian d. beach scouring and/or lowering e. loss of connectivity	a. reduced prey b. osmoregulation (due to delta/lagoon loss) c. increased predation
Riparian Loss	Beaches, Embayments, Deltas, Rocky Shores	a. nutrient input b. erosion/sediment transport c. large wood function in spit formation	<u>Physical/Chemical</u> a. increased temperature b. organic input (food web) <u>Biological</u> a. shade b. erosion c. large woody debris function	a. reduced prey b. increased predation

Gaps/Critical Uncertainties in our Empirical Knowledge

The following are what I believe are important gaps in our knowledge about salmon in nearshore ecosystems.

1. How do juvenile Chinook salmon use the habitats associated with the shoreline areas of Puget Sound?
2. What are the linkages between habitat use and population viability parameters (e.g., productivity)?
3. How do juvenile salmon move around in Puget Sound, and how does this differ among populations?
4. Are there differences in how different populations, different races (e.g., summer vs. fall chum salmon) and different life history strategies use shoreline/littoral habitats?
5. What factors affect the residence time of juvenile chum salmon in deltas?
6. How do hydrodynamic processes affect distribution and movements of juvenile salmon within Puget Sound?
7. What is the capacity of nearshore habitats to support salmon?

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PSNERP and the Nearshore Partnership

The **Puget Sound Nearshore Ecosystem Restoration Project** (PSNERP) was formally initiated as a General Investigation (GI) Feasibility Study in September 2001 through a cost-share agreement between the U.S. Army Corps of Engineers and the State of Washington, represented by the Washington Department of Fish and Wildlife. This agreement describes our joint interests and responsibilities to complete a feasibility study to "… *evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects that have a federal interest and are supported by a local entity willing to provide the necessary items of local cooperation.*"

Since that time, PSNERP has attracted considerable attention and support from a diverse group of individuals and organizations interested and involved in improving the health of Puget Sound nearshore ecosystems and the biological, cultural, and economic resources they support. The **Puget Sound Nearshore Partnership** is the name we have chosen to describe this growing and diverse group and the work we will collectively undertake, which ultimately supports the goals of PSNERP but is beyond the scope of the GI Study. We understand that the mission of PSNERP remains at the core of the Nearshore Partnership. However, restoration projects, information transfer, scientific studies and other activities can and should occur to advance our understanding and, ultimately, the health of the Puget Sound nearshore beyond the original focus and scope of the ongoing GI Study. As of the date of publication for this Technical Report, the Nearshore Partnership enjoys support and participation from the following entities:

King Conservation District

King County

Lead Entities

National Wildlife Federation

NOAA Fisheries

Northwest Indian Fisheries Commission

Northwest Straits Commission

People for Puget Sound

Pierce County

Puget Sound Partnership

Recreation and Conservation Office

Salmon Recovery Funding Board

Taylor Shellfish Company

The Nature Conservancy

U.S. Army Corps of Engineers

U.S. Department of Energy – Pacific Northwest National Laboratory

U.S. Environmental Protection Agency

U.S. Geological Survey

U.S. Fish and Wildlife Service

U.S. Navy

University of Washington

Washington Department of Ecology

Washington Department of Fish and Wildlife

Washington Department of Natural Resources

Washington Public Ports Association

Washington Sea Grant

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Information about the Nearshore Partnership, including the PSNERP work plan, technical reports, the Estuary and Salmon Restoration Program, and other activities, can be found on our Web site at: *www.pugetsoundnearshore.org*.

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RESTORING OUR
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