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Rules and Concepts for Modeling Estuarine and Marine Habitat Effects

Summer and Fall Chum Salmon in Hood Canal and the Strait of Juan de Fuca

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Chapter 1
Introduction

The Ecosystem Diagnosis and Treatment (EDT) method is a widely used tool for prioritizing habitat restoration and protection measures for salmon populations. EDT provides a systematic way to diagnose habitat conditions that have contributed to the current state of salmon populations and to assess priorities for developing restoration and protection plans. It provides an analytical procedure for assessing the potential benefits to salmon populations of actions that might be taken to address habitat related issues that impede recovery. EDT is being used throughout much of the Columbia basin, Puget Sound, and Washington coastal regions to develop salmon recovery plans. The general process for the application of EDT in watershed planning is explained in Lichatowich et al. (1995) and in greater detail in various reports and publications.[1]

The method applies species-specific habitat rules that relate environmental conditions to life stage survival responses of salmonid fishes. The rules are one part of the modeling procedure that characterizes habitat conditions and assesses how they affect species performance. EDT species-habitat rules have been developed for most anadromous species of *Oncorhynchus*, including Chinook salmon, chum salmon, coho salmon, bull trout, cutthroat trout, and rainbow-steelhead trout (Lestelle et al. 2004 and 2005). Pink salmon rules are under development.

Until now, species-habitat rules have been formulated for use in freshwater riverine and large lake environments only. Consequently, EDT assessments to date have been made without the aid of explicit rules for estuarine and marine environments. Instead, various estuaries and the ocean environment have been characterized as sets of assumptions about salmonid survival under different scenarios, including historic and current conditions and favorable versus unfavorable ocean conditions. For river mouth estuaries and nearshore segments in Puget Sound, Hood Canal, and the Strait of Juan de Fuca, the characterization procedure was done with the aid of biologists knowledgeable about conditions in these areas. This procedure, however, has not provided sufficiently detailed diagnostics for estuarine and nearshore environments to produce efficient modeling of actions for these areas.

The species-habitat rules presented here were formulated for application to summer chum salmon as part of recovery planning efforts for populations in Hood Canal and the eastern Strait of Juan de Fuca. Although much of the background material in this document focuses on Hood Canal, the rules are applicable to chum salmon throughout Puget Sound and the Strait of Juan de Fuca. Members of a technical team working on summer chum salmon issues within Hood Canal and the eastern Strait participated in this work. Estuarine and marine rules will be completed in the near future for pink salmon in these same geographic areas, applying much of the same information contained here.

The rules presented here are based on a synthesis of the issues affecting chum salmon performance within estuarine and marine habitats as described in numerous publications and reports. The approach used in formulating these rules is, in part, an extension of earlier work characterizing stream mouth estuaries and large segments of the Puget Sound complex for salmon survival.

[1] Many of these reports may be found at http://www.mobrand.com/library.html.

Devising a set of rules that quantitatively relates salmonid survival in estuarine and marine ecosystems to habitat characteristics is a challenging task—estuarine ecosystems are recognized as being more complex than the freshwater ecosystems for which there are formulated rules that work well. This task would be overwhelming if the approach were to model the many systems and processes that drive food webs, ecological interactions, and migration patterns in order to project salmon population performance; however, in EDT the approach is simpler.

The EDT approach begins with a set of working hypotheses about the factors that affect survival—these hypotheses are formulated from the available scientific literature, drawing as much as possible on hypotheses already described. In cases where hypotheses are lacking or insufficient, new hypotheses are developed through a synthesis of available information. Then, the job of building the rules is one of allocating mortality to life stages and factors in a manner consistent with those hypotheses.

Although there may be alternative hypotheses about the factors that affect survival from which alternative rule sets could be developed, it is believed that the species-habitat rules described in this document—and the hypotheses upon which they are based—provide a reasonable and useful starting rule set for chum salmon in estuarine and marine ecosystems.

The rules presented here have been developed to be consistent with the overall conceptual structure applied in EDT; thus, an appropriate suite of environmental attributes were identified and defined for use in characterizing estuarine and marine habitats of chum salmon that could map into the structure used in EDT.

It is envisioned that, with the data structure and rules presented here, definitions for Properly Functioning Conditions (PFC) in estuarine and marine environments may be developed, as done previously for freshwater riverine habitats.

The background, conceptual framework, data structure, and rationale for species-habitat rules for chum salmon in estuarine and marine environments are provided in this document, which is divided into five chapters:

- Chapter 1 provides a very brief introduction to the approach and to the document.
- Chapter 2 summarizes the major biotic and abiotic issues believed to affect chum salmon performance in estuarine and marine environments as described in the scientific literature—including overviews of the various habitats used by chum salmon within the estuarine and marine environments and of the distribution, biology and life history of the species as relates to these environments.
- Chapter 3 describes the conceptual framework—components of population performance, the information structure in EDT, the nature of the rules and the hypotheses upon which they are based, and the role that the explicit definition of the rules plays in documenting the way in which habitat affects performance.
- Chapter 4 describe the rules associated with specific life-stage survival factors for chum salmon in the estuarine and marine environments and presents a subset of the rules, focusing on those that address key issues identified in Chapter 2.
- Chapter 5 summarizes the characterization of Hood Canal and the eastern Strait using the environmental attributes presented here, illustrating the way in which available data have been synthesized to characterize these areas.

This document is intended to encourage a dialogue between interested parties regarding species-habitat rules for chum salmon in estuarine and marine environments. The rules in EDT are hypotheses based on scientific literature and expert knowledge. Their utility to produce useful and accurate representations of salmonid responses to different habitat conditions has been demonstrated in numerous applications throughout the Pacific Northwest. However, continued review and refinement of the rules and EDT structure are encouraged for all species rule sets. Dialogue is particularly needed for this rule set, which is a first for the estuarine and marine environments.

Chapter 2
Review of Chum Salmon Performance in Estuarine and Marine Environments

The biological rules were formulated to address key issues that affect chum salmon performance in estuarine and marine environments as identified in the scientific literature. This chapter provides background information useful for understanding the nature and complexity of those issues, focuses on selected key issues for chum performance, and provides a synthesis of these issues, qualitatively identifying the working hypotheses around which the rules are formulated.

2.1. Background

Before focusing on the key issues affecting chum salmon performance in estuarine and marine waters, it is helpful to first consider some background for these issues. The first section provides a definition of habitat and its function within the larger landscape context; the following gives a brief overview of the distribution, biology, and life history of chum salmon to introduce many of the issues subsequently described in greater detail.

2.1.1. Landscape Structure and Habitats

Chum salmon encounter a large array of habitats over the course of their lives in estuarine and marine ecosystems. These ecosystems are more complex than freshwater ecosystems (Jay et al. 2000). To date, estuarine scientists have not considered any estuarine/marine habitat classification scheme adequate for assessing habitat-biotic relationships in these estuarine and marine ecosystems (Jay et al. 2000; Simenstad et al. 2000). The classification systems of Cowardin et al. (1979) and Dethier (1990), while seen as useful for enumerating types of habitats, have been considered inadequate for assessing biotic responses to habitat variability and change. The complexity of processes, both physicochemical and ecological, that affect the way in which organisms respond across the habitat landscape in these ecosystems makes classifying habitats in these environments difficult.

Habitat has been conventionally defined in estuarine and coastal ecosystems as an organism's occupation or use of a particular type of local environment (Simenstad et al. 2000). Simenstad et al. (2000) conclude that this definition is inadequate for an ecosystem perspective, particularly with respect to estuarine and coastal ecosystems. They cite Safriel and Ben-Eliahu (1991) as providing a more comprehensive definition of habitat appropriate for these ecosystems—the environment of a community confined to a portion of the landscape, including three components: (1) physicochemical features such as salinity and temperature; (2) resources such as food and space; and (3) interacting organisms other than those functioning as resources, such as predators, competitors, and mutualists. In this context, Simenstad et al. (2000) define habitat structure as the arrangement of objects or features in the environment, consistent with McCoy and Bell (1991).

Using these definitions, Simenstad et al. (2000) propose that habitat embraces any part of the environment on which an organism depends, directly or indirectly. Hence, habitat is seen as unique to specific organisms, encompassing all the physicochemical and biological requirements of an organism within a spatial unit. Organisms moving through estuarine and coastal ecosystems, like juvenile salmon, integrate many different habitats along their route. Survival, or performance, appears to be determined at a habitat landscape scale versus being the outcome of encountering a sequence of discrete habitats. Simenstad et al. (2000) state that use of habitat landscapes in this manner by organisms involves multiple scales of space and time. They find that it may be a useful convention to visualize habitats as discrete segments of the environment that fit together in a manner consistent with the ways in which entire communities of organisms persist.

Fresh et al. (2003) conclude that the importance of nearshore habitats to the biota, like salmon, depends upon site-specific features of those habitats and their landscape context along the nearshore. Landscape context is described as the integration of habitats with all other elements of the landscape, including arrangement, size, shape, location, connectivity to other habitats, and accessibility.

To effectively assess the roles of estuaries on the performance of chum salmon, Simenstad (2000) argued that both a larger estuarine landscape scale as well as the watershed estuary (i.e., subestuary) scale must be considered. The concepts of habitat as proposed by Simenstad et al. (2000) and Fresh et al. (2003) are consistent with the way in which habitat is defined and applied in EDT—where habitat is regarded as the integration of all of the factors, abiotic and biotic, that affect a population's performance.

In Chapter 3, a range of environmental attributes is defined that are mapped to a set of habitat factors, which, in turn, are used to drive chum salmon survival within the analysis. Moreover, this approach to modeling salmon performance is based on how life histories experience habitats over a landscape. The developmental stage of the species together with the arrangement, location, and connectivity of habitats are all important to assessing population performance. The major elements of habitat affecting performance of chum salmon within the estuarine and marine environments in a manner suitable for arranging and integrating within segments of landscape identified here draw on classification systems and habitat descriptions from Cowardin et al. (1979), Dethier (1991), Jay et al. (2000) and Simenstad (2000a).

Both chum and pink salmon have the least dependency on freshwater of all anadromous salmonids (Behnke 2002), with a life history linked more to the vast Pacific Ocean with its enormous supply of food than to the relatively limited food supplies in freshwater. Newly emerged chum fry in rivers of Puget Sound and Hood Canal exit the freshwater environment rapidly. Moving initially into the river mouth estuary, they follow a course that traverses first the shallow nearshore environment, before moving into the deeper water associated with Puget Sound and the Strait and finally into the North Pacific Ocean.

Technically, all of Puget Sound, including Hood Canal and the Strait of Juan de Fuca, are considered estuarine because freshwater is measurably diluted by seawater. These areas are referred to in this document as estuarine. However, there is clearly a continuum of estuarine characteristics—from strong to faint—moving from the southern ends of Hood Canal and Puget Sound to the western extremity of the Strait. Salinity characteristics can range between approximately 16 ppt in southern reaches of Hood Canal to more than 31 ppt in the Strait with conditions varying seasonally (Friebertshauser et al. 1971). The water column of Hood Canal is usually highly stratified, with a shallow lens of fresh to brackish water at the surface overlaying waters of near ocean salinity (Simenstad 2000a).

Within this estuarine system, there are numerous river mouth estuaries (subestuaries) and still more abundant tidal marshes along the shoreline. A subestuary encompasses the lower portion of a river or stream from the upper extent of tidal influence to the outer edge of its delta. The subestuary of a chum salmon spawning stream provides the newly emerged fry with their first exposure to the estuarine environment. Subestuaries can be extensive, as on the Skagit River, or very small, as those associated with the many small creeks entering Puget Sound.[2] They consist of marsh, lagoon, tidal sloughs, spits, and other landforms that comprise the transition between fresh and salt water.

Tidal marshes are salt and freshwater marsh habitats subject to tidal inundation, though sometimes infrequently. Juvenile salmon can access these habitats during high tides and can spend extended times in these systems, transitioning from a freshwater to a salt water physiology (Hirschi et al. 2003b; Williams et al. 2003). The subestuaries and tidal marshes of Puget Sound provide critical functions in the ecology of salmon. They serve directly as feeding and migratory habitats in addition to being major sources of the detritus important in estuarine food webs. The subestuary deltas connect to the nearshore of Puget Sound and the Strait. At the landscape scale, a landscape segment includes the shallow nearshore corridors as well as the interlinked subestuaries and tidal marshes along those corridors (Simenstad 2000b).

The area encompassed by the nearshore environment has been defined somewhat differently through the years. Fresh et al. (1979) defined this area as the littoral and inner sublittoral (bottom) and neritic (surface) waters inshore of the 20-m depth level (after Hedgpeth 1963). Williams and Thom (2001) defined the area as the place where direct functional interactions occur between upland and marine habitats, typically including habitats from the marine riparian zone to the lower limit of the photic zone, approximately 30 m below mean lower low water (MLLW). Within the nearshore, the intertidal (regularly uncovered by tidal fluctuation) and shallow subtidal (rarely uncovered) zones are areas frequently referred to when describing chum salmon utilization.

The shallow nearshore corridor encompasses beaches and flats with substrates ranging from cobbles, gravels, sand, and mud substrates. Often the beaches support near continuous bands of eelgrass. Eelgrass is a marine seagrass that forms meadows, literally pastures of flowing grass that range from patchy to contiguous and extensive (Williams et al. 2001). Eelgrass habitats are important feeding areas for chum salmon and are a major source of detritus for estuarine food webs. Another macrophyte common in the nearshore corridor is kelp, which grows into dense forests where rocky substrates are available. Kelp provides feeding and migratory habitat for juvenile chum (Schaffer 2003) besides serving other important functions in estuarine and marine ecosystems.

Elements of the shallow nearshore environment important to juvenile chum are identified as (Simenstad 2000a; Simenstad 2000b; Williams et al. 2000):

- Shallow-water, typically low-gradient habitats with fine, unconsolidated substrates;
- Presence of aquatic vegetation, emergent marsh vegetation, and shrub/scrub or forested riparian vegetation;
- Areas of low current and wave energy;
- Concentrations of small, non-evasive invertebrates; and
- Interspersed subestuaries along the nearshore corridor.

[2] / Subestuaries here include the small "pocket" estuaries described by Beamer et al. (2003) and tidal creeks described by Hirshi et al. (2003b).

2.1.2. Overview of Summer and Fall Chum Distribution, Biology, and Life History

This section summarizes some aspects of chum salmon life history that are relevant to the development of species-habitat rules for chum salmon. Extensive reviews of the biology and life history of Hood Canal and Strait of Juan de Fuca summer chum are provided in Tynan (1997) and Ames et al. (2000). More comprehensive information for chum salmon in general, including both summer and fall chum, is found in Salo (1991) and Johnson et al. (1997). An understanding of some of the key differences between summer and fall chum was vitally important in devising the rules. Unless specified, the following summary refers to chum in general.

Throughout their distribution in North America and Asia, chum salmon commonly exhibit both an early and late timing pattern when returning to their natal streams (Salo 1991). Early timed runs are called summer chum, while the late runs are called fall chum. In Puget Sound, the late returning populations are further distinguished as being either fall or winter runs, based on peak return timing (Johnson et al. 1997).

NOAA Fisheries has designated Hood Canal and Strait of Juan de Fuca summer chum as an ESU, based on distinctive life history and genetic traits (Johnson et al. 1997). In Hood Canal, eleven streams have been identified as recently having indigenous summer chum (Ames et al. 2000): Big Quilicene River, Little Quilicene River, Dosewallips River, Duckabush River, Hamma Hamma River, Lilliwaup River, Union River, Tahuya River, Dewatto River, Anderson Creek, and Big Beef Creek. They have also been observed in small numbers on occasion in the Skokomish River in Hood Canal. In the eastern Strait, summer chum populations are recognized in Snow and Salmon creeks in Discovery Bay and JimmyComeLately Creek in Sequim Bay. They have also been reported in Chimacum Creek in Admiralty Inlet and in the Dungeness River.

Fall chum are distributed much more extensively throughout the Puget Sound region than summer chum. They are located in the same streams where summer chum are produced.

The uniqueness of summer chum in Hood Canal and the eastern Strait is best characterized by their late summer arrival to natal streams and their late winter/early spring fry migration to the estuary. Tynan (1997) provides detailed information on return and spawn timing for each population. While spawning varies somewhat between some populations, it typically occurs from late August through late October. Fry emerge from the gravel between early February and May, with peak emergence being March 22 and April 4 for Hood Canal and Strait populations respectively (Ames et al. 2000). In contrast, Hood Canal fall chum spawn predominantly in November and December, and fry emerge approximately one month later than summer chum, between late April and mid-May (Koski 1975; Tynan 1997).

Summer chum spawn soon after freshwater entry in the lower reaches of the mainstem streams. The use of lower reaches may be an adaptation to the low flow conditions present at arrival time; September is frequently the month of lowest flow in Hood Canal streams. In Big Beef Creek, Koski (1975) reported that summer chum (now extinct) spawned in the lower 0.8 km of the stream, while later timed chum extended their spawning to 6.4 km of stream. Similar spatial patterns of spawning occur in other Hood Canal and Strait streams. In contrast to summer chum, fall chum spawn in side channels, tributaries, and springs, as well as in mainstem creeks and rivers. Fall chum will use heavily reaches or streams with strong groundwater influence, if available (Salo 1991).

Emerging during the darkness of night, chum fry immediately move downstream, likely entering the stream mouth estuary the same night of emergence within Hood Canal streams (Simenstad

2000b). Transition from freshwater to brackish and saline waters within the estuary can therefore be very brief—less than 12 hours. Emergence and fry emigration to the estuary from a single watershed likely occurs over several weeks, similar to emergence patterns seen for other salmonids. Instream feeding during migration by chum in general is probably insignificant except in very large rivers where spawning migrations are extensive (Simenstad 2000b).

Simenstad (2000b) reported that the residence time of chum fry within larger Hood Canal natal subestuaries is likely less than one week, suggesting that it is very brief in the smallest subestuaries. He suggests that fry may be held longer in the larger, more complex subestuaries than in the small or simplified subestuaries because of the better feeding conditions and lower water velocities associated with marshes and dendritic channels.

Terrestrial drift insects are often prominent in the diet of chum fry in the inner portions of subestuary deltas and along the large margins of large deltas (Congleton 1979; Mason 1974; Simenstad 2000b). Small subestuaries and tidal marshes appear to be stopover sites for chum fry migrating along the nearshore corridor, moving in with the tide and utilizing both terrestrial and marine based food webs, before moving out again on the receding tide (Mason 1974; Hirschi et al. 2003). This pattern of utilization has been observed for chum salmon within Hood Canal (Hirschi et al. 2003).

Upon departing the natal subestuary, chum fry inhabit shallow nearshore areas. For the first few weeks of estuarine life, they have been observed in the top 2-3 centimeters of surface waters and extremely close to shore. A description of early life in waters of Hood Canal is useful here (Ames et al. 2000):

> "Chum fry arriving in the Hood Canal estuary are initially widely dispersed (Bax 1982), but form loose aggregations oriented to the shoreline within a few days (Schreiner 1977, Bax 1983, Whitmus, 1985). These aggregations occur in daylight hours only, and tend to break up after dark (Feller 1974), regrouping nearshore at dawn the following morning (Schreiner 1977, Bax 1983). Bax et al. (1978) report that chum fry at this initial stage of out-migration use areas predominantly close to shore. "Early run" chum fry in Hood Canal (defined as chum juveniles migrating during February and March) usually occupy sublittoral seagrass beds with residence time of about one week (Wissmar and Simenstad 1980). Schreiner (1977) reports that Hood Canal chum maintain a nearshore distribution until they reach a size of 45-50 mm, at which time they move to deeper offshore areas."

Within the nearshore corridors, chum fry feed primarily on small crustaceans, such as harpacticoid copepods, and other epibenthic invertebrates, such as small gammarid amphipods (Kaczynski et al. 1973; Healey 1979; Simenstad et al. 1982). Simenstad (2000b) states that their diet is "surprisingly specific", targeting two or three species of harpacticoid copepods (i.e., *Harpacticus uniremis* and *Tisbe* sp.). He states that extremely high densities of these organisms often occur in eelgrass beds. This high selectivity for specific copepod species has been found within estuaries between Washington and Alaska (Salo 1991).

The period of estuarine residence appears to be the most critical phase in the life history of chum salmon, having a major role in determining the size of the subsequent adult run (Johnson et al. 1997). Chum salmon are considered second only to Chinook salmon in dependence upon estuarine waters (Salo 1991). In general, chum salmon grow rapidly in estuaries. They prefer shallow sublittoral habitats before moving into neritic habitats. Juveniles from most runs of chum salmon migrate in schools through northern Puget Sound and into the Strait of Juan de Fuca (Fresh 1979).

2.2. Issues Affecting Estuarine and Marine Survival

Habitat condition, as habitat was more broadly defined earlier in this document, can affect fish performance in a variety of ways, such as through growth, behavior, physiology, and survival. Ultimately, the importance of habitat condition must be measured in terms of how it affects survival, either directly or indirectly. In this section, the major biotic and abiotic issues affecting chum salmon performance in the estuarine and marine environments described in the scientific literature are summarized. Many of the findings and hypotheses reported in literature for Puget Sound come from studies conducted in Hood Canal; the development of the rules for chum salmon relies heavily on those studies.

Koski's (1975) study comparing the survival and fitness of summer chum and fall chum in Big Beef Creek within the Hood Canal basin is of special interest. Although this study focused on survival and fitness from egg deposition to fry emergence, Koski attempted to understand the implications to post-emergence survival. He considered how differences in life history traits between the two races affected post-emergence fitness. One possible implication, he suggested, was in having an influence on marine survival. He reported that summer chum appear to have a lower estuarine/marine survival than fall chum produced in the same stream. He estimated that the average marine survival of summer chum returning to Big Beef Creek from two brood years (1968 and 1969) was approximately one-third of that for fall chum. His survival estimates for the two races (ranging between about 1 to 5%), including fishing, agree very closely with those observed throughout the range of chum salmon (Salo 1991).[3]

The differential estuarine/marine survival between summer and fall chum, as suggested by Koski (1975), is a key working hypothesis in the development of the rules for estuarine and marine environments. The interest here is in understanding what contributes to this differential survival and the extent to which the difference may be attributed to habitat conditions. Simenstad (2000b) proposes that the major reasons for the apparent differential survival are related to the way in which conditions within the estuarine environment affect the two races.[4] He presents a conceptual model—a hypothesis—to explain how estuarine conditions in Hood Canal influence survival of the two races, consistent with Koski's estimates of marine survival. Aspects of his hypothesis are incorporated into the following descriptions of issues affecting chum performance. Issues for the estuarine and ocean phases of chum life history are addressed separately below.

2.2.1. Estuarine Life History

The period of estuarine residence by juveniles is believed to be the most critical phase in the life history of chum salmon (Johnson et al. 1997), having a major effect on the abundance of adult recruits. The effect of estuarine life on survival is often ascribed to one of more of the following factors: arrival time, residence time, and estuarine condition.

[3] / A critical assumption in Koski's analysis is that the fishing exploitation rate on both races was equal for the two brood years studied. It appears from data presented in Ames et al. (2000) that exploitation rates increased dramatically on summer chum sometime in the mid 1970s, after returns would have been completed for the brood years of interest to Koski.

[4] / While Simenstad (2000b) is inclined to believe that the apparent differences in marine survival are due to how the two races are affected differently within the estuarine environment, he acknowledges that at least some part of the difference may be due to the two races not sharing the same ocean conditions. He states that oceanic migration routes may differ between the two races. He finds however that "statistical concordance among early/late, wild/hatchery chum recruit:spawner ratios and age class structure suggests all are influenced by the same oceanic conditions."

2.2.1.1. Estuarine arrival time

Johnson et al. (1997), citing numerous studies, concluded that entry timing into the estuary may be the most important determinant of estuarine survival due to the strong seasonality and interannual variation in zooplankton abundance patterns. The issue is simply: is prey abundant when the fry immigration commences. The correspondence between fry immigration and zooplankton patterns in any given year has been seen as the primary cause of large variations that can occur from year to year in pink and chum salmon marine survival (Bax 1983b). For this reason, managers of pink and chum hatchery programs in some regions monitor annual plankton blooms for determining fry release timing. Bax (1983b) concluded, after reviewing limited available information on zooplankton patterns and related factors for Hood Canal, that considerable year-to-year variation exists both temporally (within year) and spatially in zooplankton abundance in this body of water.

Despite this variation, general patterns exist for zooplankton abundance in the Puget Sound, Strait of Juan de Fuca, and Strait of Georgia regions (Dempster 1938; Sibert 1979; Naiman and Sibert 1979; Simenstad et al. 1980; Hebard 1956; Harrison et al. 1983; Strickland 1983). The epibenthic (shallow nearshore and benthic associated) component generally peaks prior to the neritic (surface pelagic in deep water) component. Simenstad et al. (1980) reported a pattern of increasing abundance of epibenthic zooplankton, including species of harpacticoids, along beaches in Hood Canal from late winter to late spring in 1977-1979. Sibert (1979) reported a similar pattern for *Harpacticus uniremis* within the Nanaimo River estuary. Harpacticoids, especially *H. uniremis*, are preferred food organisms preyed on by small chum fry within the shallow nearshore environment.

Tynan (1997) provides a good summary of abundance patterns for neritic zooplankton in Puget Sound and Hood Canal:

> "In an average year, peak volumes of zooplankton have been documented to occur in the main basin of Puget Sound from May through September, with minimum values occurring in March and April (Hebard 1956, cited by Bax 1983b). Strickland (1983) reported peaks in phytoplankton abundance during mid-late May in the main basin and in Dabob Bay, with annual minimum chlorophyll a values observed prior to the first week in April. Although complicated by life strategy differences attached with the composite of mixed phyto- and zooplankton species present, peaks in zooplankton abundance appear to just follow peaks in phytoplankton (Strickland 1983). Water temperature and secchi disk data collected by Schreiner (1977) and water temperature data reported by Bax et al. (1978; 1979; 1980) during chum migration studies indicate that primary productivity in the vicinity of Bangor in Hood Canal during the years studied likely did not increase until the first week in April. Dempster (1938) documented low volumes of plankton in Hood Canal surface waters from early January through late March, with peak plankton volumes apparent in late April. Primary productivity increases were commensurate with seasonal solar radiation increases, which caused surface water temperatures (at 1 m depth) in the Canal to climb from 7-8°C in March to 13-15°C in June in the aforementioned chum migration studies."

In general, the estuarine arrival timing and feeding strategy of juvenile chum would seem to be well adapted to these general patterns of zooplankton abundance: epibenthic organisms peaking first for small fry, closely followed by neritic organisms for larger fry. Salo (1991) concluded that the movement offshore generally coincides with the decline of inshore prey resources and is normally at a time when the fish have grown to a size that allows them to feed upon the larger neritic organisms and avoid predators residing in deeper water.

Based on these general patterns, summer chum that arrive first to the estuary would experience greater variation in interannual marine survival, due to the increased likelihood of variability in zooplankton abundance early in the year. If this is true, it suggests that summer chum would be more sensitive than fall chum to factors that affect the timing and abundance of prey organisms in the shallow nearshore environment. Simenstad (2000) hypothesizes that the diversity in emigration timing across chum races may be the adaptive strategy employed by summer chum given the stochastic nature of estuarine conditions. Some scientists in the region call this a "jackpot" strategy: accept the risk of lower returns in most years for the sake of occasional big payoffs.

2.2.1.2. Estuarine residence time

The length of time that salmon species are exposed to estuarine conditions appears to be a major factor in determining survival between emigration from freshwater and return. In general, estuaries provide prey resources that are more optimal with respect to prey size, distribution, and density than those provided in oceanic habitats (Simenstad et al. 1982).

Simenstad et al. (1982) addressed the importance of estuaries to salmon: "We hypothesize that salmon use estuaries as refugia from predators, for optimum availability of preferred food organisms promoting rapid growth, and as a physiological transition area. What has not been established, however, is the quantitative significance of such estuarine factors to the ultimate survival of adults."

There appears to be no documentation of quantitative significance in the literature since that paper was written. What seems clear is that there are distinct differences in marine survival rates between populations exposed to sizeable estuaries versus those that are not. This is most evident in comparing Washington north coastal populations to those in Puget Sound.[5] These coastal populations experience only tiny river mouth estuaries before moving directly into the open ocean. Marine survival rates for Chinook and coho produced in Puget Sound streams are typically at least twice those for Washington coastal streams, often three to four times as high. While it is not possible to draw a similar comparison here for chum salmon, based on some experience on the Quinault River, it is likely that the difference is of the same magnitude.[6] These comparisons are admittedly rough—more precise ones should consider the differences in life histories spent in freshwater (i.e., coastal Chinook and chum typically reside longer in freshwater).[7]

The length of time that juvenile salmon are exposed to an estuary depends upon both estuary size and the speed at which they travel through it. The speed at which juvenile salmon move through an estuary, either actively or passively with the current, is a factor affecting survival—within limitations imposed by overarching life history needs and associated time windows.

In Hood Canal, the speed at which chum fry migrate has been related to arrival time from the natal streams. Migration rate has been found to range between 4-14 km per day (Salo et al. 1980), with the fastest rates occurring early in the migration period--i.e., during the time when

[5] / To draw such a comparison more fairly, one needs to assume that populations encounter the same oceanic conditions beyond their estuaries, which is not the case in at least some years. The weight of evidence, however, suggests that the primary reason for such differences in survival is due to estuarine exposure.

[6] / Comparisons between Washington coastal and Puget Sound populations are based on one author's many years of experience evaluating run sizes and marine survivals in the Queets and Quinault rivers and on analyses made since then of populations in Hood Canal (Lestelle et al. 1993) and Puget Sound (various EDT analyses).

[7] / One author found that Washington north coastal salmon appear to spend a relatively brief time, often perhaps only several days or less, within their river mouth estuary prior to ocean entry. Data and summaries are available in annual reports of the Quinault Tribe.

summer chum are predominantly present. Travel speed slows as the juvenile migration period progresses. Tynan (1997) projected, using a conservative travel rate (7 km/d) for early migrants, that summer chum emigrating from the Union River on the extreme end of the Canal would require 14 days to clear the Canal. Traveling at 14 km/day, the high end of the migration rate, would take 7 days. In contrast, fall chum traveling at the low end of the range of migration rates would take roughly one month to move through the Canal. These projections are consistent with the assertion that duration of estuarine exposure affects overall marine survival using Koski's estimates of marine survival.

Two hypotheses have been proposed by scientists about the factors that control migration rate of juvenile chum through Hood Canal. One hypothesis is that foraging success is the primary determinant of migration rate; fry that find abundant prey when they enter the Canal move more slowly than those that do not (Simenstad et al. 1980; Simenstad 2000). The second hypothesis is that surface outflow velocity through the Canal, driven by prevailing winds and river discharge, determines migration rate; high outflow velocities passively move fish quickly through the Canal while lower velocities allow fish to move more slowly (Bax 1983a).[8]

Both hypotheses, it is believed, lead to a similar effect: significantly less exposure by early migrants (i.e., summer chum) to a major component of the estuarine complex, resulting in reduced overall marine survival. Koski's estimates of marine survival for both summer and fall chum are consistent with this assertion. Moreover, of the two chum races, summer chum appear to be disadvantaged for delaying finding optimal foraging conditions within the nearshore environment compared to fall chum. Koski (1975) reported that summer chum spend a longer time than fall chum within the incubation environment. He suggests this is a strategy to delay emergence timing. In Koski's opinion, such a strategy underscores the importance for this species to emigrate to the estuary when prey are more likely to be available. However, in delaying their emergence, in this case to what seems a maximum delay possible based on their condition at emergence, summer chum emerge with significantly less lipid reserves than fall chum—a condition not generally well adapted to delaying finding good food resources within the estuary.

Implications of these two hypotheses differ with respect to the potential effect of shoreline development on marine survival. The foraging success hypothesis suggests that any shoreline-associated activity reducing forage availability would exacerbate the natural condition of less prey available early in the migration period. Thus, summer chum would be particularly sensitive to shoreline development, more so than fall chum. In contrast, the surface outflow hypothesis suggests that chum fry moving passively and quickly due to high water velocities, although somewhat affected by shoreline development, would be less sensitive to this development than they would be under the forage hypothesis.

These differences in implications between the two hypotheses with respect to the effects of shoreline development on fry survival warrant a closer look at each hypothesis. The formulation of the rules depends upon the interpretation and application of these hypotheses.

<u>The foraging success hypothesis</u>. The foraging success hypothesis proposes that three factors working together control the overall migration rate of chum fry out of Hood Canal (Simenstad 2000):

[8] / Tynan (1997) seems to suggest a third hypothesis that doesn't specifically depend on the mode of travel, whether active or passive. This hypothesis suggests that summer chum are adapted to a rapid movement out of the Canal, and once they have exited, they are able to find optimal foraging conditions for growth and survival. It is concluded that even if there has been some adaptation, there would be a survival consequence compared to if they found optimal conditions immediately within the Canal. Hood Canal summer chum have less lipid reserves than fall chum (Koski 1975) and would seem ill equipped for even a relatively quick journey through the Canal in hopes of finding good food resources beyond.

1. Foraging success—the presence of abundant forage holds fish longer in the Canal because they are finding their preferred prey without needing to search for it;
2. Surface water circulation—circulation in the Canal, generally south to north, is likely to help transport neritic fry that are away from the shoreline, thus affecting the migration rate of large fry (>50 mm); and,
3. Shallow water habitat with eelgrass—abundant shallow nearshore habitat (<2 m), particularly with eelgrass present, will hold small fry (< 50 mm) longer than habitats without such areas, promoting feeding and growth.

Factors one and three are closely related and operate in conjunction with one another.

Simenstad (2000b) describes the movement and feeding of small chum fry (<50 mm) as occurring in shallow water (≤ 2 m deep). (Newly emerged fry enter the natal subestuary at approximately 38 mm.) He refers to them as epibenthic fry in this size range because they are associated with shallow water and feed on epibenthic organisms. They migrate in dense schools during daylight along the shoreline; as they grow, they tend to break up and disperse at night, moving slightly offshore, returning to the shoreline again during daylight. It is hypothesized that this pattern occurs in order to avoid predation by larger fish in deeper water (presumed to be less effective during night). Along the shoreline chum fry migrate very close to, but not necessarily in, native eelgrass (*Z. marina*) habitat. During this time, they are highly specific in their prey. If epibenthic prey are not abundant, the juveniles must then rapidly migrate further to other shallow sublittoral habitats in search of prey. Thus, even though there may be neritic prey of significant densities and sizes, residence time during this period is a function of prey abundance in both the epibenthic and neritic zooplankton communities (Simenstad et al. 1980). If the juveniles find abundant prey along the shallow nearshore corridor, migration slows to utilize those resources. As juveniles approach 50 mm in size, they venture into neritic waters more and more, especially at night. By the time they are 60 mm, most chum fry appear to freely migrate and feed in neritic waters.

Growth rates are fastest if chum find their preferred prey within the shallow nearshore. Simenstad et al. (1980) indicate that growth is typically much slower for early migrants (i.e., summer chum) than for later migrants (i.e., fall chum) because less forage is available. Fish encountering poor foraging success as epibenthic fry may not make the transition to neritic fry by the time they exit the Canal. This may be the case for summer chum in some years. If the fry migrating along the shoreline encounter a subestuary delta, particularly a large one like the Skokomish, good feeding conditions may hold the fry there for several days. When fry make the transition to neritic behavior, the surface outflow may assist them in moving out of the Canal and into the Strait.

Healey (1979) found the same pattern on the Nanaimo estuary delta and arrived at the same conclusion as Simenstad regarding the effect of food availability on migration rate of young fry.

The foraging success hypothesis, in addressing migration and growth rates, implies that human activities that adversely affect production of epibenthic organisms could negatively affect chum performance, particularly those in the earliest part of outmigration.

The surface outflow hypothesis. The surface outflow hypothesis says that the migration rate of chum fry, including individuals less than 50 mm in length, is strongly affected by the water velocities in the upper water column (Bax 1982) (Figure 1).

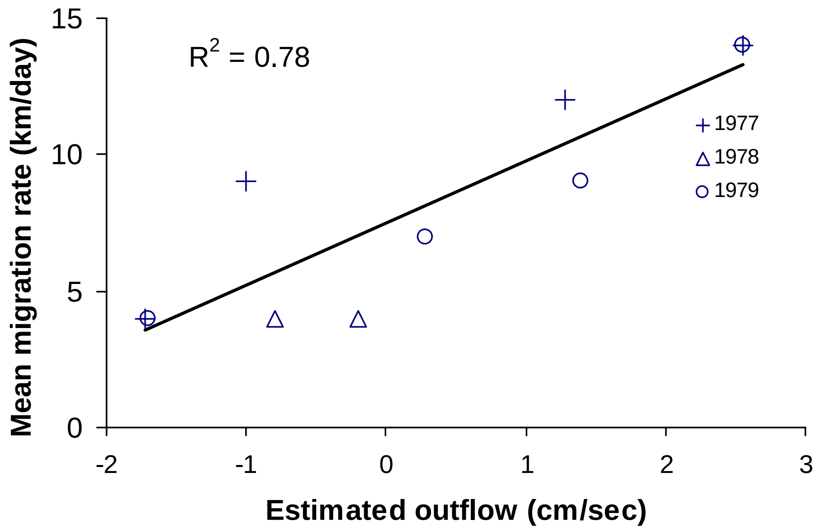

Figure 1. Mean rate of migration of groups of marked juvenile chum salmon over three days following release into Hood Canal, and the estimated residual surface outflow at 5 m depth at time of recapture—from Bax (1982).

The direction of surface flow is south to north in the Canal; hence, water currents aid in moving juveniles north toward the Strait. Fry during the early migration period (i.e., summer chum) would be most affected by high water velocities because current speed is generally highest during February and March. Bax (1982; 1983b) concludes, however, that migration patterns out of the Canal are not entirely driven by surface outflow. He states that there is an active migration component as well but suggests that it is innate, related to an overall adaptive timing strategy. His hypothesis does not include an aspect of forage availability affecting migration rate, though he implies that it may have contributed to an innate behavior to move quickly from the Canal.

On its face, the Bax hypothesis implies that shoreline development should have little or no effect on migration rate or survival of summer chum in Hood Canal. Bax himself did not mention that shoreline development could affect chum performance. However, that to the extent that his hypothesis is operative in nature, it is believed that there would be some adverse effect on chum performance, particularly on summer chum. As noted previously, summer chum apparently sacrifice lipid reserves within young fry in order to delay emergence from spawning beds, which would likely adversely affect survival if they need to migrate a long distance prior to locating good feeding areas. Shoreline development that affects epibenthic organisms would result in fewer prey organisms available for outmigrating summer chum fry.

Salo, renowned expert on chum salmon, concluded that mechanisms associated with both hypotheses seem to be operative in Hood Canal (Salo 1991). After reviewing the major findings of both Simenstad and Bax[9], he stated "the migration pattern of chum is a combination of active and passive movements," related to the availability of preferred prey organisms and to surface outflow.

Salo described another factor that appears to affect the migration rate of chum fry along the nearshore—the presence of pink salmon fry (Salo 1991) (Figure 2).

[9] Salo was involved in the research of both Simenstad and Bax.

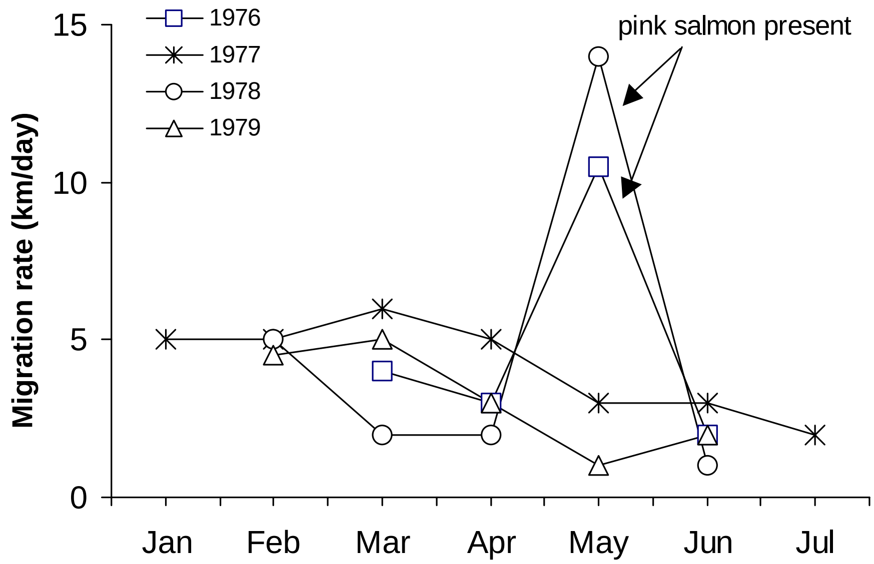

Figure 2. The most common migration rates and the rates at which distinguishable proportions of the 45-59 mm size group of juvenile chum salmon migrated through Hood Canal from 1976-79 (fish intercepted at Bangor Annex, Hood Canal). The points are joined to emphasize consistent monthly patterns—from Salo (1991).

Salo (1991) describes the presence of pink salmon fry as a density-dependent factor, where pink fry migrating with chum fry increase the overall density of outmigrant fry, implying that migration rate is density dependent. High densities of the two species in aggregate result in an accelerated migration rate—further evidence for the foraging success hypothesis, where high densities of migrating small salmonid fry reduce forage availability, resulting in faster migration. It should be noted, however, that chum fry apparently change their migration behavior in freshwater when pink fry are present, both with respect to vertical distribution in the water column and time of day when migrating (Salo 1991). These observations might mean that the faster migration rate of chum seen in Figure 2 when pinks are present could be the result of interspecific interactions unrelated to density effects. Regardless of the mechanism, the presence of pinks generally results in accelerated migration rate and reduced survival of chum fry.

2.2.1.3. Estuarine characteristics

As mentioned in the preceding section, certain characteristics of the estuary can affect residence time, fish utilization patterns, and presumably survival. Those characteristics identified above are prey availability, amount of shallow shoreline, and surface outflow velocity. There are other estuarine characteristics, or factors, that affect juvenile salmon performance. Many of these are inter-related. Some are entirely natural to estuarine and marine ecosystems, while others can be strongly affected by human activities. This section summarizes the major characteristics of estuaries that affect chum performance, highlighting the ways in which human activities can alter those characteristics when applicable.

Estuarine characteristics considered relevant to the objectives of this document are:

- eelgrass distribution and abundance
- extent of shallow shoreline
- extent of shoreline development
- riparian condition

- sources of detritus
- exposure
- water surface outflow
- subestuaries
- kelp distribution
- ecological interactions (competition and predation)

Eelgrass distribution and abundance. As noted previously, the preferred prey organisms of small chum fry (<55 mm) are often associated with eelgrass meadows located in the shallow nearshore environment. Simenstad (2000b) states that eelgrass habitat is perhaps one of the most important habitats for summer chum. Both juvenile chum and Chinook feed on the small crustacea associated with the leaves of eelgrass and found at the base of eelgrass plants (Williams et al. 2001). Extremely high densities of these prey organisms often occur in eelgrass (Simenstad 2000b). Eelgrass also provides refuge to juvenile salmon from predators. Eelgrass is one of the major sources of detritus for driving estuarine food webs (Wissmar and Simenstad 1998). Simenstad (2000b), referring to work reported in Simenstad and Wissmar (1985), says that it may be *the* major source of organic matter to intertidal/shallow subtidal food webs in Hood Canal. Eelgrass grows on a wide variety of substrates ranging from fine sands to gravel, but it grows best in medium-fine sand with some organic matter (Williams et al. 2001).

Eelgrass is harmed by any activity that disturbs the sediment where it grows or reduces light. Particularly harmful are shoreline modifications that lead to steeper beaches and/or coarser substrates, such as building bulkheads (Williams and Thom 2001) (Figure 3).

Bulkheads that intrude into the intertidal zone increase the rate of beach erosion, resulting in coarsening of the substrate. In general, bank hardening associated with shoreline development also inhibits or eliminates sources of beach sediment in the source regions of drift cells. In addition, any activity that reduces light to eelgrass beds, such as those that increase turbidity or cause shading, can also affect eelgrass. Docks can shade areas of eelgrass beds. Also, high inorganic nutrient levels can fuel seaweed or ulvoid blooms that can smother eelgrass, which has occurred in Dungeness Bay (Haring 1999). The consequence of such activities is either fragmentation or loss of eelgrass as a contiguous migration corridor for juvenile salmon that provides high quality forage opportunities and predator refuge (Simenstad 2000b).

Extent of shallow shoreline. As noted previously, Simenstad (2000b) refers to the extent of shallow shoreline present within estuarine areas as one of three principal factors affecting the migration rate of chum fry in Hood Canal. Chum fry less than 50 mm in length migrate primarily along the shoreline, preferring shallow water less than 2 m in depth. Their preferred prey in this life phase occurs in these areas. This association with very shallow water by small fry is also believed to provide some degree of refuge from piscivorous fish species (Simenstad et al. 1980; Salo 1991). When small chum fry do not find shallow water habitat along their migration route, they are forced into deeper water where they are thought to move faster and be more exposed to predators. Simenstad (2000b) concludes that "Fry that have not yet achieved the neritic phase are constrained to migrate along shallow water habitats where their rate of migration, bioenergetic status and vulnerability to predation is likely dependent upon the state of shoreline habitats."

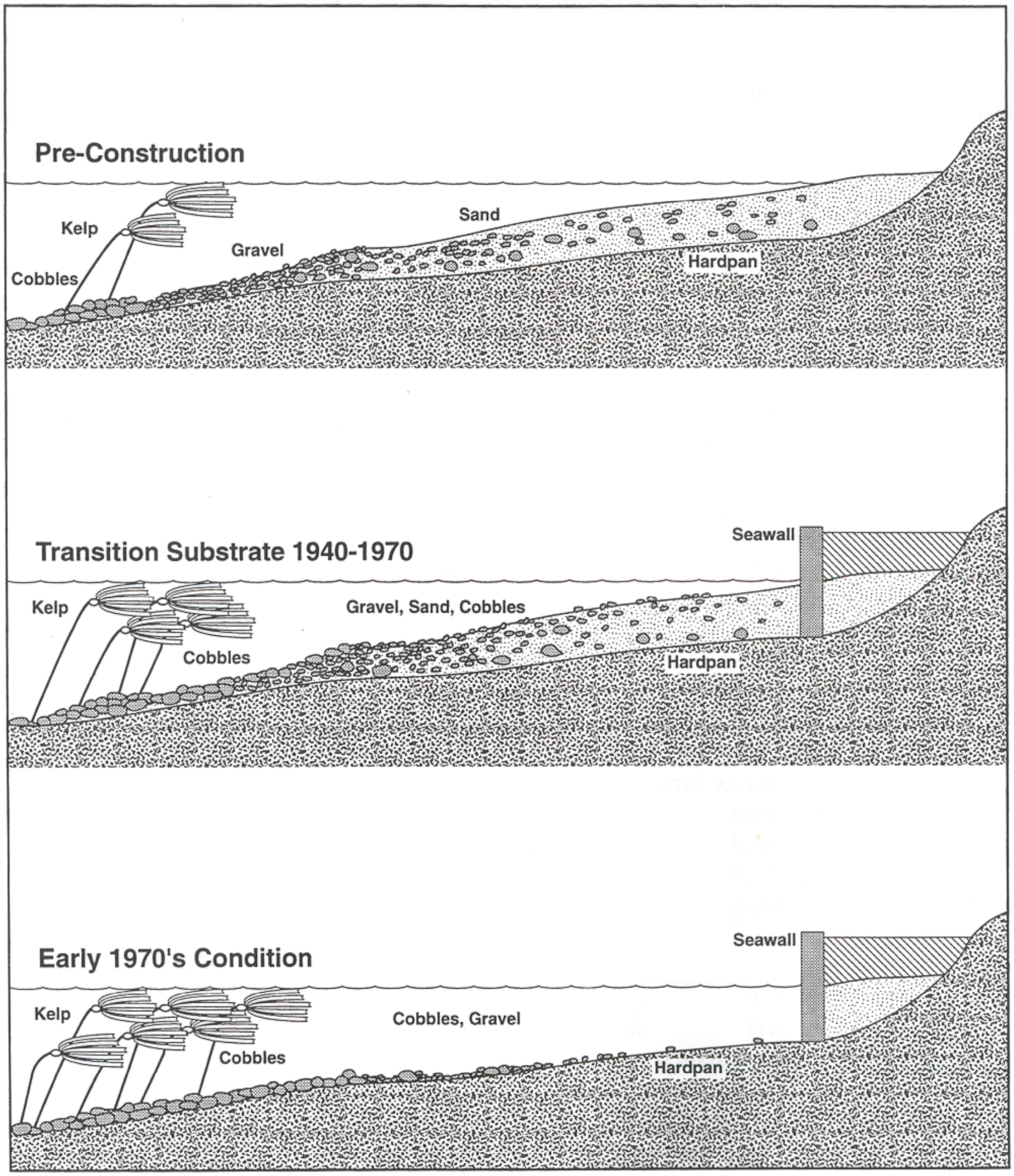

Figure 3. Illustration of changes to the beach at Lincoln Park following seawall construction in the mid 1930s—from Thom et al. (1994).

Extent of shoreline development. The extent of shoreline development can adversely affect some of the other characteristics included in this list, particularly eelgrass distribution and the extent of shallow shorelines.

Shoreline development is widespread through large portions of Puget Sound, Hood Canal, and the eastern Strait (Williams and Thom 2001; Hirschi et al. 2003a). Acute impacts include filling and excavation, which is more of a problem on subestuary deltas but has occurred along intervening shorelines as well (Simenstad 2000b). Intertidal fills and bulkheads have occurred extensively in some areas. Filling immediately alters the bathymetry and topography at the site (Williams and Thom 2001) and can substantially change beach profiles, marsh channel morphometry, and habitat connectivity. Filling has occurred in various areas along the Canal and in areas of the eastern Strait. Placement of bulkheads and other hardened materials like riprap that protrude into the intertidal zone can change sediment characteristics, steepen beach profiles, and coarsen the substrate. In areas where marinas have been constructed, shallow water habitat has been lost due to dredging and excavation.

Riparian condition. A riparian zone is the area on or by land bordering a stream, lake, tidewater, or other body of water that forms the interface between terrestrial and aquatic ecosystems. The riparian zone along subestuaries and the nearshore shoreline can be an important source of forage for salmon fry feeding in these areas (Levings and Jamieson 2001, cited by Williams et al. 2001; Simenstad 2000b). Terrestrial insects are an important part of the diet of chum fry within the inner portion of subestuary deltas.

Land clearing associated with logging over the past century and shoreline development have been extensive along many areas of the Hood Canal shoreline. Riparian vegetation has been lost in many areas and has not been recovered.

Sources of detritus. Food webs of Pacific Northwest subestuaries and the intertidal zones of larger estuarine complexes like Puget Sound are based predominantly on detritus; juvenile salmon, in large part, are supported by detritus-based trophic pathways in these areas (Wissmar and Simenstad 1998). The composition of organic matter within different areas can vary depending on a variety of factors, including anthropogenic effects. Although many questions still exist about estuarine food web processes (Wissmar and Simenstad 1998), estuaries apparently vary in their productivity with respect to prey production for juvenile salmon. Healey (1982) concluded that estuarine productivity, either for the estuary as a whole or in segments, is related to efficiency of trapping and processing detritus, which is related to its configuration with respect to tidal channels, intertidal marshes, creek and river delta configuration, lower intertidal and subtidal weed beds, and basin morphology.

Major sources of detritus in estuaries are rivers, phytoplankton, benthic algae, marsh, and eelgrass. The quality of organic matter is more important to estuarine food webs than the quantity of organic material delivered to the estuary, implying that sources are most important (Wissmar and Simenstad 1998). Terrestrial and marsh detritus tend to be less incorporated into the food web than detritus from phytoplankton and benthic algae. Simenstad (2000b), referring to work reported in Simenstad and Wissmar (1985), states that eelgrass may be *the* major source of organic matter to intertidal/shallow subtidal food webs in Hood Canal. Eelgrass detritus is also a major component of food web processes in the Nanaimo estuary (Healey 1982).

Human activities that alter detritus inputs or the trapping efficiency of estuarine subsystems are expected to impact estuarine productivity for juvenile salmon food (Healey 1981). Destruction of marshes and simplification of subestuary features by diking, straightening, and filling would reduce certain types of detritus and the trapping efficiency of estuarine subsystems. Any activities that reduce eelgrass density, as described previously, would reduce eelgrass carbon inputs.

Exposure. The extent that a shoreline is exposed to wave energy can affect the suitability of the shallow nearshore to support small chum fry. This appears to be related to both swimming capabilities of small fry as well as to opportunities for finding abundant prey. Beaches exposed to significant wave action are high energy environments. Waves pound the shore, eroding particles and suspending fine sediments, creating a constantly dynamic environment for plants and animals. These areas can have high diversities of types of organisms but typically support a low biomass (Little 2000). Such environments do not appear to be used much by chum fry, suggesting they are not well suited for fry survival.

Small chum fry are most often found in shallow nearshore areas—sometimes in just a few cm of water (Healey 1982); they appear to prefer bays and sheltered areas (Johnson 1965; Simenstad et al. 1982; Salo 1991). Areas of relatively high energy within subestuaries are avoided even though preferred prey are present, with fry preferring quiet backwaters adjacent to deeper water and associated with finer sediments (Healey 1979).

<u>Water surface outflow</u>. As described previously, surface water outflow velocity has been correlated with migration rate in Hood Canal. Bax (1982) concluded that surface outflow from the Canal was an important mechanism affecting migration rate. His findings were largely based on experiments conducted with fed hatchery chum fry and therefore may have been influenced by fish already entering the neritic phase. Simenstad (2000) appears to interpret the findings to mean that the outmigration rate of neritic chum fry is affected by surface outflow. Salo (1991) concluded that surface outflow is a factor in chum outmigration rate for all sizes of fry.

Bax (1982) suggests that prevailing winds from the south in late winter and early spring is the primary factor for surface water outflow moving north in Hood Canal at those times. Simenstad et al. (1980) state that outflow is also related to freshwater runoff patterns in rivers entering Hood Canal. The influence of freshwater runoff suggests that surface outflow rates in late winter and early spring may be somewhat cyclical, tied to decadal oscillations in weather patterns.

<u>Subestuaries</u>. Subestuaries are important to juvenile chum, as described previously—the natal subestuary provides the first exposure to the estuarine environment. Complex, large subestuaries tend to hold chum fry longer, providing good rearing areas before the fry emigrate into the nearshore environment (Simenstad 2000). Subestuaries also serve as stopover sites for fry migrating along the nearshore shoreline, providing short-term nurseries and refugia from predators, and they are also important contributors of detritus to the larger estuarine environment.

Human development has been pervasive in many of the subestuaries of Puget Sound, including those along Hood Canal and the Strait. Perhaps the most widespread form of development has been diking within subestuaries associated with the closing of distributaries and filling of wetlands and tidal channels. These activities have affected both the size and quality of subestuaries for salmonid rearing. Simenstad et al. (1980) list the extent to which many subestuaries have been reduced in size. Other human activities, particularly those on the east side of Puget Sound, have resulted in severe contamination of sediments with toxic substances.

<u>Kelp distribution</u>. Shaffer (1998; 2003) reported that kelp forests provide some of the same functions performed by eelgrass for migrating juvenile salmon, including chum salmon. Kelp provides substrate for production of prey used by juvenile salmonids, and it affords refuge from predators. Kelp typically occurs in rougher substrate and higher energy areas than those areas where eelgrass occurs in high abundance.

Within the Puget Sound complex, including the Strait, kelp abundance is believed to be either similar to or greater than historic levels (Williams et al. 2003), which may be due, in part, to armoring of shorelines that has increased erosion and exposed more rocky substrata.

<u>Ecological interactions</u>. Ecological interactions between chum salmon and other species, including hatchery-produced fish, can be significant within estuarine and marine environments.

A large body of scientific literature reports on the potential for these interactions and their possible effects on chum production. Ames et al. (2000) provide a good summary of the interactions thought to be operative on summer chum; many, and perhaps all, of the same issues would apply to fall chum. It was concluded that competition and predation effects on summer chum are likely most significant with other salmonids, both of wild and hatchery origin. In particular, interspecific interactions appear to occur between pink and chum fry (see, for example, Figure 2), resulting in an accelerated migration rate for chum when pink are present. Other interactions are known to occur with seabirds, marine fish, and marine mammals—although the extent of these interactions is uncertain.

2.2.2. Ocean Life History

This section discusses the effects of oceanic conditions on chum salmon performance. Pink salmon are included because of their similarity to chum with respect to the importance of early marine life history. It is unclear where estuarine effects on these species end and oceanic effects begin—this document uses the western end of the Strait of Juan de Fuca, but this is largely arbitrary. Oceanic conditions, which include circulation patterns, water temperature, and sea surface salinity, extend their influence into Puget Sound.

Ocean related survival of salmon varies dramatically; it is believed to be primarily determined by prey distribution and abundance within the ocean, particularly along the eastern boundary of the North Pacific (Francis and Hare 1997; Gargett 1997). Conditions related to salmon survival within the Northeast Pacific Ocean are driven by two climate processes: the Pacific Decadal Oscillation (PDO) and the El Nino-Southern Oscillation (ENSO). Both ENSO and PDO are patterns of Pacific climate variability that include changes in sea and air temperatures, winds, and precipitation (Mantua and Mote in press). These processes are believed to influence phytoplankton and zooplankton production patterns in the outer Strait of Juan de Fuca and the North Pacific Ocean (Gargett 1997; Li et al. 2000).

ENSO is Earth's dominant source of year-to-year climate variation (Rasmussen and Wallace 1983); it influences interannual variation in climate, ocean circulation, and sea surface temperature, but apparently within the context of the PDO. The PDO is believed to create regime shifts in climate that last 20 to 40 years, with a complete cycle being twice that. The lifetime of a typical ENSO event ranges from 6 to 18 months and complete ENSO cycles have a 2 to 7 year period. The PDO has been described as a long-lived ENSO-like pattern of Pacific climate variability (Zhang et al. 1997, cited by Hare and Mantua 2001). The spatial patterns between the two are very similar: both favor anomalously warm sea surface temperatures near the equator and along the coast of North America, and anomalously cool sea surface temperatures in the central North Pacific. In reviewing a number of papers on these phenomena, it is unclear how the two processes interact.

Due to its long periodicity, the PDO has been particularly difficult to study, with only two complete PDO cycles having been observed during the period of good instrumentation (Mantua and Mote in press). It is, therefore, difficult to understand the PDO's potential effect on species like salmon. The PDO was in its cool phase from about 1890 to 1925 and from 1945 to 1977. It was in its warm phase from 1925 to 1945 and from 1977 to at least the mid to late 1990s. It is now generally believed that the PDO has shifted back to its cool phase, beginning about 1998 (Mantua and Mote in press).

The marine survival of salmon has been linked to both ENSO and PDO patterns. ENSO events begin as warming episodes in the tropical Pacific zone, causing large scale intrusions of anomalously warm water northward along the coastline of the Pacific Northwest. These epizodes vary greatly in intensity. The marine growth and survival of salmonids can vary by species and location during ENSO events (Ames et al. 2000). ENSO effects can also lead to reduced snow pack and river flows in western Washington (Ames et al. 2000, citing Mantua undated).

Following a number of papers in the 1990s linking salmon survival to climate patterns, Hare et al. (1999) identified an "inverse production regime" driven by the PDO, where the warm phase of the PDO is beneficial to Alaska stocks and detrimental to certain Washington, Oregon, and California (WOC) stocks. British Columbia stocks showed a mixed response. The cool phase of the PDO has the opposite effect on Alaska and WOC stocks. Gargett (1997) proposed that these effects on salmon survival were associated with what she called an "optimal stability window"—a set of optimal conditions linking the stability of ocean circulation patterns to phytoplankton and zooplankton production and ultimately to salmon production. This concept seems to explain the apparent relationship between salmon abundance for some species and decadal variability associated with the PDO, as well as the out-of-phase variation between northern and southern salmon stocks.

For WOC stocks, coho and Chinook have been adversely affected during the warm phase of the PDO (Hare et al. 1999). Since 1977, the effects of the PDO shift combined with frequent ENSO events resulted in a generally hostile ocean environment for these species, causing extremely poor survival in some years. Effects on marine survival for other salmon species are less clear south of Alaska. Results presented by Hare et al. (1999) suggest that species in British Columbia occupy a transitional region: with coho and Chinook being affected in a similar manner as stocks to the south; and chum, pink, and sockeye being affected as those in Alaska. Their results show that at least some Washington State chum have responded like chum to the north—i.e., benefiting during the warm phase of the PDO, which is opposite to the way in which WOC coho and Chinook have responded. Ames et al. (2000), however, suggested otherwise, indicating that preliminary evidence showed that Puget Sound chum may be responding favorably to the recent PDO regime shift.

A group of Canadian scientists, seeking to understand possible mechanisms further, performed a meta analysis on 120 wild stocks of sockeye, pink, and chum salmon from rivers in Puget Sound to Norton Sound in Alaska, a distance of more than 3000 km (Pyper et al. 2001; Mueter et al. 2002a; Mueter et al. 2002b; Pyper et al. 2002). These scientists analyzed correlations between spawner-recruit data and three coastal environmental variables--upwelling index, surface sea temperature, and surface sea salinity; their datasets spanned the period 1948 to 1996, with differing numbers of years available for different stocks. They were looking for and comparing spatial scales of correlation in the marine variables with salmon survival, hoping to learn at what scale survivals varied among stocks similarly and how survivals correlated with the marine variables.

Pyper et al. (2002) concluded on the basis of these analyses that the key biological or physical environmental processes influencing year-to-year variation in chum survival operate primarily at local or regional spatial scales as opposed to the scale of the entire northeastern Pacific Ocean. Variability covaried on a scale of up to about 1000 km with the strongest association occurring within approximately 550 km. Pyper et al. (2002) further concluded that it appears that mechanisms causing chum survival to covary similarly between populations were primarily operating in the early marine life phase, meaning that populations located within Washington State and southern British Columbia appear to be affected similarly by marine conditions. Populations originating further north appear to be responding to marine conditions localized to those areas. Pyper et al. (2001) reported similar patterns of covariance by pink salmon; they concluded that pinks were being affected at a slightly smaller scale—by marine conditions somewhat closer to natal streams. These findings suggest that chum and pink fry originating in

Puget Sound are strongly affected by marine survival conditions localized to this region, encompassing at least the Strait of Juan de Fuca and the area south of the western edge of Vancouver Island. Pyper et al. (2001, 2002) offered no explanations about how PDO and ENSO processes may be affecting localized marine conditions.

Although the effect of the PDO on coho and Chinook seems fairly well accepted, the pattern of response by pink and chum salmon to regime shifts is less clear. Li et al. (2000), following up on Gargett's hypothesis about an optimal stability window, investigated the effects of a regime shift in climate and ocean circulation patterns on phytoplankton and zooplankton abundance in the Strait of Juan de Fuca and Strait of Georgia. They reported a scarcity of published data on plankton and nutrient measurements in the Strait of Juan de Fuca and concluded on the basis of their modeling that plankton populations are relatively insensitive to interannual changes in estuarine circulation in the Georgia-Fuca main body, which is strongly affected by runoff from the Fraser River. They expected that plankton would be more responsive to circulation patterns; instead, they concluded that the processes governing plankton abundance must be more complex, related to ecological and physical marine processes involving both interannual and decadal scale processes.

Similarly, Gargett et al. (2001) concluded that the optimal stability window concept appears to be more applicable to populations that emigrate directly to the marine environment from freshwater, like those on the outer coast of Washington, as opposed to those that first enter a large estuarine complex. Survival patterns for fish that move through an estuarine complex first may be more insensitive to interannual variability associated with the PDO and ENSO. Feeding conditions for chum and pinks appear to be more tied to complex relationships associated with the transitional water bodies than to processes in the open ocean. The responses of these bodies to the PDO are less clear.

While uncertainty remains about the role of the PDO on marine survival of chum salmon, recent returns of both summer and fall chum to Puget Sound strongly suggest that they are being positively affected. A similar pattern appears evident for pink salmon.

2.3. Synthesis and Working Hypotheses

Conclusions regarding the primary issues affecting chum salmon performance within the Puget Sound region are summarized in Table 1. Emphasis is given to the Hood Canal branch of Puget Sound.

Table 1. Conclusions regarding the most important issues affecting chum salmon performance within the Puget Sound region with emphasis on Hood Canal.

Issue	Conclusions	Life stages affected
Estuarine/marine survival		
Relative survival between summer and fall chum	• Hood Canal summer chum survive on average at approximately 1/3 the rate of fall chum currently • Historically, difference in survival between the races in Hood Canal was less than seen in recent decades due to more productive forage areas within the shallow nearshore zone and in interspersed subestuaries	Small fry <60 mm
Forage availability		
Prey within subestuaries	• Both terrestrial and aquatic based prey are important within subestuaries • Subestuaries are important "stop-over" feeding areas for chum fry migrating along the nearshore shoreline • Prey availability within subestuaries is related to riparian conditions within the subestuary and the lower portion of the adjoining freshwater system and to adjacent wetlands, marshes, and mudflat	Small fry <55-60 mm

Table 1. Conclusions regarding the most important issues affecting chum salmon performance within the Puget Sound region with emphasis on Hood Canal.

Issue	Conclusions	Life stages affected
	• Relative amounts of detrital input to subestuary systems are important to overall system productivity • Land uses within and adjoining subestuaries that result in diking or disconnecting wetlands, sloughs, and secondary channels from main channels will reduce amounts of prey • Subestuaries that have high forage availability will hold fry longer and promote rapid growth and facilitate transition to salt water	
Terrestrial based prey within shallow nearshore environment	• Riparian zone of the shoreline can be an important source of prey • Land uses that remove riparian vegetation will reduce inputs of prey to the nearshore environment	Small fry <55-60 mm
Epibenthic prey within shallow nearshore environment	• Epibenthic zooplankton, particularly some species of harpacticoids, are an especially important source of food to small fry • Within year pattern of abundance can vary but generally follows a predictable pattern, peaking prior to the neritic zooplankton peak • Abundance of preferred species varies by month and tends to peak prior to peak abundance of neritic zooplankton • Abundance of preferred species is subject to being heavily cropped by juvenile chum • Eelgrass meadows are major production areas of epibenthic prey for chum fry and provide important feeding areas • Epibenthic organisms are more abundant along beaches less exposed to wave action • Forage availability in bays and segments of Hood Canal and Puget Sound is related to detrital inputs from eelgrass, marsh, and adjoining watersheds; eelgrass is the major source of detritus in many areas of Hood Canal • Migration rate of chum fry is strongly influenced by forage availability; abundant prey slows migration rate for feeding, promoting rapid growth; scare prey accelerates migration in search of preferred prey • Shift to neritic life style (associated with deep water) is accelerated by abundant epibenthic prey; shift is slowed by scarce epibenthic prey • Summer chum are not as adapted to delaying finding good forage as fall chum because of less lipid reserves due to delayed emergence from spawning beds • Shoreline development that results in deepening of existing shallow water areas, coarsening of substrates from sand or mixed-sand to cobble, and docks and piers will reduce eelgrass abundance and associated epibenthic prey production	Small fry <55-60 mm
Neritic prey within deepwater areas of Puget Sound complex (including Hood Canal and Strait of Juan de Fuca)	• Neritic zooplankton are more abundant and uniform in distribution within the inland sea/estuarine complex of Puget Sound (including SJDF) than in the open ocean • Within year pattern of abundance can vary but generally follows a predictable pattern; interannual variability in abundance pattern can have a strong effect on interannual survival of chum fry • Peak abundance tends to follow peak abundance of inshore epibenthic prey • The PDO can have a strong influence on the abundance and timing of zooplankton within the SJDF but mechanisms are complex involving ecological interactions; generally, the recent regime shift has been favorable to early marine survival of chum	Large fry (subyearlings) >55-60 mm
Neritic prey within the coastal waters of North Pacific (outside Strait of Juan de Fuca)	• The PDO can have a strong influence on the abundance and timing of zooplankton within the zone but mechanisms are complex involving ecological interactions; generally, the recent regime shift has been favorable to early marine survival of chum	Large fry (subyearlings) >55-60 mm
Current outflow velocities		
Flow velocities within subestuaries	• High flows during fry outmigration from natal streams will tend to push fry through the subestuary unless suitable refuge or slow water areas exist • Accelerated emigration out of natal subestuary by high flows is disadvantageous to fry survival because it results in sudden, abrupt changes in habitat types experienced by newly emerged fry and exposes them to greater predation risk in deep water when pushed out beyond the delta face • Land uses that accelerate spring runoff or reduce refuge sites in subestuaries from high flows will result in faster emigration rates from natal subestuaries and reduced survival	Small fry <55-60 mm
Surface outflow velocities within the nearshore zone	• Small fry will be moved out of an area faster when relatively high surface outflow velocities occur compared to when low velocities predominate • Relatively rapid, passive movement from nearshore areas will generally be unfavorable to survival because it diminishes feeding opportunities on epibenthic prey, exposing fry to a greater array of predators per unit of time; summer chum have less lipid reserves than fall	Small fry <55-60 mm

Table 1. Conclusions regarding the most important issues affecting chum salmon performance within the Puget Sound region with emphasis on Hood Canal.

Issue	Conclusions	Life stages affected
	chum upon entry into the nearshore environment, making them less adapted to a forced, extensive migration from an area as Hood Canal • Shoreline development that results in reduced epibenthic prey abundance will exacerbate the effects of high surface outflows on fry survival because it would diminish opportunities for forage and growth upon arrival to the nearshore environment • Surface outflow velocities in Hood Canal and southern Puget Sound vary both intra- and interannually due to variability in runoff and wind; velocities tend to be greatest in late and early spring • The relative contribution of water surface outflow velocities to diminished marine survival of Hood Canal summer chum compared to fall chum is less than the contribution of poor forage availability (based on weight of evidence considering findings both in Hood Canal and Nanaimo estuary)	
Cover and structure, habitat diversity		
Subestuaries—natal and non-natal	• Complexity of channels and structure within natal subestuaries provides refuge from high flows and predators; structure in non-natal estuaries provides refuge from predators • Interspersed subestuaries and tidal marshes along the nearshore shoreline provide "stop-over" feeding sites, predator refuge, and more effective transitioning from freshwater to saltwater conditions	Small fry <55-60 mm
Shallow nearshore	• Shallow beaches provide predator refuge for small fry migrating along shoreline • Eelgrass provides habitat structure for predator refuge for small and larger fry • Kelp forests provide habitat structure for predator refuge for small and larger fry • Areas of low wave exposure and calm water provide bioenergetically preferred feeding sites • Land uses and shoreline development that steepen beaches, coarsen substrates, eliminate or reduce eelgrass or kelp will reduce the quality of the nearshore environment for small fry	Small fry <55-60 mm
Ecological interactions		
Competition – interspecific competition with wild fish	• Potential for competition for food between summer and fall chum fry is small due to timing differences in outmigrations • Potential for competition for food between summer chum and Chinook, coho, steelhead, and cutthroat populations is small due to timing differences in outmigrations and differences in habitat utilization (potential is greatest with Chinook for species listed); potential for competition between fall chum and hatchery Chinook is somewhat greater than for summer chum • Potential for competition for food between both summer and fall chum and pink salmon is high during strong pink abundance years; chum fry behavior is changed when pink are abundant	All size classes of subyearlings
Competition –with hatchery fish	• Potential for competition for food between summer chum and hatchery chum can be substantial due to the possibility for very large numbers of hatchery fish • Potential for competition for food between summer chum and hatchery Chinook, coho, steelhead, and cutthroat populations is small due to timing differences in outmigrations and differences in habitat utilization (potential is greatest with Chinook for species listed) • Potential for competition for food between both summer and fall chum and hatchery pink salmon is high where large numbers of the latter are released	All size classes of subyearlings
Predation on chum fry	• Potential for predation effects on chum fry by wild cutthroat, steelhead, coho, and Chinook can be high when these populations of other species are abundant; cutthroat are known to be particularly effective predators on chum fry • Potential for predation effects on chum fry by hatchery cutthroat, steelhead, coho, and Chinook can be high when hatchery releases of these other species are large • Potential for predation by seabirds, marine fish, and marine mammals is generally relatively low, though unusual concentrations of seabirds and certain species of marine fish can cause high predation	All size classes of subyearlings
Predation on chum adults	• High concentrations of marine mammals (seals, sea lions, and orcas) can cause high predation losses on schooling adult chum	Adult fish
Obstructions to access within subestuaries		
Barriers to juvenile fish passage	• Tidal gates and other impediments to free movement by juvenile chum can block access to blind channels and off-channel sites within subestuaries	Small fry <55-60 mm

Chapter 3
Conceptual Framework

This chapter describes the key concepts for understanding the way in which information, or knowledge, is structured within EDT—the conceptual framework. The first section addresses the components of population performance in EDT; the second section describes the information structure; and the third and fourth sections outline the rule structure for estimating productivity and key habitat, respectively.

3.1. Components of Population Performance

EDT is a method for characterizing the quality and quantity of aquatic habitat in relation to species-specific survival. The underlying premise in this method is that biological capacity and productivity of a fish population are functions of the environment; therefore, environmental conditions are reflected in the shape of its production function (Reisenbichler 1989). Specifically, it is assumed that habitat based estimates of capacity and productivity create a Beverton-Holt production function (Beverton and Holt 1957) that serves as an index of potential biological performance of the species in the modeled environment (Figure 4).

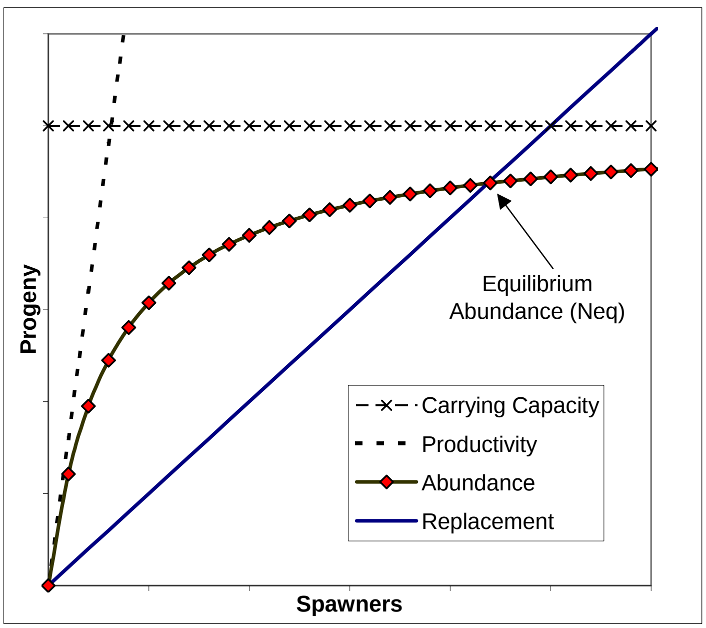

Figure 4. Features of a Beverton-Holt production function. Productivity is the density independent survival, which, along with density dependent factors of the environment, determines abundance limited by the total capacity of the environment. Replacement is the minimum number of spawners required to maintain a given abundance. Under steady-state environmental conditions, the population abundance equilibrates at Neq, the point where abundance crosses the replacement line.

Capacity defines the "size" of the environment with respect to a species, while productivity is the survival rate without density effects (density independent survival). Moussalli and Hilborn

(1986) showed that a Beverton-Holt function for a population can be disaggregated into similar functions describing survival and capacity of the environment at different life stages. In EDT, capacity and productivity are calculated for each life stage at a stream reach scale and then integrated to estimate overall population capacity and productivity.

Productivity in EDT is equivalent to the concept of intrinsic productivity discussed in McElhany et al. (2000) to describe viable salmonid populations with respect to the Endangered Species Act. Productivity in EDT is survival without density dependence effects, i.e., the approximate rate that would occur when competition for resources is eliminated. As abundance increases, survival is increasingly modified by density dependent factors of the environment to the point where the quantity of resources becomes limiting and abundance approaches the capacity. In Figure 4, productivity is the slope of the abundance curve at its origin. Productivity is a function of the quality of the environment (Moussalli and Hilborn 1986).[10] The definition of productivity as applied here is consistent with its use by Hilborn and Walters (1992) in population dynamics modeling.

Environmental capacity limits how large a population can grow given finite space and food resources, depicted by the asymptote in Figure 4. Environmental capacity controls the extent that density dependence is operative at different population (or density) levels. Capacity is a function of the quantity of key habitats and food resources available.[11] The term key habitat here refers to those habitat types that are the primary types utilized by the species in a life stage—they are the types that are preferred or required by the species in the life stage. Given a steady-state condition, abundance will increase toward the capacity and will equilibrate at a point below capacity where the Progeny/Spawners is equal to 1.0 (Figure 4). This equilibrium abundance, or Neq, is a function of both capacity and productivity.

Using the recursive property of the Beverton-Holt function highlighted by Moussalli and Hilborn (1986), the population level production function can be decomposed in EDT into similar functions for each life stage. Life stages for chum salmon as applied in EDT are defined in Appendix A.

The maximum productivity (survival rate) and capacity (density) under optimal conditions that occur in nature may be estimated from the scientific literature. These survival and density values are referred to as reference benchmarks.[12] Benchmarks provide a set of descriptions for performance under optimal conditions expressed as survival and maximum densities for each life stage—they are the theoretical natural limits on survival and density for a species. These conditions constitute what can be thought of as "as good as it gets" for survival of the species in nature. Estimated benchmark survivals and densities applied to chum salmon in EDT are provided in Appendix B.

The species-habitat rules are used to adjust the maximum benchmark performance to account for habitat conditions in specific stream reaches or estuarine-marine segments. The EDT rules adjust the theoretical benchmarks downward to reflect local conditions that typically are less ideal for survival than those associated with the benchmarks, due to natural or anthropogenic

[10] Productivity measured across the full life cycle also incorporates sex ratio, fecundity, and fitness.

[11] Environmental carrying capacity illustrated in the stock-production relationship is actually a function of both quantity of resources (ones that are competed for) and environmental quality—easily seen in a disaggregated production function, see Moussalli and Hilborn (1986) and pages 284-285 in Hilborn and Walters (1992).

[12] Benchmark values for productivity and capacity are theoretical, derived within a theoretical construct for how members of a population interact with one another within their environment. The values serve as working hypotheses about the natural limits on survival and density for a species.

constraints. As a result, fish performance will almost always be less than the benchmark maximum levels.

The EDT rules provide a systematic way to quantify survival conditions for any reach or segment by computing performance in the local environment relative to the benchmarks. This procedure ensures that productivity and capacity values computed for each life history segment are: (a) bounded by the biological limits of the species; (b) scaled consistently across time, space, and life stage; and (c) scaled consistently with the benchmark values. While the rules are based on knowledge contained in the literature, they should be thought of as hypotheses about the ways in which survival is affected by environmental conditions.

It is important to distinguish the benchmarks from the historic or pristine conditions (often referred to as the Template or Reference condition in EDT). Maximum performance of fish in a particular stream or estuarine segment is almost always less than the benchmarks because even pristine conditions are not "perfect." The benchmark descriptions serve as a point of reference for both the present-day and historic conditions and for all watersheds and the estuarine-marine environment.

3.2. EDT information structure

Information is structured, consisting of all forms of knowledge, for estuarine and marine environments in the same manner as it was done for the freshwater environments. Information used to derive biological performance parameters in EDT is organized through a hierarchical data or information structure with three levels. Together, these levels can be thought of as an information pyramid in which each level builds on information from the next lower level (Figure 5). Moving up through the levels provides an increasingly organism-centered view of the ecosystem.

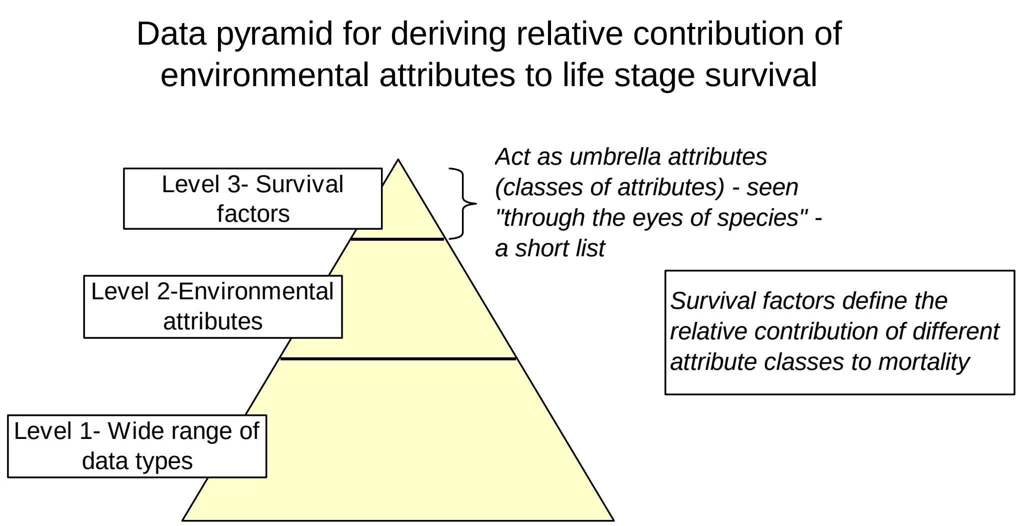

Figure 5. The EDT Information Structure can be visualized as a "data pyramid." Information begins as raw data and observations (Level 1), is organized into a species-neutral description of the environment (Level 2), and is then characterized as performance of a particular species (Level 3).

Levels 1 and 2 together characterize the environment as it can be described by different types of data. This provides the characterization of the environment needed to analyze biological performance for a species. Level 1 and Level 2 information is not specific to a species but instead forms a species-independent description of the aquatic environment. The Level 3 category of information, on the other hand, is a characterization of that same environment from a different perspective: "through the eyes of the salmon"(Mobrand et al. 1997). This category describes biological performance in relation to the state of the environment described by the Level 2 information.

The flow of information from Level 1 to Level 3 and subsequently through the EDT model is seen in Figure 6. It results in estimates of the population performance parameters described previously. The entire procedure provides a pathway for linking potential management actions to outcomes that are relevant to society's values or objectives. It provides a system of logic (rationale) to explain how actions are transferred into desired outcomes.

Before proceeding with a more complete description of the data levels, it is useful to first describe how geographic units and related scales are delineated for the analysis. Information is collected and synthesized at more than one scale.

3.2.1. Spatial Units and Scale

The Puget Sound estuarine complex is separated into two broad environmental types, consistent with the way in which survival issues are addressed in Chapter 2: (1) subestuaries and tidal marshes and (2) nearshore and deepwater estuarine. Beyond the Strait of Juan de Fuca, the ocean is divided into broad regions for modeling.

Subestuaries and tidal marshes, as defined here, are tidally influenced habitats that extend higher than MHHW (mean higher high water) and have, with two exceptions, noticeable direct freshwater input. In effect, they encompass a continuum of subestuary types from river mouth subestuaries down to very small features that have some subestuary characteristics—classified into seven types, as shown in Table 2.

Table 2. Subestuary and tidal marsh classification applied in EDT.

Type	Description
River mouth subestuary	Tidally influenced portion of stream mouths designated as rivers (with some exceptions).
Creek mouth subestuary	Tidally influenced portion of stream mouths with named creeks and that have (or had) anadromous fish spawning (with some exceptions).
Tidal channel with salt marsh and FW input	Tidally influenced portion of stream mouths with unnamed creeks without current or historic anadromous fish spawning and that have some associated tidally influenced marsh.
Tidal channel without salt marsh with FW input	Tidally influenced portion of stream mouths with unnamed creeks without current or historic anadromous fish spawning and that have some associated tidally influenced marsh.
Salt marsh without tidal channel with FW input	Tidally influenced marsh without a channel connection to marine water body with some freshwater input.
Tidal channel with salt marsh and no FW input	Tidally influenced marsh with a channel connection to marine water body and without freshwater input.
Salt marsh without tidal channel with no FW input	Tidally influenced marsh without a channel connection to marine water body and without freshwater input.

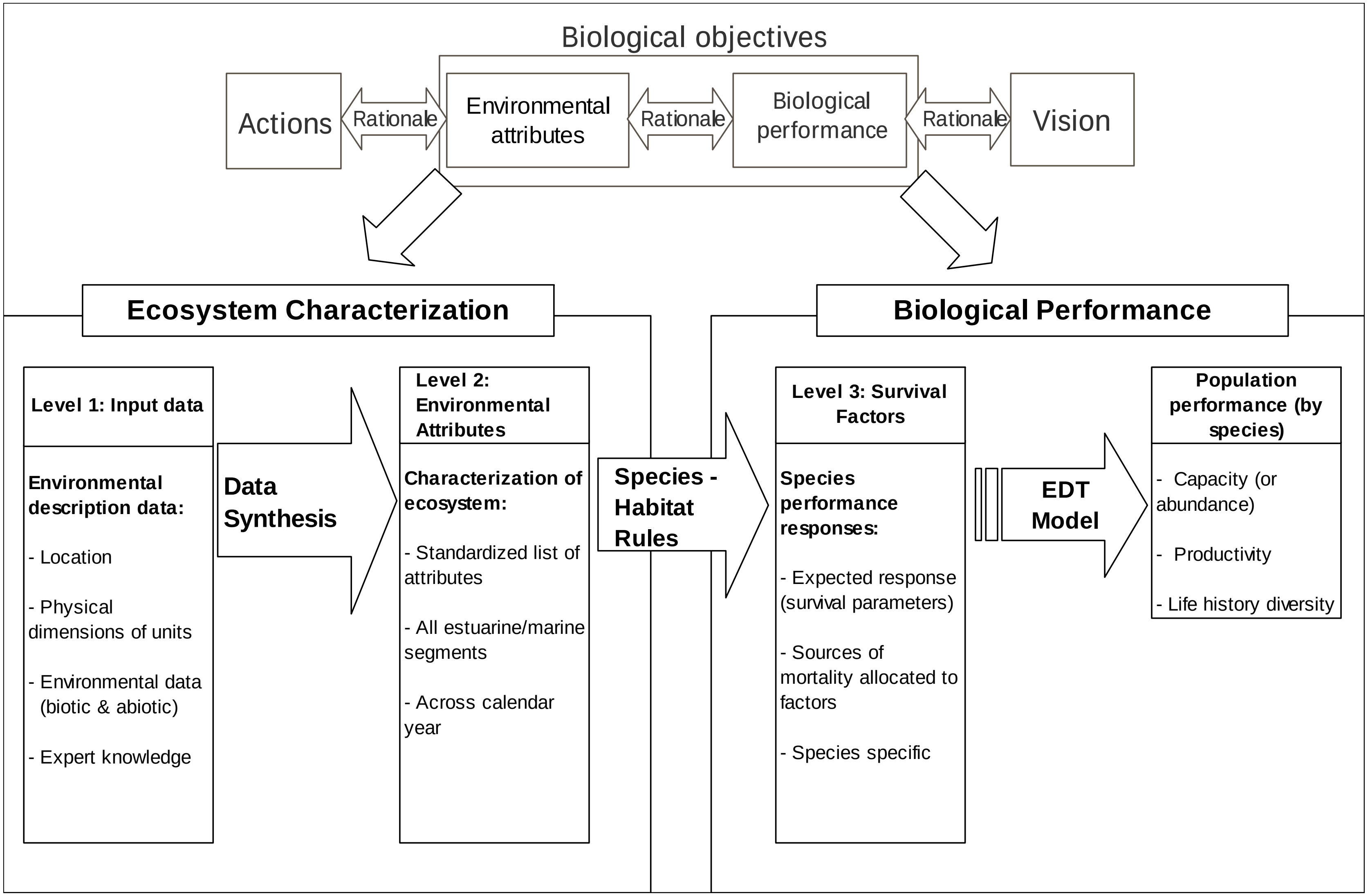

Figure 6. EDT Information Structure. Species-Habitat rules relate characteristics of the environment to potential performance of the focal species.

Each of these types is delineated and characterized separately; they may or may not have spawning streams directly connected to them. If a connecting freshwater stream is being analyzed as part of a spawning population, the natal subestuary is treated as a distinct modeling unit for the sake of the focus population. Natal subestuaries are characterized in greater detail as explained in Chapter 4.

All subestuaries and tidal marshes not directly connected to a spawning population's watershed are summarized as a part of a larger estuarine segment. In Hood Canal, 149 subestuaries and tidal marshes were identified and incorporated into the analysis. North of Hood Canal, along the west side of Admiralty Inlet, and then along the entirety of the Strait of Juan de Fuca, another 70 subestuaries and tidal marshes were identified and included in the analysis—for a total of 219 in the analysis.

The entire Puget Sound complex (including Hood Canal and the Strait) is divided into segments of an approximate scale to place the mouth of no more than one major river into a segment.

Figure 7 (displayed across two pages) shows segment boundaries for Hood Canal and the Strait. In general, segments are delineated so that river mouths are located approximately midway along a segment's shoreline. The primary trunks of Puget Sound, including Hood Canal, are segmented so that there are eastside and westside segments, joined approximately in mid channel. Large bays are delineated as single segments, often with a major river entering approximately halfway along the length of the shoreline. In Hood Canal, 20 segments were delineated. North of Hood Canal, along the west side of Admiralty Inlet, and then along the entirety of the Strait of Juan de Fuca, another 22 segments were delineated—for a total 42 in the analysis.

Each segment was further divided into two zones, a shallow littoral zone, approximately coinciding with the intertidal zone, and a deeper water zone, referred to for this application as the intertidal zone (ITZ) and the neritic zone. Different attributes were used to characterize each zone.

Much of the data used to characterize the intertidal zone within each segment is contained in the Washington Department of Natural Resource's ShoreZone database, henceforth referred to as ShoreZone (Berry et al. 2001).[13] Shoreline units, or *Shore Units*, are alongshore stretches of beach with similar geomorphological characteristics. The average length of a shore unit in the database is 0.5 miles, although their lengths vary substantially. Hood Canal and the Strait of Juan de Fuca (including Admiralty Inlet) have 574 and 362 shore units delineated, respectively.

In addition to spatial scale, a monthly temporal scale was used for characterizing conditions within the subestuaries and segments. For many attributes, conditions are assumed to be constant for all months. Other attributes have variable conditions over a 12 month period.

[13] / The WDNR ShoreZone Inventory database describes various physical and biological characteristics of the intertidal and shallow subtidal zones of Washington's saltwater shorelines statewide. The database provides a characterization of shoreline morphology, substrate, wave exposure and elements of the biota.

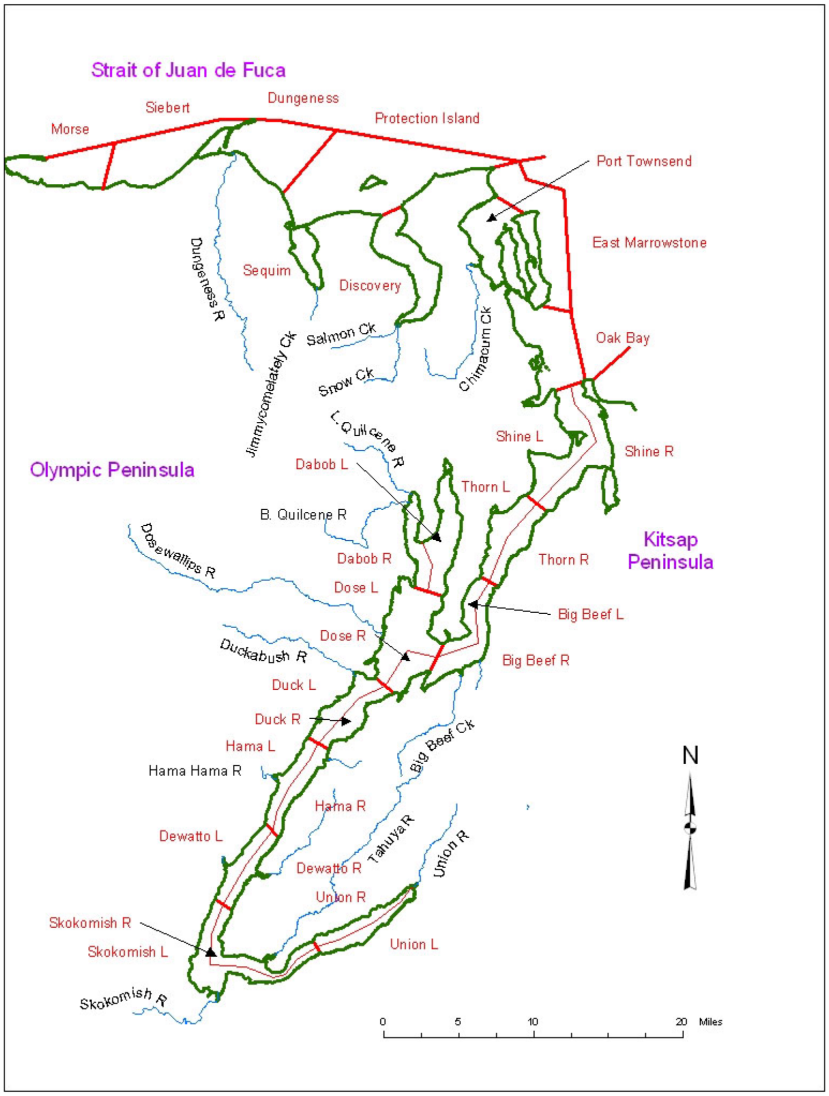

Figure 7. Segmentation of Hood Canal and the Strait of Juan de Fuca.

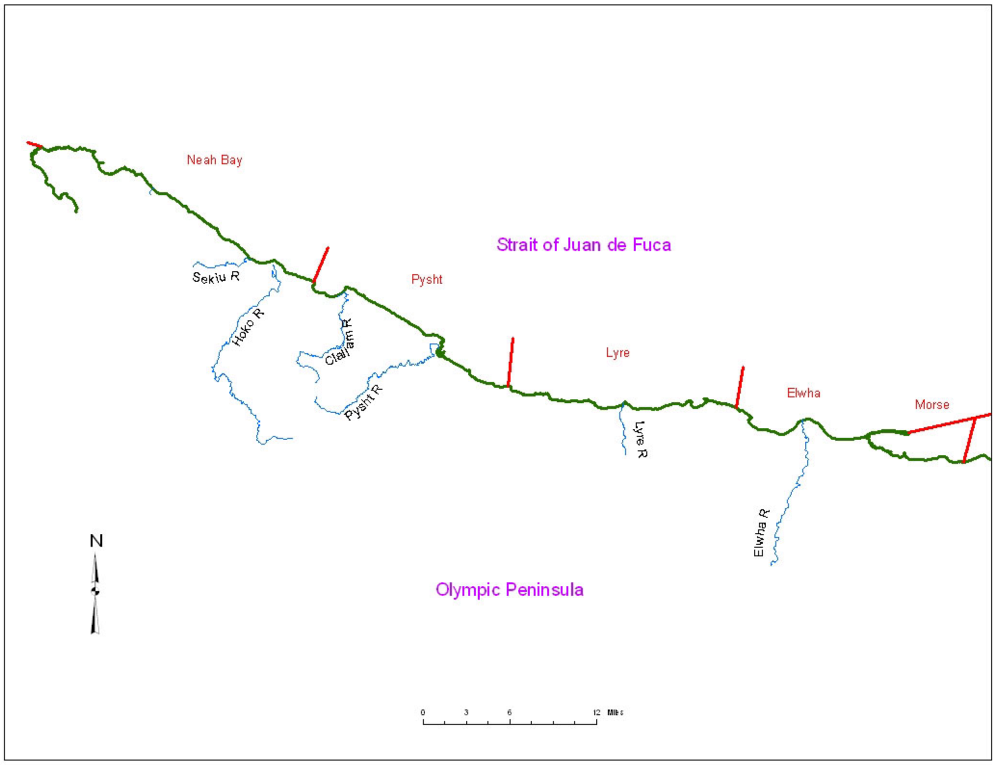

Figure 7 continued. Segmentation of Hood Canal and the Strait of Juan de Fuca.

3.2.2. Level 1 Information

Level 1 information within the EDT Information Structure consists of all the various types of data and information available to be used in characterizing the environment. These data exist in many forms and pedigrees—they may be contained in formal databases, such as ShoreZone, or they may be conclusions presented in reports. Within a watershed, Level 1 data include such items as flow, sediment load, temperature, physical habitat, land use and ownership, elevation, slope, and so on. Within estuarine and marine environments, important data include various physical descriptors contained in the ShoreZone database such as shoreline type, percent shoreline developed, width of the intertidal zone, distribution of eelgrass, and so on. The rules were developed to be driven largely by data contained in the ShoreZone database to ensure that a major part of the data needed is readily available. Also included as Level 1 data is any information on the spatial and temporal structure of the data. Some segments of the Puget Sound complex will have more data than others with respect to certain habitat components, such as condition of subestuaries. Level 1 information includes empirical measurements as well as conclusions of expert observers.

Table 3 lists Level 1 data that are incorporated directly into the characterization of the estuarine and nearshore environment of Puget Sound—other data may be used as well. These data form the basis for the refined description of the environment in Level 2.

Table 3. Partial list of Level 1 data applied in analysis. Data obtained from ShoreZone are listed along with subestuary and tidal marsh sites.

ShoreZone code	Name	Attribute class	Scale	Zone	Definition	Type of data needed to characterize reach
ReachLength	Reach length	Unit size	Reach	All	Length of reach; applies to all zones. Measured in feet.	ShoreZone - data available
ReachWidth	Reach width	Unit size	Reach	All	Width of reach; applies to all zones. Width of intertidal reaches (excluding river mouth estuaries) is available in the Washington ShoreZone database (intertidal defined to begin at 0 ft elevation, MLLW). Measured in feet.	ShoreZone - data available
ShoreCodeSZ	Shoreline type - SZ	Shoreline features	Reach	Intertidal	The dominant shoreline type within the reach, based on types used in Washington ShoreZone (a simplification of the BC shoreline classification).	ShoreZone - data available
SubstrateCode	Substrate type	Shoreline features	Reach	Intertidal	The dominant substrate type within the reach, based on seven types used in Washington ShoreZone.	ShoreZone - data available
TideRange	Tidal range	Shoreline features	Reach	Intertidal	Vertical tidal change expressed in meters.	ShoreZone - data available
ExposureCode	Wave exposure	Energy exposure	Reach	Intertidal	The extent that the reach is exposed to wave action (consistent with exposure definition used in Washington ShoreZone). Convert the ShoreZone field Exp_Class, which is alpha code, to numeric.	ShoreZone - data available
ShoreModTotPct	Shoreline modification total percent	Shoreline features	Reach	Intertidal	The percent of the bank that has been modified by bulkhead, riprap, and other man-made structures, based on data in Washington ShoreZone.	ShoreZone - data available
ShoreMod1Code	Shoreline primary modifier type	Shoreline features	Reach	Intertidal	The primary type of shoreline modification occurring with the reach unit as used in ShoreZone. Convert the ShoreZone "smodtext" (alpha) to numeric.	ShoreZone - data available
ShoreMod1Pct	Shoreline modification - primary type percent	Shoreline features	Reach	Intertidal	The estimated percent of the shoreline in the reach unit modified by the primary type of modifier, as used in ShoreZone.	ShoreZone - data available
PierDockCount	Pier and dock count	Shoreline features	Reach	Intertidal	The number of piers, docks, and wharves that occur within the reach unit.	ShoreZone - data available
SlipsSmallCount	Vessel slips count - small vessels	Shoreline features	Reach	Intertidal	The number of slips for vessels smaller than approx. 100 ft in length.	ShoreZone - data available
SlipsLargeCount	Vessel slips count - large vessels	Shoreline features	Reach	Intertidal	The number of slips for vessels larger than approx. 100 ft in length.	ShoreZone - data available
RiparianVegPct	Riparian vegetation	Riparian condition	Reach	Intertidal	The percent of the reach with vegetation that hangs over into the intertidal zone based on Washington ShoreZone data. Riparian estimated only for unconsolidated (gravel, pebble, sand, mud, etc) shorelines.	ShoreZone - data available
EelgrassCode	Eelgrass abundance	Biological community	Reach	Intertidal	The abundance of eelgrass (*Z. marina* and *Z. japonica*) within the reach unit; abundance expressed as continuous, patchy, or not present, based on data in Washington ShoreZone.	ShoreZone - data available
KelpCode	Kelp abundance	Biological community	Reach	Intertidal	The abundance of kelp (all species) within the reach unit; abundance expressed as continuous, patchy, or not present, based on data in Washington ShoreZone.	ShoreZone - data available
SaltMarshCode	Salt marsh abundance	Biological community	Segment	Intertidal	The abundance of sites within the reach unit where salt tolerant vascular plants are continuous, patchy, or absent, based on data in Washington ShoreZone.	ShoreZone - data available
RiverMouthEstCount	River mouth estuary count	Shoreline features	Reach	Intertidal	Number of river mouth estuaries within the shoreline unit. These might be considered pocket estuaries because of scale.	Manual inspection of overlays of GIS layers.
CreekMouthEstCount	Creek mouth estuary count	Shoreline features	Reach	Intertidal	Number of creek mouth estuaries (type of pocket estuary) within the shoreline unit.	Manual inspection of overlays of GIS layers.
TidalMarshCount	Tidal channel estuary count	Shoreline features	Reach	Intertidal	Number of tidal channel estuaries (type of pocket estuary) within the shoreline unit.	Manual inspection of overlays of GIS layers.

3.2.3. Level 2 Information

Level 2 information within the EDT Information Structure consists of a standardized set of attributes used to characterize the aquatic environment for the modeling process (Table 4). Level 2 Environmental Attributes create a generalized depiction of the environment, essentially as a set of conclusions derived from the Level 1 information (Figure 6). Application of the attributes differs with regard to the various components of the estuarine and marine environments (Table 4).

Table 4. Organization of Level 2 Environmental Attributes for the estuarine and marine environments. Salmonid Survival Factors (Level 3) are shown associated with groups of Level 2 attributes. Associations can differ by species and life stage. See Appendix F for association matrices for chum salmon.

Environmental attributes (Level 2)		Ocean region	Estuarine nearshore-deepwater segment	Subestuary unit	Related survival factors
1 Climate					
Climate regime	Pacific Decadal Oscillation (PDO)	x	x		Food
2 Basin/shoreline features					
Morphometry	Unit length	x	x	x	Flow Food Habitat diversity Key habitat quantity Predation
	Unit width	x	x	x	
	Intertidal zone (ITZ) width		x		
	Slope of intertidal zone		x		
Flow and circulation	Stream flow - change in average annual peak flow			x	
	Stream flow - change in average annual peak low flow			x	
	Surface outflow average velocity		x		
	Wave exposure		x		
Shoreline/ channel structure	Accessibility to subestuary habitats			x	
	Channel complexity			x	
	Channel depth - tidal channels			x	
	Confinement - hydromodifications			x	
	Density of subestuary and tidal marsh types		x		
	Dock-slip density		x		
	Loss in function of subestuary and tidal marsh types		x	x	
	Ratio of river/creek watersheds to ITZ in segment		x		
	Ratio of total emergent vegetation to ITZ in segment		x		
	Ratio of emergent vegetation to watershed size			x	
	Ratio of subestuary size to watershed size			x	
	Riparian function - subestuary			x	
	Riparian vegetation - segment		x		
	Shoreline modifications in segment (percent)		x		
	Shoreline type (percent)		x		
	Wood debris in subestuary			x	
3 Biological community					
Competitors or	Hatchery salmonid releases		x	x	Competition

Table 4. Organization of Level 2 Environmental Attributes for the estuarine and marine environments. Salmonid Survival Factors (Level 3) are shown associated with groups of Level 2 attributes. Associations can differ by species and life stage. See Appendix F for association matrices for chum salmon.

Environmental attributes (Level 2)		Ocean region	Estuarine nearshore-deepwater segment	Subestuary unit	Related survival factors
predators	Status of marine fish		x		Food Habitat diversity Predation
	Status of marine mammals		x	x	
	Status of seabirds		x	x	
	Status of wild salmonids		x	x	
Food resources and/or refuge	Eelgrass - all percent		x		
	Eelgrass - continuous percent		x		
	Kelp - all percent		x		
	Kelp - continuous percent		x		
	Salmon carcasses		x	x	
	Zooplankton within the upper water column		x		
4 Water quality					
Chemistry	Dissolved oxygen		x	x	Chemicals (toxics) Temperature
	Metals in water column		x	x	
	Metals/pollutants in sediments		x	x	
	Misc toxic pollutants - water column		x	x	
Temperature	Temperature - daily maximum		x	x	

Level 2 Environmental Attributes are measurable characteristics of the environment that relate to salmonid performance. They are the main input to EDT. EDT Environmental Attributes are similar to the concept of environmental attributes used by Morrison et al. (1998) to describe species-habitat relationships for terrestrial environments. In concept, a set of Level 2 Attributes may be described for analyzing the environment with respect to any species. Environmental Attributes are defined in Table 5.

Some of the Level 2 attributes listed in Table 4 actually encompass more than one attribute. Those attributes that refer to subestuaries and tidal marshes, for example, encompass seven types of environmental features (each being a separate attribute here), listed in Table 2.

The attribute "Density of subestuary and tidal marshes" in Table 4 also encompasses seven different attributes, one for each of the different types in Table 2. Similarly, the attribute that refers to wild salmonid status and hatchery salmonid releases encompasses multiple Level 2 attributes.

Table 5. Definitions of Level 2 Environmental Attributes applied to estuarine and marine environments.

Category	Attribute	Definition	Data source
1 Climate			
Climate regime	Pacific Decadal Oscillation (PDO)	The prevailing state of the Pacific Decadal Oscillation (PDO) corresponding to the scenario of interest.	Assumption about scenario being analyzed.
2 Basin/shoreline features			
Morphometry	Unit length	Length of subestuary (natal), segment or region; applies to all zones. Measured in meters.	Maps and ShoreZone database.
Morphometry	Unit width	Width of subestuary (natal), segment or region; applies to all zones. Measured in meters.	Maps and ShoreZone database.
Morphometry	ITZ Width	Width of the intertidal zone for the segment. Measured in meters.	ShoreZone database.
Morphometry	Slope of intertidal zone	Average slope of the intertidal zone within the segment (weighted by ShoreZone unit length).	Derived from tidal range and ITZ width in ShoreZone database.
Flow and circulation	Stream flow - change in average annual peak flow	The extent of relative change in average peak annual discharge compared to an undisturbed watershed of comparable size, geology, orientation, topography, and geography (or as would have existed in the pristine state). See definitions applied to corresponding input stream.	Same rating as applied in lower freshwater reach for stream.
Flow and circulation	Stream flow - change in average annual peak low flow	The extent of relative change in average daily flow during the normal low flow period compared to an undisturbed watershed of comparable size, geology, and flow regime (or as would have existed in the pristine state). See definitions applied to corresponding input stream.	Same rating as applied in lower freshwater reach for stream.
Flow and circulation	Surface outflow average velocity	Average velocity of the surface outflow within the segment during a month measured in cm/sec.	From Bax (1982) for Hood Canal; similar approach as in Bax (1982) for other areas of Puget Sound or from inferences.
Flow and circulation	Wave exposure	Average wave exposure of the intertidal zone within the segment (weighted by ShoreZone unit length).	ShoreZone database.
Shoreline/channel structure	Accessibility to subestuary habitats	The extent that all portions of a subestuary are accessible to juvenile salmonids during tidal stages that would normally facilitate access; e.g., tidal gates may block access.	Knowledge of technical experts.
Shoreline/channel structure	Channel complexity	The extent that the subestuary's channel pattern is dendritic or sinuous through its course; natural channels may be simple or complex; estuarine development typically alters complex patterns to simple ones.	Knowledge of technical experts or by visual inspection of WDOE's Wash Coastal Atlas photos.
Shoreline/channel structure	Channel depth - tidal channels	Range of depths in primary tidal channels at MLLW during the low flow period (describes conditions that may result in migration delay or stress for adult salmon). Depths may be influenced by aggradation of channels or change in flow.	Knowledge of technical experts or by visual inspection of WDOE's Wash Coastal Atlas photos.
Shoreline/channel structure	Confinement - hydromodifications	The extent that man-made structures within or adjacent to the subestuary channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain and delta (due to streamside roads, revetments, diking or levees). See definitions applied to corresponding input stream.	Knowledge of technical experts or by visual inspection of WDOE's Wash Coastal Atlas photos.
Shoreline/channel structure	Density of subestuary and tidal marsh types	Density of subestuary and tidal marsh types within the shoreline segment by the seven types. Density as number per mile of shoreline.	Manual inspection of overlays of GIS layers with knowledge of technical experts (may suffice to visually inspect WDOE's Wash Coastal Atlas photos).
Shoreline/channel structure	Dock-slip density	The density of docks, piers, and slips within the segment, expressed as the total number per mile of shoreline.	ShoreZone database.
Shoreline/channel structure	Loss in function of subestuary and tidal marsh types	Average percent loss of function of subestuary and tidal marsh types within the segment by the seven types.	Knowledge of technical experts (as in Hood Canal) or derived by EDT rules (see text).
Shoreline/channel structure	Ratio of emergent vegetation to watershed size	Ratio of the amount of area encompassing emergent vegetation within the subestuary to the size of the subestuary's watershed.	Manual inspection of overlays of GIS layers with knowledge of technical experts (may suffice to visually inspect WDOE's Wash Coastal Atlas photos).
Shoreline/channel structure	Ratio of river/creek watersheds to ITZ in segment	Ratio of the total area of river and creek watersheds entering the segment to the intertidal zone area within the segment.	Simple ratio of watershed areas (data readily available) to area from ShoreZone database.
Shoreline/channel structure	Ratio of subestuary size to watershed size	Ratio of the amount of area encompassing emergent vegetation and mudflat within the subestuary to the size of the subestuary's watershed.	Simple ratio of emerg vegetation and mudflat areas (from experts or by review of WDOE Wash Coastal Atlas photos) to watershed area.

Table 5. Definitions of Level 2 Environmental Attributes applied to estuarine and marine environments.

Category	Attribute	Definition	Data source
Shoreline/channel structure	Ratio of total emergent vegetation to ITZ in segment	Ratio of total area of emergent vegetation to the intertidal zone area within the segment	Simple ratio of emerg vegetation (from experts or by review of WDOE Wash Coastal Atlas photos) to ITZ area from ShoreZone database.
Shoreline/channel structure	Riparian function - subestuary	A measure of riparian function that has been altered within the subestuary.	Knowledge of technical experts associated with freshwater assessment.
Shoreline/channel structure	Riparian vegetation - segment	The total percent of the shoreline within the segment with vegetation that hangs over into the intertidal zone based on Washington ShoreZone data. Riparian estimated only for unconsolidated (gravel, pebble, sand, mud, etc) shorelines.	ShoreZone database.
Shoreline/channel structure	Shoreline modifications segment percent	The total percent of the shoreline that has been modified by bulkhead, riprap, and other man-made structures, based on data in Washington ShoreZone.	ShoreZone database.
Shoreline/channel structure	Shoreline type (percent)	Percent of shoreline within segment composed of four different shoreline types containing substantial amounts of sand substrate. Shoreline types are those used in Washington ShoreZone (a simplification of the BC shoreline classification). The four types are sand flats, sand and gravel flats, sand and gravel beaches, and sand beaches.	ShoreZone database.
Shoreline/channel structure	Wood debris in subestuary	Amount of wood within the subestuary's channels. Dimensions of what constitutes wood are defined here as pieces >0.1 m diameter and >2 meter in length.	Knowledge of technical experts associated with freshwater assessment.
3 Biological community			
Competitors or predators	Hatchery salmonid releases	Relative magnitude of hatchery Chinook, coho, fall chum, summer chum, pink, steelhead and cutthroat that utilize the subestuary or estuarine segment.	Knowledge of technical experts associated with freshwater assessment.
Competitors or predators	Status of marine fish populations	Status of marine fish populations in the segment.	Knowledge of technical experts.
Competitors or predators	Status of marine mammals	Status of marine mammals in the subestuary or estuarine segment.	Knowledge of technical experts.
Competitors or predators	Status of seabirds	Status of seabirds in the subestuary or estuarine segment.	Knowledge of technical experts.
Competitors or predators	Status of wild salmonids	Status of wild salmonids by species: Chinook, coho, fall chum, summer chum, pink, steelhead, cutthroat	Knowledge of technical experts.
Food resources and/or refuge	Eelgrass - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous eelgrass; abundance classified as continuous, patchy, or not present in Washington ShoreZone.	ShoreZone database.
Food resources and/or refuge	Eelgrass - continuous percent	The total percent of the lineal shoreline within the segment containing continuous eelgrass; abundance classified as continuous, patchy, or not present in Washington ShoreZone.	ShoreZone database.
Food resources and/or refuge	Kelp - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous kelp (all species); abundance classified as continuous, patchy, or not present in Washington ShoreZone.	ShoreZone database.
Food resources and/or refuge	Kelp - continuous percent	The total percent of the lineal shoreline within the segment containing continuous kelp (all species); abundance classified as continuous, patchy, or not present in Washington ShoreZone.	ShoreZone database.
Food resources and/or refuge	Salmon carcasses	Relative abundance of anadromous salmonid carcasses within the subestuary watershed.	Knowledge of technical experts associated with freshwater assessment.
Food resources and/or refuge	Zooplankton within the upper water column	Index of average abundance of zooplankton within the segment during a month (in neritic waters).	Knowledge of technical experts or applies default value.
4 Water quality			
Chemistry	Dissolved oxygen	Average dissolved oxygen within the water column for the specified time interval.	Knowledge of technical experts.
Chemistry	Metals in water column	The extent of dissolved heavy metals within the water column.	Knowledge of technical experts.
Chemistry	Metals/pollutants in sediments	The extent of heavy metals and miscellaneous toxic pollutants within the stream sediments and/or soils adjacent to the stream channel.	Knowledge of technical experts.
Chemistry	Misc toxic pollutants - water column	The extent of miscellaneous toxic pollutants (other than heavy metals) within the water column.	Knowledge of technical experts.
Temperature	Temperature - daily maximum	Maximum water temperatures within the stream reach during a month.	Knowledge of technical experts.

The attribute "Shoreline type" in the ShoreZone database encompasses 15 types of shorelines/substrates—this classification is a simplification of the British Columbia shoreline classification:

- Rock platform
- Rock cliff
- Rock with gravel beach
- Rock with sand and gravel beach
- Rock with sand beach
- Gravel beach
- Sand and gravel beach
- Sand beach
- Sand flat
- Mud flat
- Estuary wetland
- Man-made
- Sand and gravel flat
- Gravel flat
- Channel

Eight types of hatchery salmonid releases are rated—classified by species and whether or not yearlings or subyearlings are included:

- Subyearling Chinook
- Yearling Chinook
- Coho (yearlings)
- Fall chum
- Summer chum
- Pink
- Steelhead (yearling and older)
- Cutthroat (yearling and older)

Seven salmonid species are rated for population status within subestuaries and estuarine segments:

- Chinook
- Chum—fall
- Chum—summer
- Coho
- Pink
- Cutthroat
- Steelhead

The Level 2 characterization describes conditions in the estuarine and marine environments within geographic locations (e.g., a stream mouth estuary or a nearshore segment), by time of year (specific months), and by scenario (template, current[14], or a future scenario). Thus, values assigned for each Environmental Attribute represent conclusions—i.e., assumptions—about the environment by estuarine segment, month, and scenario based on the Level 1 data and observations. These assumptions become operating hypotheses for these attributes under specific scenarios. Where Level 1 data are sufficient, Level 2 conclusions can be derived directly or through simple algorithms. However, where Level 1 data are incomplete, experts are needed to provide knowledge about geographic areas and attributes. Regardless of the types of information used to derive the Environmental Attribute ratings, the Level 2 Environmental Attributes are measurable characteristics of the environment that can be monitored and ground-truthed over time through an adaptive process.

Most Level 2 Attributes are characterized using ratings on a scale of 0 to 4, spanning a spectrum of conditions. There is a consistent direction to the attribute ratings, where 0 or low values will tend to correspond with pristine environmental conditions, or at least be favorable to salmonid survival, and higher values tend toward more degraded conditions.

Table 6 gives examples of the index values for three Environmental Attributes used to characterize the nearshore estuarine environment.

Table 6. Examples of rating indexes for Level 2 Environmental Attributes used in characterizing the shallow nearshore environment of Puget Sound. The three attributes shown are used, along with others, to assess the available food supply for juvenile salmon in nearshore segments.

Percent of shoreline having continuous eelgrass	
Rating	**Rating definition**
0	> 52.5% continuous eelgrass
1	> 37.5% and ≤ 52.5% continuous eelgrass
2	> 22.5% and ≤ 37.5% continuous eelgrass
3	> 7.5% and ≤ 22.5% continuous eelgrass
4	≤ 7.5% continuous eelgrass
Percent of shoreline modified by development	
Rating	**Rating definition**
0	≤ 12.5% shoreline developed
1	> 12.5% and ≤ 37.5% shoreline developed
2	> 37.5% and ≤ 62.5% shoreline developed
3	> 62.5% and ≤ 87.5% shoreline developed
4	> 87.5% shoreline developed
Percent of shoreline with overhanging riparian vegetation	
Rating	**Rating definition**
0	> 87.5% riparian vegetation
1	> 62.5% and ≤ 87.5% riparian vegetation
2	> 37.5% and ≤ 62.5% riparian vegetation
3	> 12.5% and ≤ 37.5% riparian vegetation
4	> 12.5% riparian vegetation

[14] The Current condition in EDT is often referred to as the Patient condition reflecting the terminology of Lichatowich et al. (1995).

A rating for each of these attributes is defined as a range of conditions—for example, a rating of 1 for the attribute "Percent of shoreline having continuous eelgrass" says that between 37.5 and 52.5 percent of the shoreline consists of continuous eelgrass. The indexing system in EDT allows for use of either integer or continuous scale ratings depending on the information available for doing the characterization. Each attribute listed in Table 6 utilizes ShoreZone data, which results in point estimates for each of these attributes. So, for example, if the amount of shoreline with continuous eelgrass from ShoreZone is estimated to be 37.5 percent, the rating value would be 1.5, the midpoint between the ratings 1 and 2. Index value definitions for Level 2 Environmental Attributes are provided in Appendix C.

Two of the Level 2 Attributes do not use the rating scale of 0 to 4. They identify segment length and segment width, and the average width of the ShoreZone intertidal zone.

3.2.4. Level 3 Information

The species-habitat rules translate the species-neutral Level 2 characterization of the environment into a species-specific depiction of habitat expressed through Level 3 Survival Factors. The factors are both species and life stage specific. They serve to group the effects of Environmental Attributes into broader synthetic concepts of habitat conditions for the species. The purpose of grouping effects of attributes in this manner is to allocate mortality by the types of factors that biologists often refer to in environmental analysis (e.g., limiting factors analysis). The Survival Factors facilitate a clearer connection between the Environmental Attributes and the contributing causes of mortality. It should be recognized that the EDT Survival Factors are not equivalent to the four direct causes of death, or fates: starvation, disease, predation, and environmental stress.

Survival Factors are defined in Table 7; the same factors are also applied in freshwater environments.

Table 7. Definitions of Level 3 Survival Factors; special applications to estuarine and marine environments are noted.

Factor	Definition
Channel stability	The effect of stream channel stability (within reach) on the relative survival or performance of the focus species; the extent of channel stability is with respect to its streambed, banks, and its channel shape and location. This attribute is applicable only to subestuaries within estuarine/marine systems.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition (with hatchery fish)	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the subestuary or estuarine/marine segment.
Competition (with other species)	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space.
Flow	The effect of the amount of stream flow or estuarine surface outflow velocity, or the pattern and extent of flow fluctuations, within the stream reach or estuarine/marine segment on the relative survival or performance of the focus species.
Food	The effect of the amount, diversity, and availability of food that can support the relative survival or performance of the focal species.
Habitat diversity	The effect of the extent of habitat complexity or diversity within a stream reach or estuarine/marine segment on the relative survival or performance of the focus species.

Table 7. Definitions of Level 3 Survival Factors; special applications to estuarine and marine environments are noted.

Factor	Definition
Harassment	The effect of harassment, poaching, or non-directed harvest (i.e., as can occur through hook and release) on the relative survival or performance of the focus species.
Key habitat	The relative quantity of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel or of the estuarine/marine segment.
Obstructions	The effect of physical structures impeding movement of the focus species on its relative survival or performance within a stream reach or an estuarine/marine segment; structures in estuarine reaches include tidal gates, culverts, and porous dikes or breakwaters.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach or estuarine/marine segment on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach or estuarine/marine segment on the relative survival or performance of the focus species. The life stage when infection occurs is when this effect is accounted for.
Predation	The effect of the relative abundance of predator species on the relative survival or performance of the focus species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the stream reach or estuarine/marine segment on the relative survival or performance of the focus species. This attribute includes turbidity effects.
Temperature	The effect of water temperature with the stream reach or estuarine/marine segment on the relative survival or performance of the focus species.
Withdrawals (or entrainment)	The effect of entrainment (or injury by screens) at water withdrawal or diversion structures within the stream reach or estuarine/marine segment on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow attribute.

The number of Survival Factors is greatly condensed from the total number of Level 2 Attributes; hence the Factors operate in a sense as "umbrella attributes." The factors represent habitat conditions pertaining to the focal species, consistent with the way habitat is defined by Simenstad et al. (2000), discussed previously.

Table 7 illustrates in a very general way the association of Level 2 Environmental Attributes to Level 3 Survival Factors. Specific associations of Level 2 Attributes and Level 3 Factors for chum salmon are found in Appendix D.

3.3. Rule structure

The species-habitat rules translate the Level 2 Environmental Attributes into the Survival Factors described above. The rules for chum and pink salmon were developed so that survival in the estuarine and marine environments is driven more by those factors that operate in a density-independent manner than those that operate through density-dependence. Reference to population density here refers to the density of the focal population (i.e., the specific population being analyzed). Survival will therefore be determined more by the factors associated with habitat quality (i.e., productivity), than with those that define habitat quantity, such as the amount of key habitat. Seen from the perspective of the focal population, this is an appropriate assumption. It is recognized that chum salmon produced from a single population compete with other chum populations within the nearshore environment—but that constitutes a density-independent effect seen from the perspective of the focal population.

3.3.1. Rules for Estimating Productivity

Productivity in EDT is a measure of the quality of the environment with respect to the focal species and population. The life stage productivity value associated with a specific estuarine or marine segment is defined as the density independent survival rate expected if the entire life stage occurred under the conditions in that segment.[15]

The rules presented here assume that productivity, P , can be partitioned into the set of sixteen independent multiplicative Survival Factors F_i , i.e.

$$P = P_0 \cdot F_1 \cdot F_2 \cdot F_3 \cdots F_{16}$$

where $0 < F_i < 1$ are relative productivity values and P_0 is the benchmark survival (Appendix B and discussion above). Each $F_i < 1$ acts to reduce P from the benchmark productivity due to habitat conditions that are less than optimal corresponding to that F_i in the given segment. When the segment has optimal conditions corresponding to all factors, i.e., $F_i = 1$ for all Level 3 factors, then, $P = P_0$.

It is assumed that each Level 3 Survival Factor F_i can be estimated as a function of the condition of the Level 2 Environmental Attributes within each segment, based on the relative importance of each attribute to survival associated with the factor. Two different approaches are used to compute F_i depending on the Survival Factor. The same approaches are used in both the natal river mouth or creek mouth subestuary and in the estuarine-marine systems beyond.

3.3.1.1. All Survival Factors except Competition and Predation

For all Survival Factors except Competition (with other species and with hatchery fish) and Predation, an approach that is simplified from the one generally used for freshwater riverine reaches (see Lestelle et al. 2004) is applied. For the freshwater riverine reaches, a synergistic form for the rules was developed that assumed Environmental Attributes often operate synergistically to affect survival expressed through the various Survival Factors. That form for the rules required the development of relationships between each individual Environmental Attribute and life stage sensitivity and a consideration of the synergy between attributes. In estuarine and marine environments, knowledge is more limited with respect to the ways in which attributes operate in concert to affect survival. Therefore a simpler approach is warranted, though one that still addresses the various issues identified earlier as determinants of survival.

The rule structure is referred to in this form of the rules as the Weighted Rating Form, to distinguish it from the synergistic form used primarily for freshwater rules. The relative importance of each attribute to the effect of a Survival Factor is defined in the rule by a weighting factor w_j used to compute an average weighted rating for all of the relevant attributes. Weights represent conclusions about the relative effect of each contributing attribute. Computation of the average weighted rating WR_i associated with a Survival Factor F_i is simply

[15] / Differences in conditions between months are handled within EDT by modeling life history trajectories to capture how groups of fish experience changes in environmental conditions in space and time.

$$WR_i = \frac{\sum_j R_{i,j} w_{i,j}}{\sum_j w_{i,j}}$$

where $R_{i,j}$ is the rating for Environmental Attribute *j*. In some cases, a grouped rating $GR_{i,j,m}$ is first obtained for a subset of *k* Environmental Attributes as

$$GR_{i,j,m} = \frac{\sum_k R_{i,j,k} w_{i,j,k}}{\sum_k w_{i,j,k}}$$

This grouped rating is then applied in place of the attributes being grouped in the equation for WR_i above. Certain attributes are grouped in this manner because of their close similarity in ecological function. Examples of these two forms are found in Chapter 4.

Each survival factor F_i is then defined as:

$$F_i = 1 - S_i$$

where S_i is the sensitivity of survival of the species to the aggregate contributing Environmental Attributes, i.e., to the average weighted rating for those attributes as defined by:

$$S_i = aWR_i^b$$

where *a* and *b* are parameters defining sensitivity S_i as a function of WR_i.

The sensitivity of the species expressed through each Survival Factor represents the working hypotheses about the response of the species to the constituent attributes across a range of conditions.

An example of a sensitivity curve for a single Survival Factor is illustrated in Figure 8. This figure shows sensitivity to the aggregate attributes contributing to the grouped rating for Food. The sensitivity curves are based on the synthesis of the issues affecting chum salmon performance summarized in Chapter 2. Results of a procedure developed in 2000 for assessing the relative condition of Puget Sound river mouth subestuaries for juvenile performance (Lestelle and Blair 2005) was taken into consideration here.

It should be noted that ratings may vary for some attributes by month to account for seasonal patterns, such as occurs for some of the flow attributes. As a result, the effect of some attributes on productivity will vary across a calendar year.

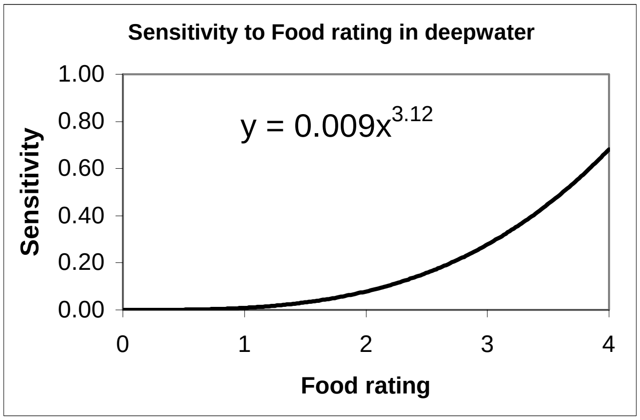

Figure 8. Example of a sensitivity relationship, here illustrating sensitivity of juvenile chum salmon to the average weighted rating of attributes contributing to the availability of forage in estuarine deepwater areas (simply called Food here).

3.3.1.2. Competition and Predation Survival Factors

The Survival Factors that address Competition and Predation directly use a different form for the rule structure. Here, it is assumed that the Environmental Attributes, specifically those that describe the status of different competing or predatory species, operate independently of each other. The Independent Form of the rule assumes a simple multiplicative effect of each competing or predatory species:

$$F_i = \prod_j (1 - S_{i,j})$$

Similar to Figure 8, the sensitivity of the focal species to each competing or predatory species is captured through an assumed relationship between the status of each competitor or predator species in the segment and sensitivity (or mortality) as defined by:

$$S_{i,j} = aR_{i,j}{}^{b}$$

where *a* and *b* are parameters defining sensitivity S_i as a function of $R_{i,j}$. These sensitivity relationships represent the working hypotheses about the effects of individual competitor or predator species on the focal species (Figure 9).

This form of the rule structure has also been applied in EDT to predation effects in large lakes and to competition and predation for bull trout in freshwater. It is considered to be the most appropriate form to use for competition and predation effects in EDT. The predation rule assumes that a Type I functional response (Holling 1959; Begon and Mortimer 1986) by predators applies. This means that predators prey on juvenile chum produced by the focal population at a constant rate with no provision for predator satiation. Seen from the perspective of the focal population, this assumption is probably reasonable.

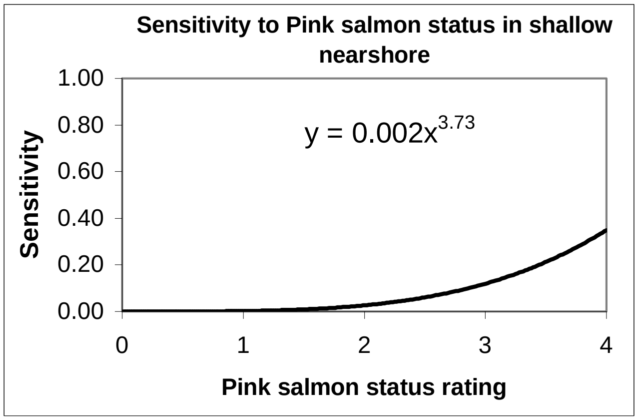

Figure 9. Example of a sensitivity relationship for interspecific competition, here illustrating sensitivity of juvenile chum salmon to juvenile pink salmon, where the rating for pink salmon represents population status.

3.3.2. Rules for estimating Key Habitat

Key Habitat is defined as the primary habitat type(s) utilized by a species during a particular life stage; it quantifies how much habitat is directly used by the species during specific life stages. Key Habitat is a Level 3 Survival Factor that affects the way in which density-dependent survival operates.

Key habitat for all life stages and geographic segments is assumed to consist of the entire area encompassed by the segment. This assumption was applied to natal subestuaries and all segments within the marine environment for chum salmon—thus, the quality of the environment is the primary constraint on capacity, operating through productivity, within an overall constraint of the size of the body of water.[16]

[16] Environmental carrying capacity illustrated in the stock-production relationship is actually a function of both quantity of resources (ones that are competed for) and environmental quality—easily seen in a disaggregated production function, see Moussalli and Hilborn (1986) and pages 284-285 in Hilborn and Walters (1992).

Chapter 4
Highlighted Survival Factors and Examples of Rules

This chapter describes specific rules for Survival Factors selected to illustrate the way in which the rules operate. These rules address the issues regarded as the most important ones facing chum salmon, particularly summer chum, within estuarine and marine systems. The logic, approach, and key studies applied are given.

The rules work in conjunction with the benchmark survival rates for each life stage and environmental type, i.e., natal subestuary, shallow nearshore (epibenthic phase), deepwater estuarine (neritic phase), and oceanic. Under benchmark survivals (i.e., ideal survival conditions), average estuarine/marine survival rates will vary depending on the state of the PDO between approximately two to six percent (fry to age 4 adult) within the EDT model.[17] The highest mortality rates (per week) are assumed to occur during the early estuarine/marine phases of life, consistent with the findings of Parker (1965, 1968), Bax (1983b), and Whitmus (1985) for pink and chum salmon. Peak natural mortality rates are assumed to be associated with the epibenthic phase of the fry outmigration, as suggested by the latter two authors.

It is important to note mortality was ascribed to the life phase where the fish experience conditions that result either in mortality at that time or that contribute significantly to subsequent death. For example, if fish experience poor forage in one life phase resulting in severely retarded growth, which then increases the likelihood for mortality in a subsequent life phase, the mortality is accounted for in the earlier life phase.

The allocations of mortality to the various Survival Factors are based on the synthesis of findings presented in Table 1 in Section 2.4. Two major working hypotheses are important underpinnings of the allocations:

- The average estuarine/marine survival rate of summer chum produced in Hood Canal under a developed state is approximately one third of that for fall chum.
- The two most significant causes of lower survival of summer chum compared to fall chum within the estuarine and marine environments are a relatively impoverished forage supply available at the typical time of outmigration and higher water surface outflow from Hood Canal during emigration. Based on the weight of evidence, a greater contribution of the impoverished food supply to the reduced survival rate of summer chum was assigned—it was assumed that the effect of food supply was approximately 3X the effect of surface outflow velocity.

The chapter is divided into two main sections. Section 4.1 addresses issues pertaining to effects that occur within the estuarine system once fry depart their natal stream's subestuary. Section 4.2 addresses conditions within the natal subestuary.

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[17] In reality, survival rates would vary to a greater extent, considering interannual variation in natural conditions. The EDT model assumes steady state average conditions.

4.1. Rules Pertaining to Estuarine System Apart from Natal Subestuary Effects

Survival Factors and their rules described in detail here are:

- Food (forage availability)
- Flow (surface outflow velocity)
- Habitat diversity
- Competition with other species

4.1.1. Survival Factor - Food

Issue: The quantity and quality of available forage affects fry outmigration rate, hence residence time within an estuarine geographic segment. An impoverished food supply prompts fry to move more rapidly to locate adequate prey. Poor foraging conditions retard growth rate, reduce exposure time to that estuarine segment, and increase vulnerability to predation (reduced growth increases vulnerability)—all of these contribute to the likelihood that survival will be reduced.

Life stages highlighted below: (1) Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound), and (2) Transient rearing fry during neritic phase

Life stage: Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound)

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- Poor foraging conditions for young fry accelerate migration along the shallow nearshore of an estuarine segment (Healey 1979; Simenstad et al. 1980; Simenstad 2000b), thereby retarding growth rate during that interval of life and increasing the likelihood of mortality;
- Summer chum fry in Hood Canal generally have less food available to them than fall chum, migrate more quickly through the Canal than fall chum, and survive at approximately one-third the rate of fall chum (Koski 1975; Simenstad 2000b);
- Eelgrass meadows provide important feeding areas for young fry within the estuarine system (Simenstad 2000b; Shaffer 1998; Shaffer 2003), and they are important sources of detritus to estuarine food webs (Sibert 1979);
- Subestuaries and tidal marshes interspersed along the estuarine shoreline provide "stop-over" feeding sites for migrating fry (Mason 1974; Simenstad 2000b; Hirschi et al. 2003b); the condition of these sites will affect their usefulness for feeding sites;
- Riparian vegetation along the estuarine shoreline is a source of terrestrial based prey for migrating chum fry (Simenstad 2000b);
- Watersheds adjoining estuarine segments and emergent marshes associated with subestuaries and tidal marshes are sources of detritus to estuarine food webs (Sibert 1979);

- Salmon carcasses displaced from adjoining spawning streams are a source (probably small) of food for rearing fry and they contribute nutrients to estuarine food webs (Cederholm et al. 2000).

The Level 2 Environmental Attributes, their level in the grouping hierarchy, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Food for fry during epibenthic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1			Macrophytes are high production areas for epibenthic prey.
2	Eelgrass – all %		0.5		Patchy eelgrass beds assumed to be less productive than continuous.
2	Eelgrass – continuous %		1		Continuous eelgrass assumed to be most productive.
1	Neritic zooplankton	0.5			Small chum fry in shallow nearshore make forays into deeper water at night.
1	Salmon carcasses	0.25			Salmon carcasses provide a direct source of food; also provide nutrients.
1	Riparian vegetation	0.6			Riparian vegetation is a source of terrestrial insect drop.
1	Wave exposure	0.5			Prey production is highest in low wave energy areas.
1	Subestuary density/function	0.6			Subestuaries and some tidal marshes are stop-over feeding sites.
2	Subestuary density		1		Density of subestuaries (no./mi) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries provide most productive feeding areas.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less productive as feeding areas.
3	Tidal chan with sm & fw			0.2	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.2	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
2	Subestuary functional loss		2		Degraded subestuaries and tidal marshes are less productive for feeding.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of feeding area.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of feeding area.
3	Tidal chan with sm & fw			0.25	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.25	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
1	Detrital input	0.6			Detritus provides energy source for estuarine food web (others listed above).
2	Ratio emerg veg to ITZ area		1		Emergent vegetation is source of detritus.
2	Ratio watersheds to ITZ area		1		Watersheds are sources of detritus.

An overall weighted average rating is obtained for the attributes shown by "rolling up" the ratings within a group beginning at the lowest group level and applying the weights shown. For example, a weighted average rating is obtained for "Macrophytes" above by obtaining a weighted average between "Eelgrass – all %" and "Eelgrass – continuous %". This resulting value is then rolled up with all other Group Level 1 ratings (some of which are themselves the result of "rolling up") to obtain the overall weighted average rating to be used in computing the sensitivity of chum salmon to the Survival Factor Food.

A relationship is developed between sensitivity and the average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to the quantity and quality of prey in the shallow nearshore environment (Figure 10). Relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is for fry spending the entire life stage subjected to the conditions associated with the ratings.

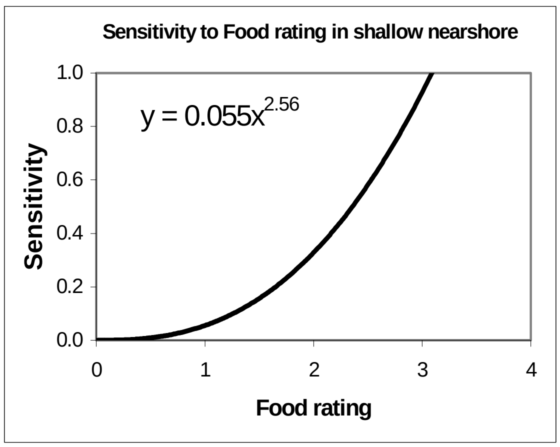

Figure 10. Assumed relationship between the average weighted rating of Level 2 Attributes assumed to contribute to prey availability for small chum fry (<55 mm) within the shallow estuarine nearshore environment. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

Examples of effect: Examples of results obtained by applying the rules to two estuarine segments are shown below. One segment, designated as Skokomish-R, encompasses the eastern shore of Hood Canal along the Great Bend (Figure 7). It takes in the shoreline directly across from the Skokomish River. Tahuya River enters this segment. The second segment, designated Dungeness, is bordered on the west side by Dungeness Spit and extends approximately 4 miles east of the Dungeness River (Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during April.

The examples show results for both historic and existing conditions for life stage productivity for the epibenthic phase of fry rearing. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Food for fry in epibenthic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Macrophytes				
Eelgrass				
Eelgrass – all %	0.8	0.9	1.5	1.8
Eelgrass – continuous %	1.0	3.9	2.7	4.0
Neritic zooplankton	0.0	0.0	0.0	0.0
Salmon carcasses	0.5	2.0	1.0	2.5
Riparian vegetation	1.9	3.1	4.0	4.0
Wave exposure	0.9	0.9	0.5	0.5
Subestuary density/function				
Subestuary density				
River mouth subestuary	3.1	3.1	3.3	3.3
Creek mouth subestuary	3.1	3.1	3.3	3.3
Tidal chan with sm & fw	2.5	2.5	4.0	4.0
Tidal chan no sm with fw	4.0	4.0	4.0	4.0
Salt marsh no tide chan with fw	4.0	4.0	4.0	4.0
Tidal chan with sm no fw	3.3	3.3	4.0	4.0
Salt marsh no tide chan no fw	3.2	3.2	3.4	3.4
Subestuary functional loss				
River mouth subestuary	0.0	1.0	0.0	3.0
Creek mouth subestuary	0.0	3.2	0.0	3.8
Tidal chan with sm & fw	0.0	3.0	0.0	0.0
Tidal chan no sm with fw	0.0	0.0	0.0	0.0
Salt marsh no tide chan with fw	0.0	0.0	0.0	0.0
Tidal chan with sm no fw	0.0	3.6	0.0	0.0
Salt marsh no tide chan no fw	0.0	3.0	0.0	2.0
Detrital input				
Ratio emerg veg to ITZ area	0.0	0.9	0.6	1.4
Ratio watersheds to ITZ area	0.0	0.0	1.4	1.4
Weighted average rating	**2.1**	**3.1**	**2.9**	**3.5**
Relative productivity	**0.84**	**0.50**	**0.59**	**0.31**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.29**	**0.18**	**0.21**	**0.11**

Life stage: Transient rearing fry during neritic phase

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- The shallow nearshore environment continues to be used for feeding as fry transition to deeper water, moving between the areas and feeding until they become entirely neritic in behavior (Simenstad et al. 1980; Simenstad 2000b);
- Eelgrass meadows and kelp forests provide feeding opportunities as fry are transitioning to deeper water (Simenstad 2000b; Shaffer 1998; Shaffer 2003);
- Subestuaries and tidal marshes continue to provide feeding opportunities, though reduced from their role for smaller fry (Mason 1974; Simenstad 2000b; Hirschi et al. 2003b); the condition of these sites will affect their usefulness for feeding sites;
- Riparian vegetation along the estuarine shoreline continues to provide a food source as fry are transitioning to deeper water;
- Detritus from watersheds and eelgrass meadows have a reduced contribution to estuarine food webs within the neritic fry rearing phase.

The Level 2 Environmental Attributes, their level in the grouping hierarchy, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Food for fry during neritic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	0.25			Epibenthic feeding by neritic fry greatly diminished than during the epibenthic phase- hence role of macrophytes is reduced.
2	Eelgrass		1		Eelgrass is particularly productive for epibenthic prey.
3	Eelgrass – all %			0.5	Patchy eelgrass beds assumed to be less productive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most productive.
2	Kelp		0.3		Kelp is identified as a production area for juvenile salmon prey.
3	Eelgrass – all %			0.5	Patchy kelp beds assumed to be less productive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most productive.
1	Neritic zooplankton	1			Neritic zooplankton is the primary source of food during the neritic phase of fry outmigration.
1	Salmon carcasses	0			Salmon carcasses likely have no influence on forage availability for neritic phase of outmigration.
1	Riparian vegetation	0.2			Role of riparian vegetation as a source of food to neritic phase is diminished from epibenthic phase.
1	Wave exposure	0.25			Effect of exposure on prey production reduced than for epibenthic phase but still operative.
1	Subestuary density/function	0.15			Role of subestuaries/tidal marshes as stop-over feeding sites reduced for neritic phase.
2	Subestuary density		1		Density of subestuaries (no./mi) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries provide most productive feeding areas.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less productive as feeding areas.
3	Tidal chan with sm & fw			0.2	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.2	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
2	Subestuary functional loss		1		Degraded subestuaries and tidal marshes are less productive for feeding.

Attribute weights for Survival Factor Food for fry during neritic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of feeding area.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of feeding area.
3	Tidal chan with sm & fw			0.25	Limited feeding opportunity exists.
3	Tidal chan no sm with fw			0.15	Limited feeding opportunity exists.
3	Salt marsh no tide chan with fw			0	No access for feeding.
3	Tidal chan with sm no fw			0.25	Limited feeding opportunity exists.
3	Salt marsh no tide chan no fw			0	No access for feeding.
1	Detrital input	0.2			Role of detrital input from emergent vegetation and watersheds to zooplankton production assumed to be negligible at a segment scale.
2	Ratio emerg veg to ITZ area		1		Emergent vegetation is source of detritus.
2	Ratio watersheds to ITZ area		1		Watersheds are sources of detritus.

Figure 11 represents the working hypothesis about the sensitivity of this life stage to the quantity and quality of prey in utilized in the neritic phase of the fry outmigration. Relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on a synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

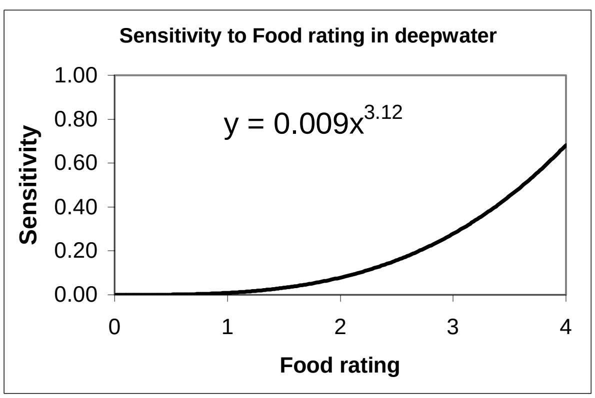

Figure 11. Assumed relationship between the average weighted rating of Level 2 Attributes assumed to contribute to prey availability for juvenile chum fry >55 mm within the neritic phase of life in the estuarine nearshore environment. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

__Examples of effect:__ Examples of results obtained by applying the rules to two estuarine segments are shown below, Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend, and the Dungeness segment, bordered on the west side by Dungeness Spit and extending approximately 4 miles east of the Dungeness River (Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during April.

The examples show results for both historic and existing conditions for life stage productivity for the neritic phase of fry rearing. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Food for fry in neritic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Macrophytes				
Eelgrass				
Eelgrass – all %	0.8	0.9	1.5	1.8
Eelgrass – continuous %	1.0	3.9	2.7	4.0
Kelp				
Kelp – all %	4.0	4.0	1.2	1.2
Kelp – continuous %	4.0	4.0	3.8	3.8
Neritic zooplankton	0.0	0.0	0.0	0.0
Salmon carcasses	0.5	2.0	1.0	2.5
Riparian vegetation	1.9	3.1	4.0	4.0
Wave exposure	0.9	0.9	0.5	0.5
Subestuary density/function				
Subestuary density				
River mouth subestuary	3.1	3.1	3.3	3.3
Creek mouth subestuary	3.1	3.1	3.3	3.3
Tidal chan with sm & fw	2.5	2.5	4.0	4.0
Tidal chan no sm with fw	4.0	4.0	4.0	4.0
Salt marsh no tide chan with fw	4.0	4.0	4.0	4.0
Tidal chan with sm no fw	3.3	3.3	4.0	4.0
Salt marsh no tide chan no fw	3.2	3.2	3.4	3.4
Subestuary functional loss				
River mouth subestuary	0.0	1.0	0.0	3.0
Creek mouth subestuary	0.0	3.2	0.0	3.8
Tidal chan with sm & fw	0.0	3.0	0.0	0.0
Tidal chan no sm with fw	0.0	0.0	0.0	0.0
Salt marsh no tide chan with fw	0.0	0.0	0.0	0.0
Tidal chan with sm no fw	0.0	3.6	0.0	0.0
Salt marsh no tide chan no fw	0.0	3.0	0.0	2.0
Detrital input				
Ratio emerg veg to ITZ area	0.0	0.9	0.6	1.4
Ratio watersheds to ITZ area	0.0	0.0	1.4	1.4
Weighted average rating	**1.5**	**1.8**	**1.8**	**2.0**
Relative productivity	**0.93**	**0.88**	**0.88**	**0.85**
Benchmark survival*	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**.33**	**0.31**	**0.31**	**0.30**

* Benchmark survival for this life phase encompasses a much longer time (30 weeks) than applied to the epibenthic phase (6 weeks), hence weekly survival is much higher in this phase.

4.1.2. Survival Factor - Flow (surface outflow velocity)

Issue: The surface water outflow rate from estuarine water bodies can move small chum fry out of the estuarine area prematurely, without affording adequate opportunity for locating suitable forage. Premature, forced migration is assumed to retard growth rate, reduce exposure time to that estuarine segment, and increase vulnerability to predation (reduced growth increases vulnerability)—all of these would contribute to the likelihood that survival will be reduced.

Life stages highlighted below: (1) Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound), and (2) Transient rearing fry during neritic phase

Life stage: Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound)

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- High rates of surface outflow from an estuarine segment move fish relatively quickly through the area and limit feeding opportunities (inferred from Bax et al. 1983b);
- Surface water outflow rate varies seasonally within Hood Canal and other areas of Puget Sound, with peak outflows occurring in late winter and early spring; outflow rates are largely wind driven but are also affected by river runoff patterns (Bax 1983a; Simenstad 2000b).

The Level 2 Environmental Attributes, their weighting relative to one another, and the rationale for including them are shown below (in this case there is only one contributing Level 2 Attribute):

Attribute weights for Survival Factor Flow for fry during epibenthic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Surface outflow average velocity	1			Surface outflow velocity directly affects fry outmigration rate.

Figure 12 represents the working hypothesis about the sensitivity of this life stage to surface outflow velocity in the shallow nearshore environment. Relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

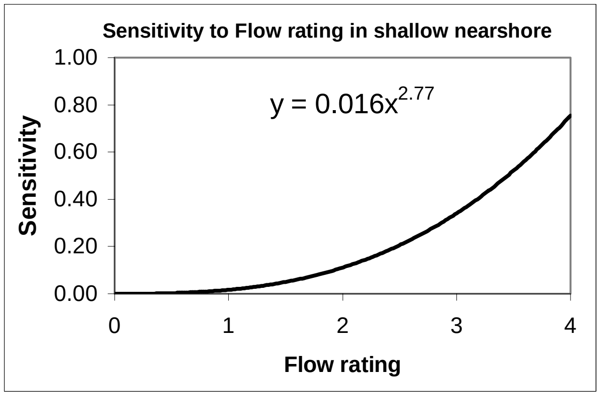

Figure 12. Assumed relationship between the Level 2 Attribute Flow and sensitivity of small chum fry (<55 mm) within the shallow estuarine nearshore environment. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

<u>Examples of effect</u>: Examples of results obtained by applying the rules to two estuarine segments are shown below, Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend, and the Dungeness segment, bordered on the west side by Dungeness Spit and extending approximately 4 miles east of the Dungeness River (Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during March.

The examples show results for both historic and existing conditions for life stage productivity for the epibenthic phase of fry rearing. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Flow for fry in epibenthic phase (examples)

Attribute (rating to right)	Segment characterization (month of March)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Surface outflow average velocity	3.0	3.0	1.5	1.5
Weighted average rating	**3.0**	**3.0**	**1.5**	**1.5**
Relative productivity	**0.66**	**0.66**	**0.95**	**0.95**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.23**	**0.23**	**0.33**	**0.33**

<u>Life stage:</u> Transient rearing fry during neritic phase

<u>Approach to rule formulation:</u> These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- High rates of surface outflow from an estuarine segment move fish relatively quickly through the area and limit feeding opportunities (inferred from Bax et al. 1983b); this effect is still operative during some part of the neritic phase because fry transition between the neritic and epibenthic phases by moving between the zones during the outmigration;
- Surface water outflow rate varies seasonally within Hood Canal and other areas of Puget Sound, with peak outflows occurring in late winter and early spring; outflow rates are largely wind driven but are also affected by river runoff patterns (Bax 1983a; Simenstad 2000b).

The Level 2 Environmental Attributes, their weighting relative to one another, and the rationale for including them shown below (in this case there is only one contributing Level 2 Attribute):

Attribute weights for Survival Factor Flow for fry during neritic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Surface outflow average velocity	1			Surface outflow velocity directly affects fry outmigration rate.

Figure 13 represents the working hypothesis about the sensitivity of this life stage to surface outflow velocity in the neritic phase of the chum salmon fry outmigration. Relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on a synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

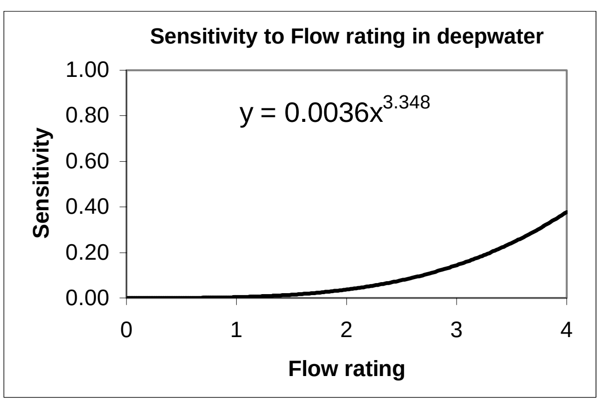

Figure 13. Assumed relationship between the Level 2 Attribute Flow and sensitivity of juvenile chum >55 mm within the deepwater of the estuarine nearshore environment. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

<u>Examples of effect</u>: Examples of results obtained by applying the rules to two estuarine segments are shown below, Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend, and the Dungeness segment, bordered on the west side by Dungeness Spit and extending approximately 4 miles east of the Dungeness River

(Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during March.

The examples show results for both historic and existing conditions for life stage productivity for the neritic phase of fry rearing. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Flow for fry in neritic phase (examples)

Attribute (rating to right)	Segment characterization (month of March)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Surface outflow average velocity	3.0	3.0	1.5	1.5
Weighted average rating	**3.0**	**3.0**	**1.5**	**1.5**
Relative productivity	**0.86**	**0.86**	**0.99**	**0.99**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.30**	**0.30**	**0.35**	**0.35**

4.1.3. Survival Factor – Habitat diversity

Issue: Certain types of estuarine and marine nearshore features attract and tend to hold chum salmon fry for rearing, and presumably, for refuge from predators, more than others. These features include shallow beaches with sand and/or silt substrates, presence of aquatic vegetation, low current and wave energy, and interspersed subestuaries and tidal marshes. When present, these features increase the probability for fry survival.

Life stages highlighted below: (1) Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound), and (2) Transient rearing fry during neritic phase

Life stage: Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound)

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- Shallow-water, typically low-gradient habitats with fine unconsolidated substrates are preferred areas during daylight hours for feeding and refuge from predators (Simenstad 2000a; Simenstad 200b);
- Aquatic vegetation, particularly eelgrass meadows, are preferred areas for feeding and refuge from predators (Simenstad 2000a; Simenstad 2000b); kelp also appears to provide structural components useful for predator refuge (Shaffer 2003);
- Shoreline development along estuarine and marine nearshore segments interrupt and modify features preferred by chum fry and can diminish the quality of the shoreline

environment to hold and grow chum fry (Simenstad 2000b; Williams et al. 2000; Williams and Thom 2001);

- Subestuaries and tidal marshes interspersed along the nearshore shoreline provide opportunities as "stop-over" sites for predator refuge, salinity acclimation, and rearing for migrating chum fry (Mason 1974; Simenstad 2000b).

The Level 2 Environmental Attributes, their level in the grouping hierarchy, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Habitat Diversity for fry during epibenthic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1.5			Macrophytes provide areas of refuge from predators.
2	Eelgrass		1		Eelgrass is particularly attractive for epibenthic fry.
3	Eelgrass – all %			0.5	Patchy eelgrass assumed to be less attractive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most attractive.
2	Kelp		0.3		Kelp provides some extent of refuge from predators.
3	Kelp – all %			0.5	Patchy kelp assumed to be less attractive than continuous.
3	Kelp – continuous %			1	Continuous kelp assumed to be most attractive.
1	Intertidal zone slope	1			Low gradient beaches (very shallow) provide refuge from predators during day time for small chum fry.
1	Percent of shoreline modified	2			Modified beaches are less likely to have features preferred by small chum fry.
1	Wave exposure	0.5			Low energy beaches are more easily utilized than high energy beaches from a bioenergetic aspect.
1	Subestuary density/function	1			Subestuaries and some tidal marshes are stop-over feeding sites, provide predator refuge, and improved acclimation to saline environment.
2	Subestuary density		1		Density of subestuaries (no./mi) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries are the largest of subestuary types and provide greatest opportunities.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less attractive as stop-over sites during fry migration.
3	Tidal chan with sm & fw			0.2	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.2	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.
2	Subestuary functional loss		2		Degraded subestuaries and tidal marshes provide less benefit to migrating fry.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of opportunities for migrant fry.

Attribute weights for Survival Factor Habitat Diversity for fry during epibenthic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of opportunities for migrant fry.
3	Tidal chan with sm & fw			0.25	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.25	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.

See Chapter 4 for a description of the way in which the weights are used in computing a weighted average rating for the attributes that contribute to this survival factor.

A relationship was developed between sensitivity and average weighted rating—representing the working hypothesis about the sensitivity of this life stage to the extent that preferred and diverse habitats exist along the nearshore environment (Figure 14). Note that relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on a synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

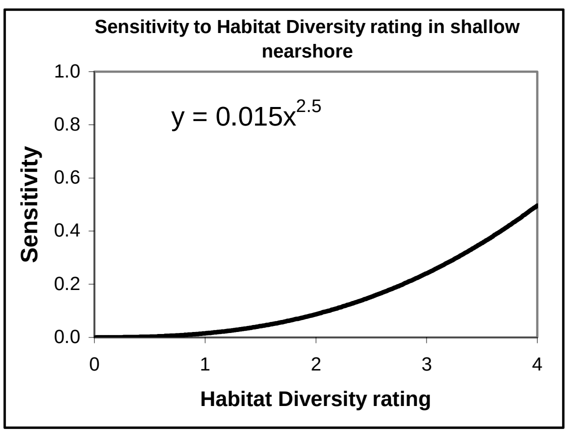

Figure 14. Habitat diversity sensitivity in shallow nearshore.

Examples of effect: Examples of results obtained by applying the rules to two estuarine segments are shown below, Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend, and the Dungeness segment, bordered on the west side by Dungeness Spit and extending approximately 4 miles east of the Dungeness River (Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during April.

The examples show results for both historic and existing conditions for life stage productivity for the epibenthic phase of fry rearing. See Appendix C for rating definitions.

Input and computed productivity for Survival Factor Habitat Diversity for fry in epibenthic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Macrophytes				
Eelgrass				
Eelgrass – all %	0.8	0.9	1.5	1.8
Eelgrass – continuous %	1.0	3.9	2.7	4.0
Kelp				
Kelp – all %	4.0	4.0	1.2	1.2
Kelp – continuous %	4.0	4.0	3.8	3.8
Intertidal zone slope	2.5	2.5	0.6	0.6
Percent of shoreline modified	0.0	2.7	0.0	0.0
Wave exposure	0.9	0.9	0.5	0.5
Subestuary density/function				
Subestuary density				
River mouth subestuary	3.1	3.1	3.3	3.3
Creek mouth subestuary	3.1	3.1	3.3	3.3
Tidal chan with sm & fw	2.5	2.5	4.0	4.0
Tidal chan no sm with fw	4.0	4.0	4.0	4.0
Salt marsh no tide chan with fw	4.0	4.0	4.0	4.0
Tidal chan with sm no fw	3.3	3.3	4.0	4.0
Salt marsh no tide chan no fw	3.2	3.2	3.4	3.4
Subestuary functional loss				
River mouth subestuary	0.0	1.0	0.0	3.0
Creek mouth subestuary	0.0	3.2	0.0	3.8
Tidal chan with sm & fw	0.0	3.0	0.0	0.0
Tidal chan no sm with fw	0.0	0.0	0.0	0.0
Salt marsh no tide chan with fw	0.0	0.0	0.0	0.0
Tidal chan with sm no fw	0.0	3.6	0.0	0.0
Salt marsh no tide chan no fw	0.0	3.0	0.0	2.0
Weighted average rating	**1.0**	**2.1**	**0.9**	**1.2**
Relative productivity	**0.98**	**0.83**	**0.98**	**0.96**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.34**	**0.29**	**0.34**	**0.34**

Life stage: Transient rearing fry during neritic phase

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- The shallow nearshore environment continues to be used for feeding as fry transition to deeper water, moving between the areas and feeding until they become entirely neritic in behavior (Simenstad et al. 1980; Simenstad 2000b);
- Eelgrass meadows and kelp forests provide feeding opportunities and refuge from predators as fry are transitioning to deeper water (Simenstad 2000b; Shaffer 1998; Shaffer 2003);
- Subestuaries and tidal marshes continue to provide feeding opportunities and refuge from predators, though reduced from their role for smaller fry (Mason 1974; Simenstad 2000b; Hirschi et al. 2003b); the condition of these sites will affect their usefulness for feeding and predator refuge;
- Shallow-water, typically low-gradient habitats with fine unconsolidated substrates are preferred areas during daylight hours for feeding and refuge from predators (Simenstad 2000a; Simenstad 200b) and continue to serve these functions as fry are transitioning to deeper water;
- Shoreline development along estuarine and marine nearshore segments interrupt and modify features preferred by chum fry and can diminish the quality of the shoreline environment to hold and grow chum fry (Simenstad 2000b; Williams et al. 2000; Williams and Thom 2001).

The Level 2 Environmental Attributes, their level in the grouping hierarchy, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Habitat Diversity for fry during neritic phase

Group level	Level 2 Attribute	Weight by group level			Rationale
		1	2	3	
1	Macrophytes	1			Macrophytes provide areas of refuge from predators.
2	Eelgrass		1		Eelgrass is particularly attractive for epibenthic fry.
3	Eelgrass – all %			0.5	Patchy eelgrass assumed to be less attractive than continuous.
3	Eelgrass – continuous %			1	Continuous eelgrass assumed to be most attractive.
2	Kelp		0.5		Kelp provides some extent of refuge from predators.
3	Kelp – all %			0.5	Patchy kelp assumed to be less attractive than continuous.
3	Kelp – continuous %			1	Continuous kelp assumed to be most attractive.
1	Intertidal zone slope	1			Low gradient beaches (very shallow) provide refuge from predators during day time for small chum fry.
1	Percent of shoreline modified	1			Modified beaches are less likely to have features preferred by small chum fry.
1	Wave exposure	0.5			Low energy beaches are more easily utilized than high energy beaches from a bioenergetic aspect.
1	Subestuary density/function	0.5			Subestuaries and some tidal marshes are stop-over feeding sites, provide predator refuge, and improved acclimation to saline environment.

Group level	Level 2 Attribute	Weight by group level 1	2	3	Rationale
2	Subestuary density		1		Density of subestuaries (no./mi) determines frequency of encounter.
3	River mouth subestuary			1	River mouth estuaries are the largest of subestuary types and provide greatest opportunities.
3	Creek mouth subestuary			0.75	Creek mouth estuaries somewhat less attractive as stop-over sites during fry migration.
3	Tidal chan with sm & fw			0.2	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.2	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.
2	Subestuary functional loss		1		Degraded subestuaries and tidal marshes provide less benefit to migrating fry.
3	River mouth subestuary			1	Degraded river mouth estuaries would contribute most to loss of opportunities for migrant fry.
3	Creek mouth subestuary			0.75	Degraded creek mouth estuaries would contribute less to loss of opportunities for migrant fry.
3	Tidal chan with sm & fw			0.25	Limited opportunity for access.
3	Tidal chan no sm with fw			0.15	Limited opportunity for access.
3	Salt marsh no tide chan with fw			0	No access for stop-over.
3	Tidal chan with sm no fw			0.25	Limited opportunity for access.
3	Salt marsh no tide chan no fw			0	No access for stop-over.

Attribute weights for Survival Factor Habitat Diversity for fry during neritic phase

See Chapter 4 for a description of how the weights are used in computing a weighted average rating for the attributes that contribute to this survival factor.

A relationship was developed between sensitivity and average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to the extent that preferred and diverse habitats exist along the nearshore environment (including deepwater) (Figure 15). Note that relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

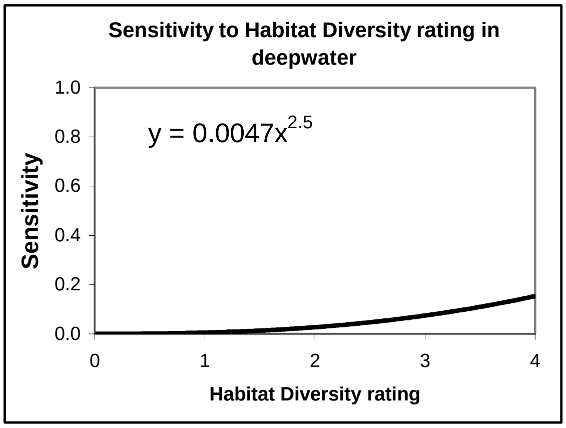

Figure 15. Habitat diversity sensitivity in deepwater within estuarine and marine environments.

Examples of effect: Examples of results obtained by applying the rules to two estuarine segments are shown below, Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend, and the Dungeness segment, bordered on the west side by Dungeness Spit and extending approximately 4 mi east of the Dungeness River (Figure 7). These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait. The example shows results for conditions during April.

The examples show results for both historic and existing conditions for life stage productivity for the neritic phase of fry rearing. See Appendix C for rating definitions.

Input and computed productivity for Survival Factor Habitat Diversity for fry in neritic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Macrophytes				
Eelgrass				
Eelgrass – all %	0.8	0.9	1.5	1.8
Eelgrass – continuous %	1.0	3.9	2.7	4.0
Kelp				
Kelp – all %	4.0	4.0	1.2	1.2
Kelp – continuous %	4.0	4.0	3.8	3.8
Intertidal zone slope	2.5	2.5	0.6	0.6
Percent of shoreline modified	0.0	2.7	0.0	0.0
Wave exposure	0.9	0.9	0.5	0.5
Subestuary density/function				
Subestuary density				
River mouth subestuary	3.1	3.1	3.3	3.3
Creek mouth subestuary	3.1	3.1	3.3	3.3
Tidal chan with sm & fw	2.5	2.5	4.0	4.0
Tidal chan no sm with fw	4.0	4.0	4.0	4.0
Salt marsh no tide chan with fw	4.0	4.0	4.0	4.0

Input and computed productivity for Survival Factor Habitat Diversity for fry in neritic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Tidal chan with sm no fw	3.3	3.3	4.0	4.0
Salt marsh no tide chan no fw	3.2	3.2	3.4	3.4
Subestuary functional loss				
River mouth subestuary	0.0	1.0	0.0	3.0
Creek mouth subestuary	0.0	3.2	0.0	3.8
Tidal chan with sm & fw	0.0	3.0	0.0	0.0
Tidal chan no sm with fw	0.0	0.0	0.0	0.0
Salt marsh no tide chan with fw	0.0	0.0	0.0	0.0
Tidal chan with sm no fw	0.0	3.6	0.0	0.0
Salt marsh no tide chan no fw	0.0	3.0	0.0	2.0
Weighted average rating	**0.8**	**1.3**	**0.6**	**0.8**
Relative productivity	**0.99**	**0.95**	**0.99**	**0.99**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.35**	**0.33**	**0.35**	**0.35**

4.1.4. Survival Factor – Competition with other species

Issue: Interspecific competition, as well as intra-specific competition between fall and summer chum races, can potentially adversely affect the performance of chum salmon within the estuarine and marine environments. It is generally assumed that such competition occurs directly over food resources. The nature of competition between pink and chum salmon is less clear and it may involve some type of behavioral interaction and associated behavioral modification.

Life stages highlighted below: (1) Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound), and (2) Transient rearing fry during neritic phase

Life stage: Transient rearing fry during epibenthic phase (applies to inner and outer areas of Puget Sound)

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the independent form (multiplicative) of the rules.

Elements of the underlying hypothesis for these rules are:

- Various fish species can compete for food resources with juvenile chum salmon, but Bakkala (1970 cited in Ames et al. 2000) states that the other species of Pacific salmon are the principal competitors;
- Chum fry change their migration pattern out of rivers in years when pink salmon are present with respect to vertical distribution and time of day (studies cited in Salo 1991), presumably due to some type of interspecific interaction; some type of similar behavioral adjustments are assumed to occur within the estuarine and marine environments;

- Chum fry migration rate within the nearshore environment is dependent on the density of pink and chum salmon fry of the same size class (Salo 1991 citing Bax 1983b), presumably due to competition for food resources and an associated reduction in prey density when competition is high.

The Level 2 Environmental Attributes, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Competition with Other Species for fry during epibenthic phase

Level 2 Attribute	Weight	Rationale
Wild Chinook status	1	Chinook fry can prey on the same organisms eaten by chum; reducing prey density
Wild coho status	0	Coho smolts prey on different organisms than those eaten by chum
Wild fall chum status	1	Fall chum fry can prey on the same organisms eaten by summer chum; reducing prey density (or visa versa)
Wild pink status	1	Presence of pink fry can cause chum fry to migrate more rapidly, presumably due to competition for food resources
Wild steelhead status	0	Steelhead smolts prey on different organisms than those eaten by chum
Wild cutthroat status	0	Cutthroat smolts and subadults prey on different organisms than those eaten by chum

Ratings for each attribute are weighted using the weights listed above to obtain average weighted ratings for each estuarine segment. A relationship was developed between sensitivity and average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to the combined effect of other competing salmonids (excluding the focal species) (Figure 16). The relationship presumes that the various species are present in the same size class at the same time. This, of course, is generally not true; hence a scalar was also applied that scales the abundance of each species to expected temporal patterns.

Note that relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

Note that sensitivity of summer chum to fall chum in Figure 16 is shown as the interaction with the greatest effect, slightly higher than shown between summer chum and pink salmon. It is assumed that conspecific interactions would be the greatest among any group (provided that the two competing groups are within the same size class in a given time period). The interaction with pink salmon is still quite strong, relative to the effect of fall chum on summer chum, based on observations presented in Figure 2.

Ratings for each attribute are weighted using the weights listed above to obtain average weighted ratings for each estuarine segment. A relationship was developed between sensitivity and average weighted rating—this represents the working hypothesis about the sensitivity of this species.

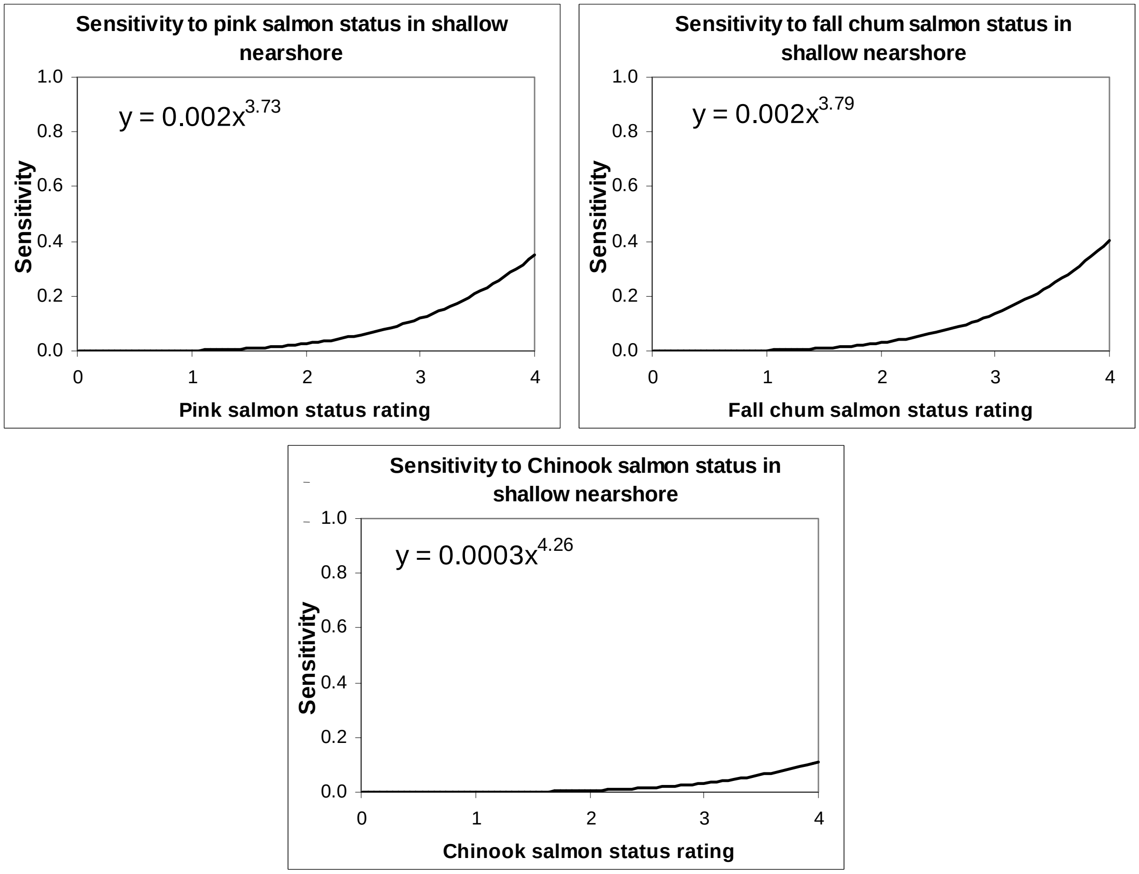

Figure 16. Sensitivity of summer chum to competition with other species in shallow nearshore environment. Summer chum is assumed here to be the focal species for the analysis, thus fall chum is identified here as a separate species for the sake of competition. Sensitivity curves would apply only to the extent shown if the focal species and competing species are within the same size class in a given time period.

Examples of effect: Examples of results obtained by applying the rules to two estuarine segments are shown below. One segment is designated as Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend. It takes in the shoreline directly across from the Skokomish River. Tahuya River enters this segment. The second segment, designated Dungeness, is bordered on the west side by Dungeness Spit and extends approximately 4 miles east of the Dungeness River. These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait.

The examples show results for both historic and existing conditions for life stage productivity for the epibenthic phase of fry rearing. See Appendix C for rating definitions.

Input and computed productivity for Survival Factor Competition with other species for fry in epibenthic phase (examples)

Attribute (rating to right)	Segment characterization			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Wild Chinook status	3	1	3	2
Wild coho status	3	2	3	2
Wild fall chum status	3	2.5	3	2.5
Wild pink status	3	2	3	2
Wild steelhead status	3	1	3	1
Wild cutthroat status	3	2	3	2
Weighted average rating	**2.4**	**1.7**	**2.4**	**1.7**
Relative productivity	**0.76**	**0.91**	**0.76**	**0.91**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.27**	**0.32**	**0.27**	**0.32**

Life stage: Transient rearing fry during neritic phase (applies to inner and outer areas of Puget Sound)

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the independent form (multiplicative) of the rules.

Elements of the underlying hypothesis for these rules are:

- Various fish species can compete for food resources with juvenile chum salmon, but Bakkala (1970 cited in Ames et al. 2000) states that the other species of Pacific salmon are the principal competitors; competition is assumed to occur both in shallow and deep water habitats, though the effect is presumed to be less in deep water due to a much greater capacity for food production;
- Chum fry change their migration pattern out of rivers in years when pink salmon are present with respect to vertical distribution and time of day (studies cited in Salo 1991), presumably due to some type of interspecific interaction; some type of similar behavioral adjustments are assumed to occur within the estuarine and marine environments;
- Chum fry migration rate within the nearshore environment is dependent on the density of pink and chum salmon fry of the same size class (Salo 1991 citing Bax 1983b), presumably due to competition for food resources and an associated reduction in prey density when competition is high; competition is assumed to occur both in shallow and deep water habitats, though the effect is presumed to be less in deep water due to a much greater capacity for food production.

The Level 2 Environmental Attributes, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Competition with Other Species for fry during neritic phase

Level 2 Attribute	Weight	Rationale
Wild Chinook status	1	Chinook fry can prey on the same organisms eaten by chum; reducing prey density
Wild coho status	0	Coho smolts prey on different organisms than those eaten by chum
Wild fall chum status	1	Fall chum fry can prey on the same organisms eaten by summer chum; reducing prey density (or visa versa)
Wild pink status	1	Presence of pink fry can cause chum fry to migrate more rapidly, presumably due to competition for food resources
Wild steelhead status	0	Steelhead smolts prey on different organisms than those eaten by chum
Wild cutthroat status	0	Cutthroat smolts and subadults prey on different organisms than those eaten by chum

Ratings for each attribute are weighted using the weights listed above to obtain average weighted ratings for each estuarine segment. A relationship was developed between sensitivity and average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to the combined effect of other competing salmonids (excluding the focal species) (Figure 17). The relationship presumes that the various species are present in the same size class at the same time. This, of course, is generally not true; hence a scalar is also applied that scales the abundance of each species to an expected temporal pattern.

Note that relative survival, i.e., survival relative to benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is that associated with fry spending the entire life stage subjected to the conditions associated with the ratings.

Examples of effect: Examples of results obtained by applying the rules to two estuarine segments are shown below. One segment is designated as Skokomish-R, encompassing the eastern shore of Hood Canal along the Great Bend. It takes in the shoreline directly across from the Skokomish River. Tahuya River enters this segment. The second segment, designated Dungeness, is bordered on the west side by Dungeness Spit and extends approximately 4 miles east of the Dungeness River. These examples were chosen to contrast a segment in southern Hood Canal with one on the eastern end of the Strait.

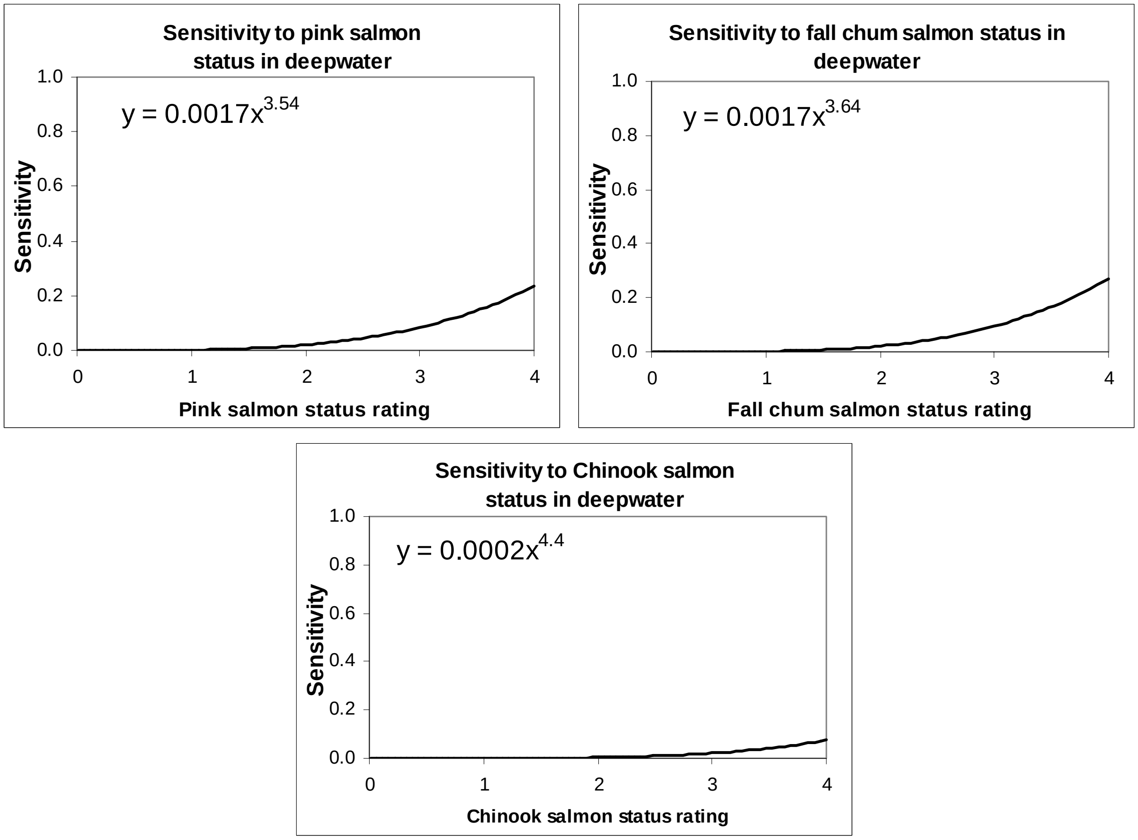

Figure 17. Sensitivity of summer chum to competition with other species in deep water. Summer chum is assumed here to be the focal species for the analysis, thus fall chum is identified here as a separate species for the sake of competition. Sensitivity curves would only apply to the extent shown if the focal species and competing species are within the same size class in a given time period.

The examples show results for both historic and existing conditions for life stage productivity for the neritic phase of fry rearing. See Appendix C for rating definitions.

Input and computed productivity for Survival Factor Competition with other species for fry in neritic phase (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Skokomish-R Historic	Skokomish-R Existing	Dungeness Historic	Dungeness Existing
Wild Chinook status	3	1	3	2
Wild coho status	3	2	3	2
Wild fall chum status	3	2.5	3	2.5
Wild pink status	3	2	3	2
Wild steelhead status	3	1	3	1
Wild cutthroat status	3	2	3	2
Weighted average rating	**2.1**	**1.5**	**2.1**	**1.5**
Relative productivity	**.83**	**0.93**	**0.83**	**0.93**
Benchmark survival	**0.35**	**0.35**	**0.35**	**0.35**
Absolute survival	**0.29**	**0.33**	**0.29**	**0.33**

4.2. Rules Pertaining to Natal Subestuary Effects

Survival Factors and their rules described in detail here are:

- Food (forage availability)
- Habitat diversity

4.2.1. Survival Factor - Food

Issue: Chum salmon fry experience their first exposure to the estuarine environment within their natal subestuary, typically within hours of fry emergence in short spawning streams of Puget Sound. The quality and quantity of food encountered within this subestuary can affect the length of time the fry remain there feeding and acclimating to saltwater prior to continuing their migration into the adjoining estuarine-marine nearshore environment. It is expected that this first exposure to estuarine feeding can have some effect on their growth trajectory in early life and their general readiness to survive the nearshore migration. An impoverished food supply prompts fry to move more rapidly to locate adequate prey. Poor foraging conditions retard growth rate, reduce exposure time to that estuarine segment, and increase vulnerability to predation (reduced growth increases vulnerability)—all of these contribute to the likelihood that survival will be reduced.

Life stage: Transient rearing fry within their natal subestuary

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- Chum fry passing through a natal subestuary that provides extensive feeding opportunities compared to one that has limited opportunities will reside there longer to feed and acclimate prior to moving into the nearshore environment beyond (inferred from conclusions drawn by Simenstad 2000b about results of Bax 1983b; inferences from Mason 1974; Healey 1979; Congleton et al. 1982);
- Poor foraging conditions within the natal subestuary will affect the growth trajectory of young fry and will increase the probability of mortality (inferred from Healey 1979; Simenstad et al. 1980; Simenstad 2000b);
- Subestuaries with extensive side channels, distributaries, and tidal marsh will have greater opportunities for feeding and more abundant prey organisms than small or simplified subestuaries (inferred from Mason 1974; Congleton et al. 1982; Simenstad 2000a; Simenstad 2000b; Hirschi et al. 2003b); the extent that subestuaries have been modified by bank hardening, filling, and straightening will affect their usefulness for feeding sites;
- Riparian vegetation along the subestuarine shoreline is a source of terrestrial based prey for migrating chum fry (Simenstad 2000b);
- Watersheds adjoining estuarine segments and emergent marsh associated with subestuaries and tidal marshes are sources of detritus to estuarine food webs (Sibert 1979);
- Salmon carcasses displaced from the spawning stream are a source (probably small) of food for rearing fry and can contribute nutrients to estuarine food webs (Cederholm et al. 2000).

The Level 2 Environmental Attributes, their assigned weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Food for fry in natal subestuary

Level 2 Attribute	Weight	Rationale
Channel complexity	1.0	A complex network of channels within the subestuary typically contains a diversity of habitat types, water velocities, and fringing marsh habitat, all of which will result in a diverse and rich food web for rearing salmonids. Simple channel systems are assumed to have a much lower potential for producing food for rearing salmonids.
Channel modification (hydromods)	1.0	Channel modifications, such as bank hardening and filling, will tend to increase water velocities, damage wetland integrity, and reduce microhabitat diversity, thereby reducing the potential of the natural channel system to produce food for salmonids.
Ratio emerg veg to watershed size	1.0	The ratio of the amount of emergent vegetation to the watershed size is assumed to be an indicator of the productive potential of the emergent vegetation system to produce food for the size of river associated with the natal subestuary.
Ratio subest size to watershed size	1.0	The ratio of the amount of emergent vegetation to the watershed size is assumed to be an indicator of the productive potential of the emergent vegetation system to produce food for the size of river associated with the natal subestuary.
Riparian function	0.5	The integrity of the riparian zone will affect the potential of this zone to produce food and detritus (for food web energy) within the natal subestuary.
Access to subestuary habitats	0.5	Connectivity between channels and parts of the subestuary will affect how juvenile salmonids and detritus (for food web) can access all available areas.
Salmon carcasses	0.5	Salmon carcasses can serve as both direct and indirect source of food for juvenile salmonids.

A relationship was developed between sensitivity and the average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to the quantity and quality of prey in the natal subestuary (Figure 18). Relative survival, i.e., survival relative to the benchmark, equals 1 minus sensitivity. The relationship is based on a synthesis of information contained in Chapter 2. The sensitivity shown is for fry spending the entire life stage subjected to the conditions associated with the ratings.

Important note: the duration of time that chum fry will typically reside in a natal subestuary is assumed to be much less than the time applied to the nearshore environment (see Appendix B - Benchmarks). Therefore the sensitivity shown in Figure 18 will be less than allowed for the nearshore environment (e.g., see Figures 10-11).

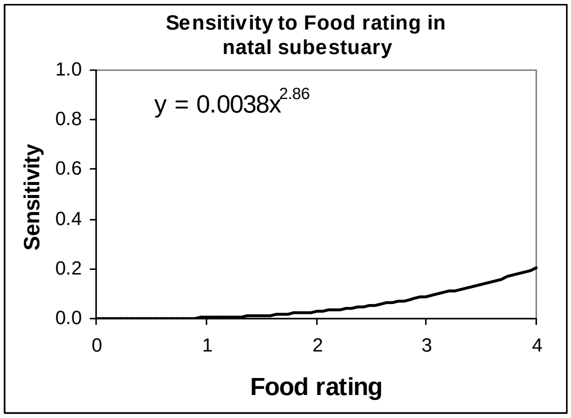

Figure 18. Assumed relationship between the average weighted rating of Level 2 Attributes assumed to contribute to prey availability for small chum fry (<55 mm) within natal subestuary. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

Examples of effect: Examples of results obtained by applying the rules to two natal subestuaries are shown below. The two subestuaries are those associated with the Union and Dosewallips rivers (Figure 7), both located in Hood Canal.

The examples show results for both historic and existing conditions for life stage productivity for fry within the natal subestuary. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Food for fry in natal subestuary (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Union subest Historic	Union subest Existing	Dose subest Historic	Dose subest Existing
Channel complexity	1.2	1.6	1.2	2.5
Channel modification (hydromods)	0.0	2.0	0.0	3.5
Ratio emerg veg to watershed size	0.3	0.7	3.5	3.6
Ratio subest size to watershed size	0.1	0.2	2.5	3.0
Riparian function	0.0	3.3	0.0	2.5
Access to subestuary habitats	0.0	1.0	0.0	0.0
Salmon carcasses	0.0	1.0	0.0	0.0
Weighted average rating	**0.3**	**1.3**	**1.3**	**2.5**
Relative productivity	**1.00**	**0.98**	**0.98**	**0.92**
Benchmark survival	**0.656**	**0.656**	**0.656**	**0.656**
Absolute survival	**0.656**	**0.643**	**0.643**	**0.604**

4.2.2. Survival Factor – Habitat Diversity

Issue: Chum salmon fry experience their first exposure to the estuarine environment within their natal subestuary, typically within hours of fry emergence in short spawning streams of Puget Sound. Some habitat types (or features) will attract and tend to hold chum salmon fry for rearing, and presumably, for refuge from predators, better than others. These features include complex channel networks associated with tidal marshes; these offer better feeding opportunities, refuge from predators, and slower water velocities than the main channel. When present, these features increase the likelihood that fry will experience good growing conditions and be better prepared to undertake the nearshore migration.

Life stage: Transient rearing fry within their natal subestuary

Approach to rule formulation: These rules are based on a weight of evidence approach drawn from material discussed in Chapter 2. They apply the weighted rating form of the rules.

Elements of the underlying hypothesis for these rules are:

- Subestuaries with multiple channels, including side and blind channels, provide refuge from predators and water velocities suitable for small fry to hold and rear (Congleton et al. 1982; Simenstad 2000b);
- Conditions that promote the diversity of habitats described above are wide floodplains where multiple channels and tidal marsh can develop, good riparian function, and high wood loads (Healey 1982; Simenstad 2000a; Collins et al. 2003)—these are areas that have not been heavily constrained by diking, filling, and channel straightening.

The Level 2 Environmental Attributes, their level in the grouping hierarchy, their weighting relative to one another, and the rationale for including them are shown in the following:

Attribute weights for Survival Factor Habitat Diversity for fry in natal subestuary

Level 2 Attribute	Weight	Rationale
Channel complexity	1.0	A complex network of channels within the subestuary typically contains a diversity of habitat types, water velocities, and fringing marsh habitat, all of which will result in a diverse suite of habitats conducive to holding salmonids and giving them refuge from high flows and predators.
Channel depth - tidal	0.5	A channel network that contains a mix of water depths, which includes areas deep enough for free passage and cover at low tides within the subestuary, will contribute toward the suite of habitat needed to hold salmonids and give them refuge from high flows and predators.
Channel modification (hydromods)	1.0	Channel modifications, such as bank hardening and filling, will tend to increase water velocities, damage wetland integrity, and reduce microhabitat diversity, thereby reducing the potential of the natural channel system to provide a diverse set of habitats that hold salmonids and give them refuge from high flows and predators.
Riparian function	1.0	The integrity of the riparian zone will affect the potential of this zone to contribute toward a diverse set of habitats that hold salmonids and give them refuge from high flows and predators.
Wood debris	0.5	The amount of wood debris, including large jams and key pieces, will affect the potential of the subestuary to contain a diverse set of habitats that hold salmonids and give them refuge from high flows and predators.
Access to subestuary habitats	0.5	Connectivity between channels and parts of the subestuary will affect how juvenile salmonids can access all habitats within the subestuary.

A relationship was developed between sensitivity and the average weighted rating—this represents the working hypothesis about the sensitivity of this life stage to habitat diversity in the shallow nearshore environment (Figure 19). Relative survival, i.e., survival relative to the benchmark, equals 1 minus sensitivity. The relationship is based on the synthesis of information contained in Chapter 2. The sensitivity shown is for fry spending the entire life stage subjected to the conditions associated with the ratings.

Important note: the duration of time that chum fry will typically reside in a natal subestuary is assumed to be much less than the time applied to the nearshore environment (see Appendix B - Benchmarks). Therefore the sensitivity shown in Figure 18 will be less than allowed for the nearshore environment (e.g., see Figures 10-11).

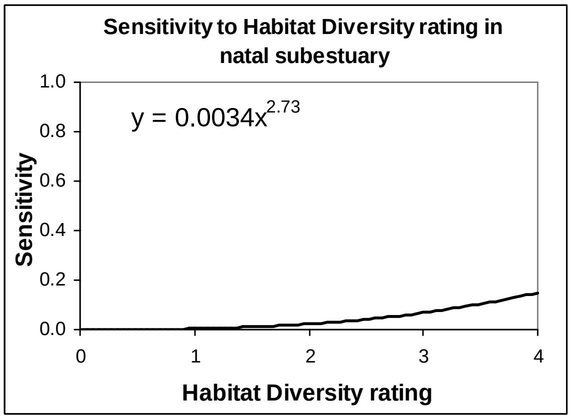

Figure 19. Assumed relationship between the average weighted rating of Level 2 Attributes contributing to Habitat Diversity and sensitivity to small chum fry (<55 mm) within the natal subestuary. Parameter values shown define the curve, obtained by identifying specific target results for certain food ratings, then fitting the curve.

Examples of effect: Examples of results obtained by applying the rules to two natal subestuaries are shown below. The two subestuaries are those associated with the Union and Dosewallips rivers (Figure 7), both located in Hood Canal.

The examples show results for both historic and existing conditions for life stage productivity for fry within the natal subestuary. See Appendix C for rating definitions. (Monthly pattern scalars that reflect seasonal variation in rating are not shown.)

Input and computed productivity for Survival Factor Habitat Diversity for fry in natal subestuary (examples)

Attribute (rating to right)	Segment characterization (month of April)			
	Union subest Historic	Union subest Existing	Dose subest Historic	Dose subest Existing
Channel complexity	1.2	1.6	1.2	2.5
Channel depth - tidal	1.8	2.5	1.5	2
Channel modification (hydromods)	0	2	0	3.5
Riparian function	0	3.3	0	2.5
Wood debris	0	3	0	2.5
Access to subestuary habitats	0	1	0	0
Weighted average rating	**0.5**	**2.3**	**0.4**	**2.4**
Relative productivity	**1.00**	**0.97**	**1.00**	**0.96**
Benchmark survival	**0.656**	**0.656**	**0.656**	**0.656**
Absolute survival	**0.656**	**0.636**	**0.656**	**0.630**

Chapter 5

Data Summarization and Segment Characterization for Hood Canal and the Strait of Juan de Fuca

For the discussion provided in this chapter, The Puget Sound estuarine complex is divided into two broad environmental types, consistent with how survival issues are addressed in Chapter 2: (1) nearshore and deepwater estuarine and (2) subestuaries and tidal marshes.

Some characteristics of these environments that are particularly important to the outcome of applying the species-habitat rules are summarized. This limited summary is intended to illustrate scales that are used and the range of attribute conditions that currently exist in Hood Canal and the Strait of Juan de Fuca. This chapter also briefly describes methods and assumptions applied in characterizing historic conditions.

5.1. Nearshore Characterization

5.1.1. Segmentation

Hood Canal and the Strait were divided into segments at scale that, approximately, places the mouth of no more than one major river into a single segment. Based on the synthesis of the issues affecting salmon performance within the Puget Sound complex, this scale seems appropriate for incorporating landscape effects on survival (see Chapter 2).

Figure 7 (Chapter 3) shows segment boundaries for Hood Canal and the Strait. Hood Canal was segmented so that there are eastside and westside segments, joined approximately in mid channel. Large bays were delineated as single segments, often with a major river entering approximately halfway along the length of the shoreline. In Hood Canal, 20 segments were delineated. North of Hood Canal—along the west side of Admiralty Inlet, and then along the entire Strait of Juan de Fuca, another 22 segments were delineated; thus, 42 segments in total were incorporated in the analysis (Table 8).

Each segment was further divided into two zones: a shallow littoral zone, coinciding approximately with the intertidal zone; and a deeper water zone, referred to for this application as the intertidal zone (ITZ) and the neritic zone. Most of the data used to characterize the intertidal zone within each segment is contained in the WDNR's ShoreZone database. Shoreline units, or *Shore Units*, are alongshore stretches of beach with similar geomorphological characteristics. The average length of a shore unit in the database is 0.5 miles, although their lengths vary substantially. Hood Canal and the Strait of Juan de Fuca (including Admiralty Inlet) have 574 and 362 shore units delineated respectively (Table 8).

Table 8. Number of segments and associated ShoreZone Units within Hood Canal and the Strait of Juan de Fuca.

Area	No. of Segments	No. of ShoreZone Units
Hood Canal	20	574
Strait of Juan de Fuca	22	362
Combined	42	936

5.1.2. Segment Characterization

Summaries of current conditions for key Level 2 Attributes in Hood Canal and the Strait are provided in a series of charts that follow. There is little commentary provided, other than to draw the reader's attention to some notable patterns across these broad landscapes. All of the results shown here are extracted from ShoreZone.

The displays show conditions moving from the southern end of Hood Canal at the Union River at the top of a chart, then moving north through the Canal and continuing along the Strait westward, ending at the Neah Bay segment. Left bank shoreline segments are designated with an "L," and right bank segments are designated with an "R," as seen from the perspective of standing at the Union River and looking up the Canal. For example, the segment Hamma-L is the segment on the west shore of Hood Canal with the Hamma Hamma River entering it, and the segment Hamma-R is the east shore segment directly opposite Hamma-L. The segment Union-O is the beginning segment at the southern end of the Canal with the Union River entering approximately at its center.

Figures 18 and 19 summarize eelgrass conditions, expressed as the percent of a segment's shoreline containing some eelgrass, i.e., patchy or continuous, and continuous eelgrass. Within Hood Canal, the right bank shoreline (i.e., north and east shorelines), tends to have a greater distribution of eelgrass. Eelgrass is limited in distribution along the Strait. The amount of shoreline with continuous eelgrass is highly variable.

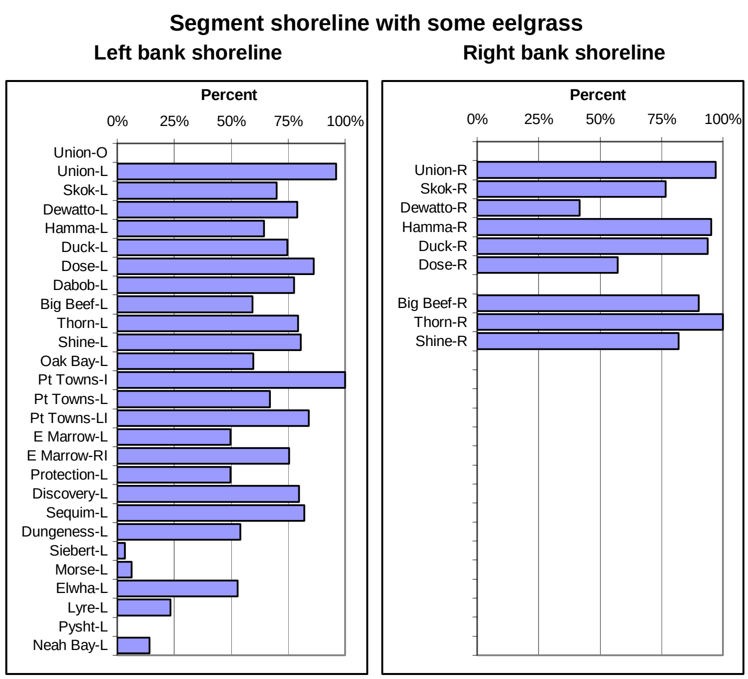

Figure 18. Percent of segment shorelines with some eelgrass (patchy or continuous abundance) from the ShoreZone database. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

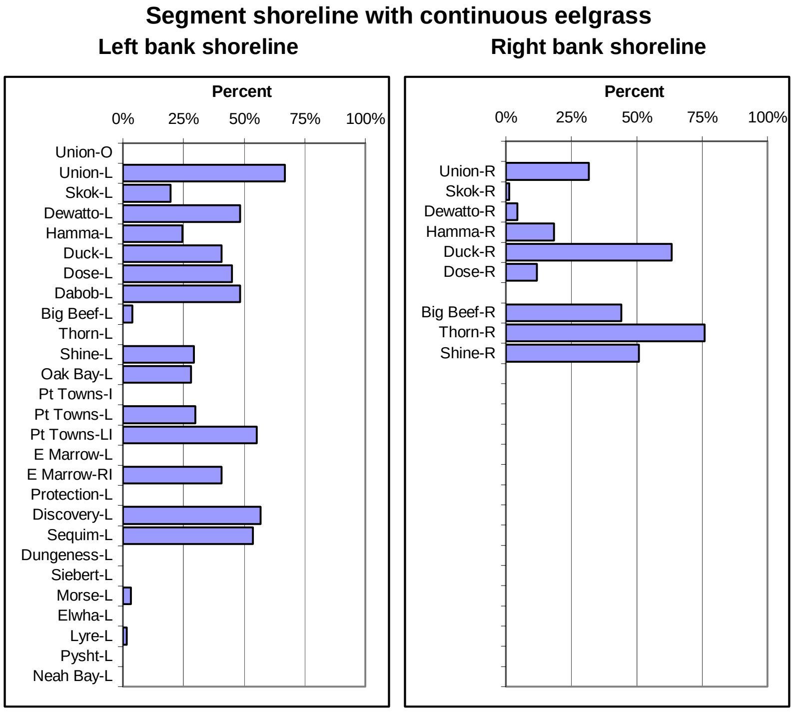

Figure 19. Percent of segment shorelines with continuous eelgrass from the ShoreZone database. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

Figures 20 and 21 summarize kelp conditions, expressed as the percent of a segment's shoreline containing some kelp, i.e., patchy or continuous, and continuous kelp. There is an obvious pattern of relatively little kelp in Hood Canal, with increasing abundance moving north, then into the Strait. Eelgrass is limited in distribution along the Strait.

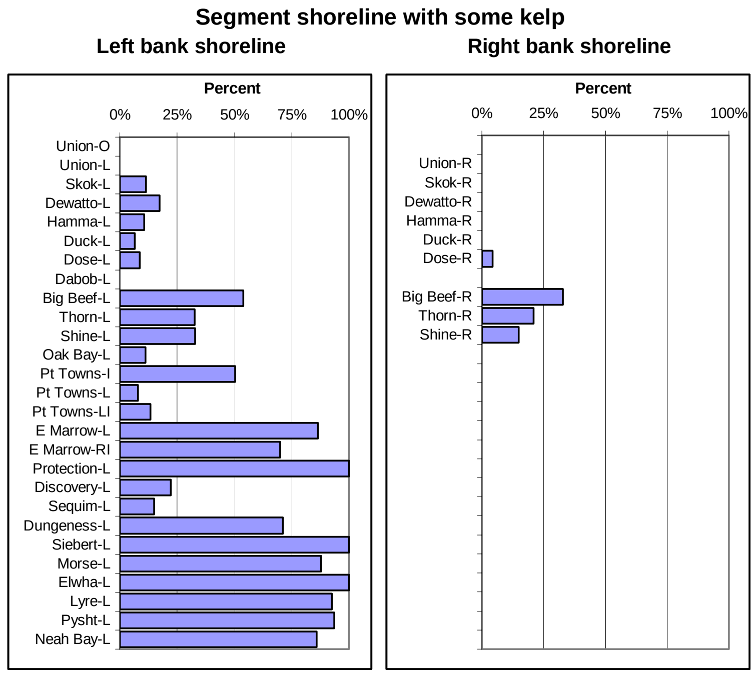

Figure 20. Percent of segment shorelines with some kelp (patchy or continuous abundance) from the ShoreZone database. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

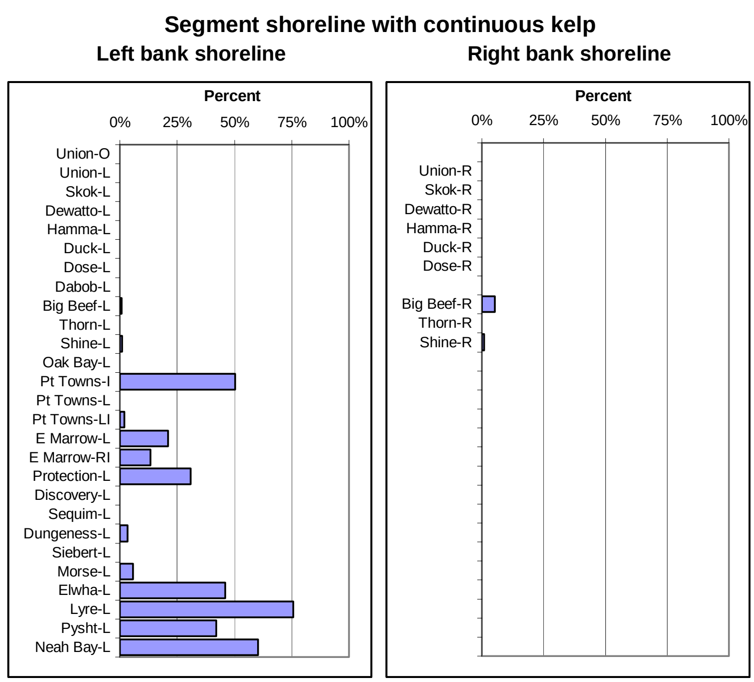

Figure 21. Percent of segment shorelines with continuous kelp from the ShoreZone database. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

Figure 22 summarizes the combined amounts of four shoreline types in ShoreZone. The four types, listed in Chapter 3, are sand and gravel beach, sand beach, sand flat, and sand and gravel flat. These four types in the aggregate were found to be significantly related to the amount of eelgrass in each segment in combination with two other attributes, as explained earlier in this Chapter.

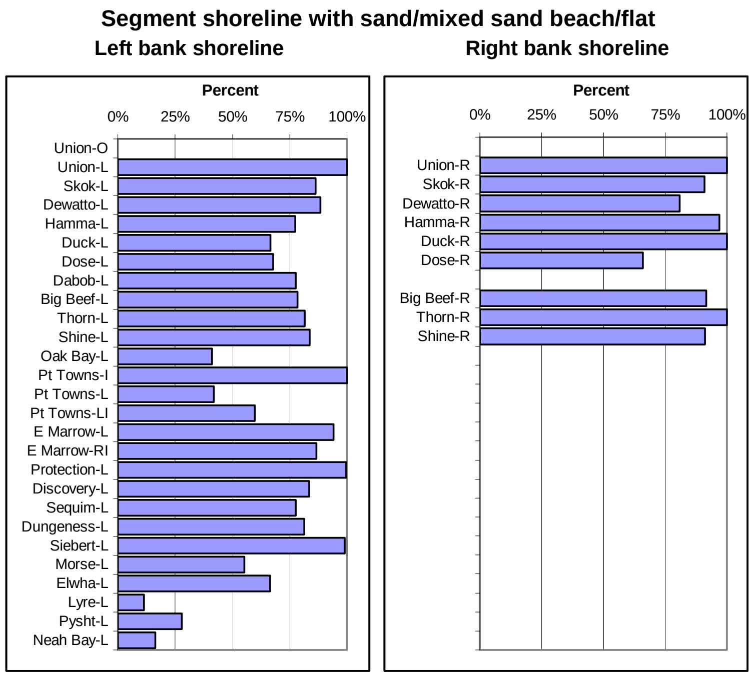

Figure 22. Percent of segment shorelines with combine shoreline types from ShoreZone of sand and gravel beach, sand beach, sand flat, and sand and gravel flat. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

Figure 23 summarizes the percent of each segment's shoreline that has been modified by human development based on ShoreZone. Note that unusually high amounts of the shoreline have been developed in the lower portion of Hood Canal, far greater than other areas with the exception of the areas encompassing and near Port Angeles. The pattern seen here has been well described by Hirschi et al. (2003a) based on field observations that verify ShoreZone results. Their report describes the extent of development in the lower half of the Canal, showing that no other area of Hood Canal or the eastern Strait has been more radically altered.

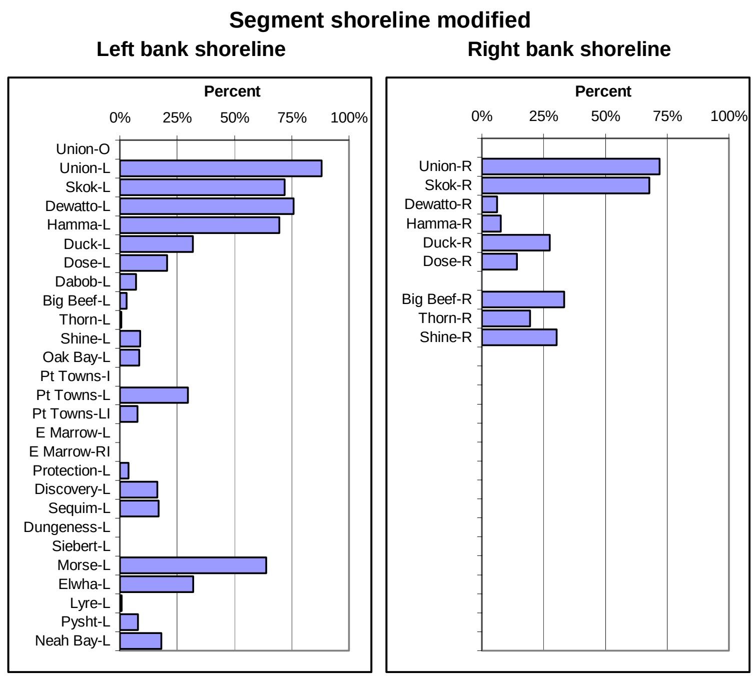

Figure 23. Percent of segment shorelines modified by human development, as identified in ShoreZone. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

Figure 24 summarizes the percent of each segment's shoreline identified as having overhanging riparian vegetation based on ShoreZone. Note that the highest quantities of overhanging vegetation tend to be along the right bank (east side) of Hood Canal north of the Skokomish segment and in northern Hood Canal along both banks. Little overhanging vegetation exists outside of Hood Canal.

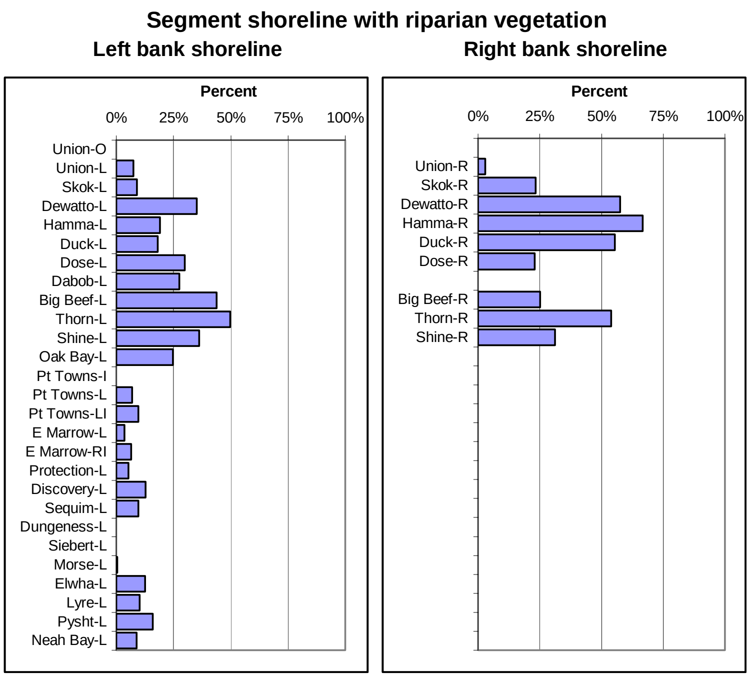

Figure 24. Percent of segment shorelines with overhanging riparian vegetation as identified in ShoreZone. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

Figure 25 summarizes the average wave exposure within each segment based on ShoreZone.

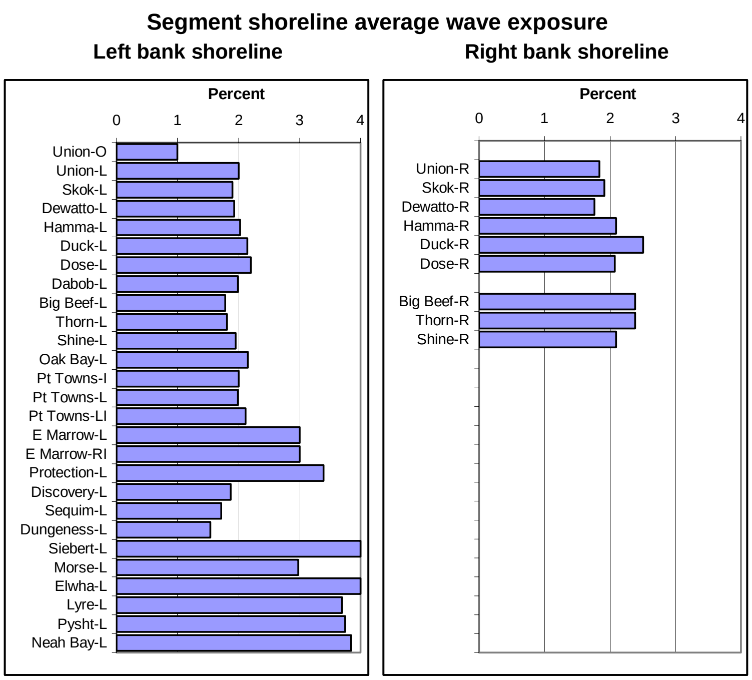

Figure 25. Average wave exposure within each segment as identified in ShoreZone. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

5.1.3. Characterization of the Historic Shallow Nearshore Environment

The EDT analysis requires that a characterization of historic conditions be made. This characterization provides the basis for assessing the magnitude of change in fish population performance that can reasonably be attributed to environmental alterations.

A short summary follows here of the procedure used to characterize historic conditions for attributes applicable to the shallow nearshore environment.

The attributes that were thought to have possibly differed historically and that were then characterized are:

- eelgrass distribution and abundance
- amount of shoreline type associated with sand beaches or flats
- kelp distribution and abundance
- riparian vegetation

Eelgrass distribution and abundance. A wide variety of possible relationships between the ShoreZone eelgrass attributes and other shoreline characteristics contained in the attribute database were analyzed. Two eelgrass attributes are characterized: (1) the percent of the segment's shoreline associated with either patchy or continuous eelgrass, and (2) the percent of the shoreline associated with just continuous eelgrass. The former is comprised of the sum of the shoreline units within a segment having either patchy or continuous eelgrass (expressed as a percent of the total segment's length). The latter is just the sum of units (as a percent of total shoreline length) with continuous eelgrass.

Excluding the island segments, which are either very small or seem to be very diverse on different sides, significant linear relationships were found between both the percent of shoreline having kelp present and the percent of shoreline associated with the four sand substrate shoreline types and percent of shoreline with eelgrass. Multiple regression on these variables was highly significant ($r^2 = 0.76$). Another variable was then incorporated and percent of shoreline was modified, to account for the many types of effects that shoreline development can have on eelgrass, as described in Chapter 2. Although addition of the variable did not improve the fit significantly, it was applied to signal that shoreline development was expected to be operating (Figure 26). One possible reason the signal in the regression is weak is that shoreline development may already be expressed in the amounts of kelp and sandy shoreline. In follow-up to this exercise, historic sand shoreline types and kelp abundance were estimated through a simple set of assumptions that losses in sand substrates, or gains in kelp, are related to percent shoreline developed and to wave exposure (see below). These estimates of historic sand types and kelp were incorporated into the procedure for estimating historic eelgrass amount. In general, this produced modestly higher amounts of eelgrass (patchy and continuous combined) under the historical scenario.

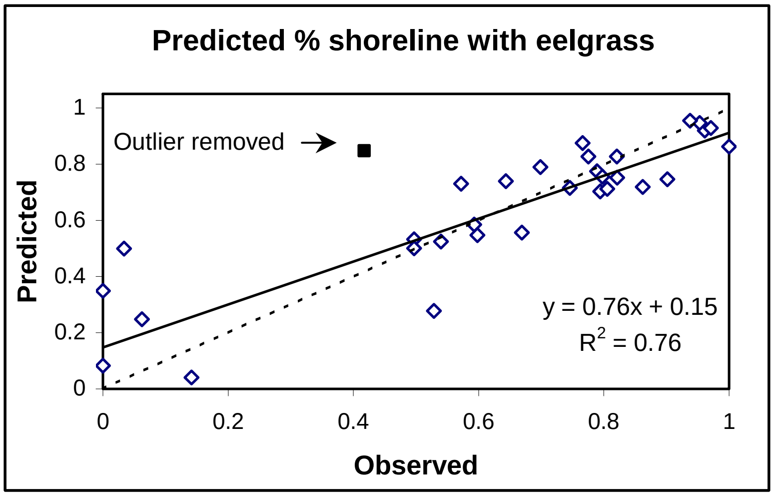

Figure 26. Pattern of predicted versus observed values for the percent of shoreline with eelgrass within a shoreline segment, excluding island segments. Outlier point is Dewatto-R, which was not used in the regression. Eelgrass here is both patchy and continuous.

The amount of shoreline with continuous eelgrass under the historical scenario was estimated by applying a regression between the percent of shoreline with either patchy or continuous eelgrass and the percent of shoreline with just continuous eelgrass (Figure 27). The regression shown was applied. This may have produced an overly high amount of continuous eelgrass for a few segments (circled). It was felt that the procedure did not adequately capture all causes of decreased eelgrass, and, therefore, the results were applied as derived.

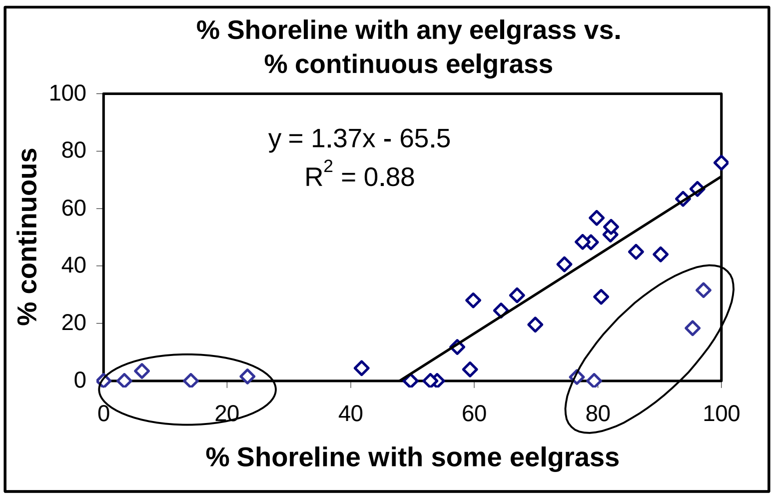

Figure 27. Relationship between the percent of shoreline with continuous eelgrass and the percent with either patchy or continuous eelgrass. Circled points were excluded from the relationship. Low values of percent shoreline with any eelgrass would necessarily have low or no continuous eelgrass. Circled points to the right appear to have unusually low amounts of continuous eelgrass associated with high percentages of shoreline with any eelgrass present. It is assumed that these are anomalies due to the effects of development, sampling error, or unusual localized conditions.

Amount of shoreline type associated with sand beaches or flats. This attribute encompasses the four shoreline types with significant components of sand and associated with beaches or flats. Historic sand shoreline types were estimated through a simple set of assumptions that losses in sand substrates are related to percent shoreline developed and to wave exposure. In areas of low wave exposure, it was assumed that there is relatively little change in sand substrates with development. As wave exposure increases, it was assumed there is a greater loss in sand substrates as development increases. This procedure produced relatively small increases in the amounts of sand dominated areas under the historical scenario where development is extensive today and where there is moderate to high wave exposure.

Kelp distribution and abundance. This attribute identifies the percent of shoreline with either patchy or continuous kelp. Historic kelp was estimated through a simple set of assumptions that specifies that increases in current day kelp are related to percent shoreline developed and to wave exposure. In areas of low wave exposure, it was assumed that there is relatively little change in kelp with development. As wave exposure increases, it was assumed there has been a greater increase in kelp as development increases. This procedure produced relatively small increases in the amounts of kelp under the historical scenario where development is extensive today and where there is moderate to high wave exposure.

Riparian vegetation. A wide variety of possible relationships between the ShoreZone attribute percent riparian vegetation and other shoreline characteristics contained in the attribute database were analyzed. The analysis focused on segments out to Dungeness, excluding the Strait to the west, because segments tended to have relatively little riparian vegetation beyond that point (Figure 24). A significant multiple regression between three variables and the percent shoreline with riparian vegetation ($r^2 = 0.65$) was developed. The three variables are the percent of shoreline with the four shoreline types having sand, slope of the intertidal zone, and the percent of modified shoreline. It is uncertain as to why areas with higher sandy shorelines tend to have a higher amount of riparian vegetation Shorelines with steeper intertidal zones had higher amounts of riparian vegetation, which is intuitively evident. The third variable, shoreline modification, was the most significant of the three variables in the relationship. This relationship was used to estimate the historical amounts of riparian vegetation along the nearshore. No changes were assumed in the Strait west of Dungeness—not the case in some areas.

5.2. Subestuary characterization

The broad category of subestuaries within this analysis was divided into two parts. First, it is recognized that all subestuaries and shoreline fringing tidal marshes are collectively a characteristic of the nearshore segment in which they enter or border. One of the Level 3 attributes is “Loss in function of subestuary and tidal marsh types” (Table 4). Second, another set of attributes is applied to characterize natal subestuaries—this characterization is used for analyzing the individual natal subestuaries apart from the analysis applied to the nearby nearshore segments.

With the aid of members of the technical team acknowledged at the front of this report, loss in function from historical condition was characterized for a total of 219 subestuaries and tidal marshes between Union River and the Elwha River (Figure 27).[18] Loss was primarily accounted for by loss in area of emergent marsh, combined with a visual assessment using maps and photographs of loss in connectivity with the marine environment or other obvious constraints imposed by development (Figure 28).

[18] Steve Todd led this effort with the help of Richard Brocksmith and Allan Carter-Mortimer.

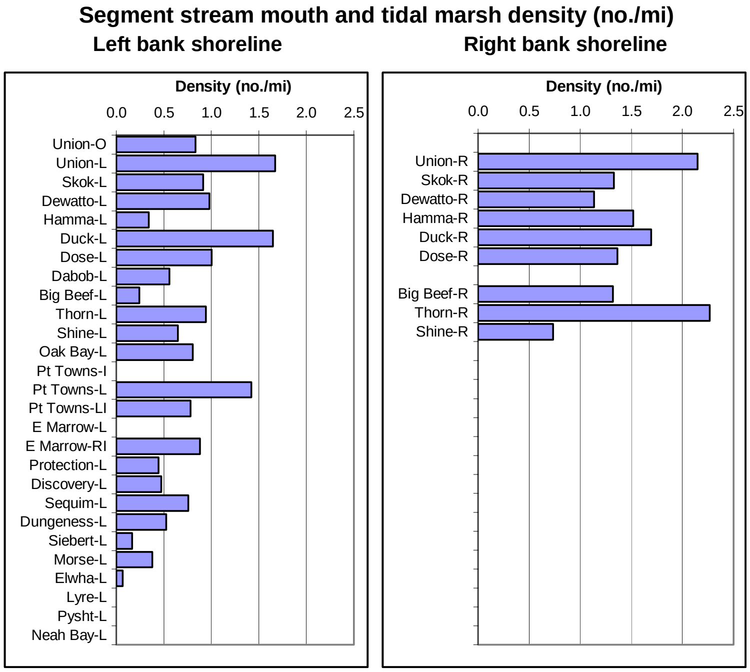

Figure 27. Density (number per mile) of subestuaries and tidal marshes by nearshore segment. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

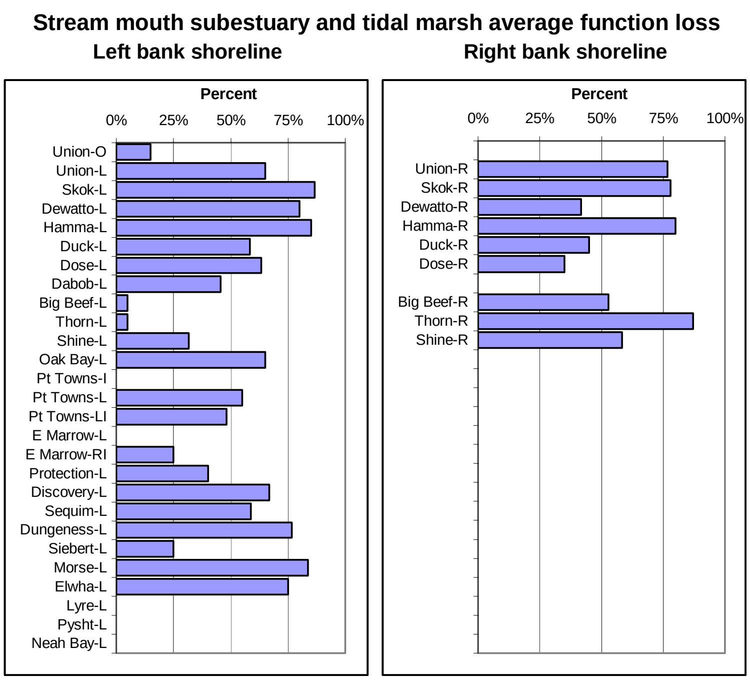

Figure 28. Average loss in function of subestuaries and tidal marshes by nearshore segment. The south and west shorelines of Hood Canal are labeled as "left bank," north and east shorelines are labeled "right bank."

For natal subestuaries, the characterization of the historical conditions was considered as a draft for review by interested parties. The data are available at the EDT web site.

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Appendices

Appendix A—Chum Salmon Life Stages

Appendix Table A-1. Chum salmon life stages (note: the 0-age transient rearing stage includes two phases)

Life stage	Description
Spawning	Period of active spawning, beginning when fish move on to spawning beds and initiate redd digging and ending when gametes are released. Note: For computational purposes, the reproductive potential associated with a spawning female is incorporated at the beginning of this stage; this potential includes sex ratio (average females per total spawners) and average fecundity per female.
Egg incubation	Egg incubation and alevin development; stage begins at the moment of the release of gametes by spawners and ends at fry emergence (losses to egg viability that occur in the instant prior to fertilization are included here).
Fry colonization	Fry emergence and initial dispersal; time period is typically very short, beginning at fry emergence and ending when fry begin active feeding associated with a key habitat.
0-age transient rearing	A transient-migratory rearing stage through the natal stream mouth estuary and the adjoining larger estuarine system, then into the open ocean. An early phase consist of epibenthic oriented feeding and migration, followed by a neritic migratory phase.
1-age transient rearing	Feeding/rearing by age 1 fish that occurs in the marine environment.
2+-age transient rearing	Feeding by sub-adult (age 2 and older) fish in the marine environment.
Migrant prespawner	Adult fish approaching sexual maturity that are migrating to their natal stream; in the ocean this stage occurs in the final year of marine life, in freshwater feeding has ceased.
Holding prespawner	Adult fish approaching sexual maturity that are largely stationary and holding, while en route to their spawning grounds; distance to the spawning grounds from holding sites may be short or long.

Appendix B—Benchmark Values for Chum Salmon

The EDT method associates survival with habitat. The productivity and capacity values derived in the EDT process are characteristics of the environment by time and location as interpreted "though the eyes of salmon" by species and life stage (Mobrand et al. 1997). The procedure for deriving these productivity and capacity values involves a shaping of survival conditions over time and space, as salmonids might experience them in completing their life cycle. The shaping of survival conditions is done with reference to a defined set of "benchmark" conditions.

From the literature it is possible to identify, or hypothesize where data are limited, habitat requirements by life stage for the species. Taking this a step further, optimal conditions and the expected survival and density limits by life stage are described. In EDT, survival and density values associated with optimal conditions are referred to as reference benchmarks. Benchmarks provide a set of descriptions for optimal conditions expressed as productivity survival, maximum densities, and habitat characteristics for each life stage. These conditions constitute what can be thought of "as good as it gets" for survival of the species in nature. Benchmark values derived from reviewing relevant sources of information have been employed here.

For chum salmon, Salo's (1991) synthesis of chum life history, which included survival values where they have been collected, has been relied upon heavily. Salo's synthesis, however, leaves a number of gaps in the survival picture across the full cycle. These gaps were filled with hypotheses about what levels of survival are reasonable based on extensive modeling with the other salmon species using EDT and a synthesis, drawn from information summarized in the body of this report, of how life stage survivals likely compare to one another.

The systematic shaping of survival conditions using the habitat rating procedures is intended to assure that productivity and capacity values for each life history segment along a trajectory are: a) bounded by the biological limits of the species, b) scaled consistently across time, space, and life stage, and c) scaled consistently with the benchmark values.

It is important to keep in mind that benchmark or optimal conditions are different from template (pre-development) conditions. Template conditions were not always optimal for salmon survival. The benchmark descriptions serve as a point of reference for both the patient and template and for all watersheds.

Benchmarks values presented here are expected to be refined as discussions with knowledgeable biologists on this topic continue.

Appendix Table B-1. Fall-winter chum salmon benchmark values

Life stage	Environmental type	Stereotypical duration (weeks)	Productivity	Density (fish/m2
Spawning	Freshwater	1	1.0	0.5
Egg incubation	Freshwater	20	0.84	400
Fry colonization	Freshwater	1	0.8	11.5
0-age transient rearing	Freshwater	3	0.55	1.0
0-age transient rearing	Natal Subestuary 1/	3	0.656	1.0
0-age transient rearing	Shallow estuarine-marine 2/	6	0.35	1.0
0-age transient rearing	Deep estuarine-marine 2/	30	0.35	1.0
1-age transient rearing	Marine	52	0.6	0.05
2+-age transient rearing	Marine 3/	52	0.9	0.001
Migrant prespawner	Freshwater	2	0.95	1.0
Migrant prespawner	Natal Subestuary 1/	4	0.8	1.0
Migrant prespawner	Estuarine-Marine 2/	52	0.9	0.1
Holding prespawner	Freshwater	2	0.98	1.0

1/ Stream-mouth estuary of the natal stream.
2/ Includes estuarine environment of an inland sea like Puget Sound and marine environment of the SJDF and ocean.
3/ Productivity values vary for different ages.

Appendix C—Level 2 Attribute Index Definitions

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
1 Climate								
Climate regime	PDO	Pacific Decadal Oscillation (PDO)	The prevailing state of the Pacific Decadal Oscillation (PDO) corresponding to the scenario of interest.	Warm phase of PDO (positive), such as occurred from the late 1970s until the late 1990s.	Not used	Not used	Not used	Cool phase of PDO (negative), such as occurred from the mid 1940s until the late 1970s.
2 Basin/shoreline features								
Morphometry	SegLength	Unit length	Length of subestuary (natal), segment or region; applies to all zones. Measured in meters.	Approximate length of the segment. This attribute is not given a rating, it is the actual estimated length in meters.				
Morphometry	SegWidth	Unit width	Width of subestuary (natal), segment or region; applies to all zones. Measured in meters.	Approximate average width of the segment. This attribute is not given a rating, it is the actual estimated average width in meters.				
Morphometry	ITZWidth	ITZ Width	Width of the intertidal zone for the segment. Measured in meters.	Average width of the intertidal zone for the segment. This attribute is not given a rating, it is the actual estimated average width in meters.				
Morphometry	ITZGrad	Slope of intertidal zone	Average slope of the intertidal zone within the segment (weighted by ShoreZone unit length).	0-6%	>6% and <18%	>18% and <30%	>30% and <42%	>42% (48% or more is given 4 on a continuous scale)

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Flow and circulation	FlwHigh	Stream flow - change in average annual peak flow	The extent of relative change in average peak annual discharge compared to an undisturbed watershed of comparable size, geology, orientation, topography, and geography (or as would have existed in the pristine state). See definitions applied to corresponding input stream. (See Konrad 2000a and b for information on flow metrics.)	Peak annual flows expected to be strongly reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <100% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be moderately reduced relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >20% and <40% decrease in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known by regulated flow levels. This condition is associated with flow regulation or water diversion projects.	Peak annual flows expected to be comparable to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR <20% change in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR <5% reduction in average T_{Qmean} compared to the undeveloped watershed state.	Peak annual flows expected to be moderately increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >20% and <40% increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR >5% and <15% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in some forested watersheds with high road density that experience significant rain on snow events, as the North Fork Stillaguamish River (Pess et al. *in review*). Note: many managed forested watersheds in the Pacific Northwest exhibit slight, if any, increases in peak annual flows since logging commenced (see Ziemer and Lisle 1998).	Peak annual flows expected to be strongly increased relative to an undisturbed watershed of similar size, geology, orientation, topography, and geography (or the pristine state for the watershed of interest); OR >40% and <110%+ increase in Q_{2yr} based on a long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state); OR >15% and <45% reduction in average T_{Qmean} compared to the undeveloped watershed state. This condition exemplified in watersheds with significant urbanization (e.g., >20%).

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Flow and circulation	FlwLow	Stream flow - change in average annual extreme low flow	The extent of relative change in average daily flow during the normal low flow period compared to an undisturbed watershed of comparable size, geology, and flow regime (or as would have existed in the pristine state). See definitions applied to corresponding input stream.	Average daily low flows expected to be strongly increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be moderately increased compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <75% increase in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be comparable to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR <20% change in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state).	Average daily low flows expected to be moderately reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >20% and <50% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.	Average daily low flows expected to be severely reduced compared to an undisturbed watershed of similar size, geology, and flow regime (or the pristine state for the watershed of interest); OR >50% and <=100% reduction in the 45 or 60-day consecutive lowest average daily flow on a sufficiently long time series (~40 yrs or longer with at least 20 yrs pertaining to a watershed development state) or as known through flow regulation.
Flow and circulation	OutflwVel	Surface outflow average velocity	Average velocity of the surface outflow within the segment during a month measured in cm/sec.	0-0.7cm/sec	0.7 cm/sec - 2 cm/sec	2 cm/sec - 3.3 cm/sec	3.3 cm/sec - 4.7 cm/sec	> 4.7 cm/sec (values > 5.3 cm/sec are given 4 on a continuous scale)
Flow and circulation	Exposure	Wave exposure	Average wave exposure of the intertidal zone within the segment (weighted by ShoreZone unit length).	Average ShoreZone rating of 1 - 1.5	Average ShoreZone rating of 1.5 - 2.5	Average ShoreZone rating of 2.5 - 3.5	Average ShoreZone rating of 3.5 - 5	Average ShoreZone rating of 5 - 6
Shoreline/channel structure	AccessSubest	Accessibility to subestuary habitats	The extent that all portions of a subestuary are accessible to juvenile salmonids during tidal stages that would normally facilitate access; e.g., tidal gates may block access.	All subestuary channels and associated wetland complexes are accessible to juvenile fish that seek entrance or passage.	Less than 10% (but >0%) of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	More than 10% and less than 30% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	More than 30% and less than 60% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.	Greater than 60% of the wetted area of wetland complexes and smaller sloughs and blind channels is blocked to access by juvenile fish by man-made structures.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Shoreline/channel structure	ChanComplex	Channel complexity	The extent that the subestuary's channel pattern is dendritic or sinuous through its course; natural channels may be simple or complex; estuarine development typically alters complex patterns to simple ones.	Multi threaded channel network (anastimozing, highly dendritic, or multiple distributaries) with numerous blind channels and extensive tidal marshes; extensive and wide delta area; channels tend to be highly stable.	Multi threaded channel network (tends toward anastimozing, dendritic, or distributaries) with some blind channels and extensive tidal marshes; relatively narrow delta area; channels tend to be highly stable. This type has a narrower delta with tidal marshes and blind channels more limited than occurs with Index 1.	Single threaded, meandering channel (sinuosity >1.3), or multi threaded channel (2-3 main channels) with relatively low moderate abundance of tidal marshes and/or blind channels.	Single threaded channel with low to moderate sinuosity (>1.1 and <1.3), no or few connecting blind channels and very limited tidal marshes.	Single threaded channel with low sinuosity (<1.1); connecting blind channels and tidal marshes extremely limited or absent.
Shoreline/channel structure	ChanDepth	Channel depth - tidal channels	Range of depths in primary tidal channels at MLLW during the low flow period (describes conditions that may result in migration delay or stress for adult salmon). Depths may be influenced by aggradation of channels or change in flow.	Average water depth in the channel thalweg in main channel(s) at low tide during the low flow period > 5 ft. Depth here refers to depth on riffle or run type habitat units.	Average water depth in the channel thalweg in main channel(s) at low tide during the low flow period > 3 ft and < 5 ft. Depth here refers to depth on riffle or run type habitat units.	Average water depth in the channel thalweg in main channel(s) at low tide during the low flow period > 1 ft and < 3 ft. Depth here refers to depth on riffle or run type habitat units.	Average water depth in the channel thalweg in main channel(s) at low tide during the low flow period > 4 in and < 12 in. Depth here refers to depth on riffle or run type habitat units.	Average water depth in the channel thalweg in main channel(s) at low tide during the low flow period < 4 in. Depth here refers to depth on riffle or run type habitat units.
Shoreline/channel structure	ConfineHydro	Confinement - hydromodifications	The extent that man-made structures within or adjacent to the subestuary channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain and delta (due to streamside roads, revetments, diking or levees). See definitions applied to corresponding input stream.	The stream channel(s) within the subestuary is essentially fully connected to its floodplain. Very minor structures may exist in the floodplain that do not result in flow constriction or restriction.	Some portion of the stream channel(s), though less than 10% (of the sum of lengths of both banks of a channel), is disconnected from its floodplain along one or both banks due to man-made structures or channelization.	More than 10% and less than 40% of the entire length of the stream channel (sum of lengths of both banks) within the subestuary is disconnected from its floodplain along one or both banks due to man-made structures or channelization.	More than 40% and less than 80% of the entire length of the stream channel (sum of lengths of both banks) within the subestuary is disconnected from its floodplain along one or both banks due to man-made structures or channelization.	Greater than 80% of the entire length of the stream channel (sum of lengths of both banks) within the subestuary is disconnected from its floodplain along one or both banks due to man-made structures or channelization.
Shoreline/channel structure	DensityRMEst	Density of river mouth estuaries	Density of river mouth estuaries within the shoreline segment. Density as number per mile of shoreline.	> 0.28 and < 0.32 sites per mile of shoreline. Densities > 0.32 per mile are assigned a value of 0.	> 0.2 and < 0.28 sites per mile of shoreline.	> 0.12 and < 0.2 sites per mile of shoreline.	> 0.04 and < 0.12 sites per mile of shoreline.	0 - 0.04 sites per mile of shoreline.
	DensityCMEst	Density of creek mouth estuaries	Density of creek mouth estuaries within the shoreline segment. Density as number per mile of shoreline.	> 0.56 and < 0.64 sites per mile of shoreline. Densities > 0.64 per mile are assigned a value of 0.	> 0.4 and < 0.56 sites per mile of shoreline.	> 0.24 and < 0.4 sites per mile of shoreline.	> 0.08 and < 0.24 sites per mile of shoreline.	0 - 0.08 sites per mile of shoreline.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
	DensityTideChanMarshFW	Density of tidal channels with salt marsh and FW input	Density of tidal channels with salt marsh and FW input within the shoreline segment. Density as number per mile of shoreline.	> 0.49 and < 0.56 sites per mile of shoreline. Densities > 0.56 per mile are assigned a value of 0.	> 0.35 and < 0.49 sites per mile of shoreline.	> 0.21 and < 0.35 sites per mile of shoreline.	> 0.07 and < 0.21 sites per mile of shoreline.	0 - 0.07 sites per mile of shoreline.
	DensityTideChanFW	Density of tidal channels without salt marsh with FW input	Density of tidal channels without salt marsh with FW input within the shoreline segment. Density as number per mile of shoreline.	> 0.49 and < 0.56 sites per mile of shoreline. Densities > 0.56 per mile are assigned a value of 0.	> 0.35 and < 0.49 sites per mile of shoreline.	> 0.21 and < 0.35 sites per mile of shoreline.	> 0.07 and < 0.21 sites per mile of shoreline.	0 - 0.07 sites per mile of shoreline.
	DensityTideMarshFW	Density of salt marshes without tidal channel with FW input	Density of salt marshes without tidal channel with FW input within the shoreline segment. Density as number per mile of shoreline.	> 0.35 and < 0.4 sites per mile of shoreline. Densities > 0.4 per mile are assigned a value of 0.	> 0.25 and < 0.35 sites per mile of shoreline.	> 0.15 and < 0.25 sites per mile of shoreline.	> 0.05 and < 0.15 sites per mile of shoreline.	0 - 0.05 sites per mile of shoreline.
	DensityTideChanMarsh	Density of tidal channels with salt marsh and no FW input	Density of tidal channels with salt marsh and no FW input within the shoreline segment. Density as number per mile of shoreline.	> 2.1 and < 2.4 sites per mile of shoreline. Densities > 2.4 per mile are assigned a value of 0.	> 1.5 and < 2.1 sites per mile of shoreline.	> 0.9 and < 1.5 sites per mile of shoreline.	> 0.3 and < 0.9 sites per mile of shoreline.	0 - 0.3 sites per mile of shoreline.
	DensityTideMarsh	Density of salt marshes without tidal channel with no FW input	Density of salt marshes without tidal channel with no FW input within the shoreline segment. Density as number per mile of shoreline.	> 2.1 and < 2.4 sites per mile of shoreline. Densities > 2.4 per mile are assigned a value of 0.	> 1.5 and < 2.1 sites per mile of shoreline.	> 0.9 and < 1.5 sites per mile of shoreline.	> 0.3 and < 0.9 sites per mile of shoreline.	0 - 0.3 sites per mile of shoreline.
Shoreline/channel structure	DockDensity	Dock-slip density	The density of docks, piers, and slips within the segment, expressed as the total number per mile of shoreline.	0 - 2 docks-slips per mile of shoreline.	2 - 6 docks-slips per mile of shoreline.	6 - 10 docks-slips per mile of shoreline.	10 - 14 docks-slips per mile of shoreline.	14 -16 docks-slips per mile of shoreline. Densities > 16 per mile are assigned a value of 4.
Shoreline/channel structure	SubestLossFunc	Loss in function of subestuary and tidal marsh types	Average percent loss of function of subestuary and tidal marsh types within the segment by the seven types. SEE BELOW					
	FuncLossRMEst	Function loss of river mouth estuaries	Loss in function of river mouth estuaries within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
	FuncLossCMEst	Function loss of creek mouth estuaries	Loss in function of creek mouth estuaries within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
	FuncLossTideChanMarshFW	Function loss of tidal channels with salt marsh and FW input	Loss in function of tidal channels with salt marsh and FW input within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
	FuncLossTideChanFW	Function loss of tidal channels without salt marsh with FW input	Loss in function of tidal channels without salt marsh with FW input within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
	FuncLossTideMarshFW	Function loss of salt marshes without tidal channel with FW input	Loss in function of salt marshes without tidal channel with FW input within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
	FuncLossTideChanMarsh	Function loss of tidal channels with salt marsh and no FW input	Loss in function of tidal channels with salt marsh and no FW input within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
	FuncLossTideMarsh	Function loss of salt marshes without tidal channel with no FW input	Loss in function of salt marshes without tidal channel with no FW input within the shoreline segment.	0 - 12% loss in function	12 - 37% loss in function	37 - 62% loss in function	62 - 87% loss in function	87 - 100% loss in function
Shoreline/channel structure	SubestEmergRatio	Ratio of emergent vegetation to watershed size	Ratio of the amount of area encompassing emergent vegetation within the subestuary to the size of the subestuary's watershed.	> 8 acres emergent marsh area per square mile of watershed. Ratios of 16 acres/mi^2 and more are assigned a value 0.	> 4 and < 8 acres emergent marsh area per square mile of watershed.	> 2 and < 4 acres emergent marsh area per square mile of watershed.	> 0.5 and < 2 acres emergent marsh area per square mile of watershed.	> 0 and < 0.5 acres emergent marsh area per square mile of watershed. A ratio of 0 is assigned a value 4.
Shoreline/channel structure	WAreaITZRatio	Ratio of river/creek watersheds to ITZ in segment	Ratio of the total area of river and creek watersheds entering the segment to the intertidal zone area within the segment.	> 0.22 square miles of watershed per acre of ITZ in the nearshore segment. Ratios of 0.25 mi^2/acre of ITZ and more are assigned a value 0.	> 0.16 and < 0.22 square miles of watershed per acre of ITZ in the nearshore segment.	> 0.09 and < 0.16 square miles of watershed per acre of ITZ in the nearshore segment.	> 0.03 and < 0.09 square miles of watershed per acre of ITZ in the nearshore segment.	> 0 and < 0.03 square miles of watershed per acre of ITZ in the nearshore segment. A ratio of 0 is assigned a value 4.
Shoreline/channel structure	SubestEmergMudRatio	Ratio of subestuary size to watershed size	Ratio of the amount of area encompassing emergent vegetation and mudflat within the subestuary to the size of the subestuary's watershed.	> 16 acres emergent marsh and delta mudflat area per square mile of watershed. Ratios of 32 acres/mi^2 and more are assigned a value 0.	> 8 and < 16 acres emergent marsh and delta mudflat per square mile of watershed.	> 4 and < 8 acres emergent marsh and delta mudflat area per square mile of watershed.	> 1 and < 4 acres emergent marsh and delta mudflat area per square mile of watershed.	> 0 and < 1 acres emergent marsh and delta mudflat area per square mile of watershed. A ratio of 0 is assigned a value 4.
Shoreline/channel structure	EmergITZRatio	Ratio of total emergent vegetation to ITZ in segment	Ratio of total area of emergent vegetation to the intertidal zone area within the segment	> 0.44 acres of emergent marsh (subestuary and tidal marsh) per acre of ITZ in the nearshore segment. Ratios of 0.5 and greater are assigned a value 0.	> 0.31 and < 0.44 acres of emergent marsh (subestuary and tidal marsh) per acre of ITZ in the nearshore segment.	> 0.19 and < 0.31 acres of emergent marsh (subestuary and tidal marsh) per acre of ITZ in the nearshore segment.	> 0.06 and < 0.19 acres of emergent marsh (subestuary and tidal marsh) per acre of ITZ in the nearshore segment.	> 0 and < 0.06 acres of emergent marsh (subestuary and tidal marsh) per acre of ITZ in the nearshore segment. A ratio of 0 is assigned a value 4.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Shoreline/channel structure	RipFunc	Riparian function - subestuary	A measure of riparian function that has been altered within the subestuary. (This is the same definition applied to the freshwater environment.)	Strong linkages with no anthropogenic influences.	>75-90% of functional attributes present (overbank flows, vegetated streambanks, groundwater interactions typically present).	50-75% functional attribute rating- significant loss of riparian functioning- minor channel incision, diminished riparian vegetation structure and inputs etc.	25-50% similarity to natural conditions in functional attributes- many linkages between the stream and its floodplain are severed.	< 25% functional attribute rating: complete severing of floodplain-stream linkages
Shoreline/channel structure	RipVegPercent	Riparian vegetation - segment	The total percent of the shoreline within the segment with vegetation that hangs over into the intertidal zone based on Washington ShoreZone data. Riparian estimated only for unconsolidated (gravel, pebble, sand, mud, etc) shorelines.	> 87.5% of segment's shoreline length contains overhanging riparian vegetation. A value of 0 is assigned when the shoreline contains 100% overhanging vegetation.	> 62.5% and < 87.5% of segment's shoreline length contains overhanging riparian vegetation.	> 37.5% and < 87.5% of segment's shoreline length contains overhanging riparian vegetation.	> 12.5% and < 37.5% of segment's shoreline length contains overhanging riparian vegetation.	> 0% and < 12.5% of segment's shoreline length contains overhanging riparian vegetation. A value of 4 is assigned when 0% of shoreline has overhanging vegetation.
Shoreline/channel structure	ShoreModPercent	Shoreline modifications segment percent	The total percent of the shoreline that has been modified by bulkhead, riprap, and other man-made structures, based on data in Washington ShoreZone.	> 87.5% of segment's shoreline length is modified by development. A value of 0 is assigned when the shoreline is 100% modified.	> 62.5% and < 87.5% of segment's shoreline length is modified by development.	> 37.5% and < 87.5% of segment's shoreline is modified by development.	> 12.5% and < 37.5% of segment's shoreline is modified by development.	> 0% and < 12.5% of segment's shoreline is modified by development. A value of 4 is assigned when 0% of shoreline is modified.
Shoreline/channel structure	(by shoreline type)	Shoreline type (percent)	Percent of shoreline within segment composed of four different shoreline types containing substantial amounts of sand substrate. Shoreline types are those used in Washington ShoreZone (a simplification of the BC shoreline classification). The four types are sand flats, sand and gravel flats, sand and gravel beaches, and sand beaches.	> 87.5% of segment's shoreline length classified as being dominated by the four ShoreZone shoreline types encompassed within definition. A value of 0 is assigned when 100% of the shoreline is identified as being comprised of the four shoreline types.	> 62.5% and < 87.5% of segment's shoreline length classified as being dominated by the four ShoreZone shoreline types encompassed within definition.	> 37.5% and < 87.5% of segment's shoreline length classified as being dominated by the four ShoreZone shoreline types encompassed within definition.	> 12.5% and < 37.5% of segment's shoreline length classified as being dominated by the four ShoreZone shoreline types encompassed within definition.	> 0% and < 12.5% of segment's shoreline length classified as being dominated by the four ShoreZone shoreline types encompassed within definition. A value of 4 is assigned when 0% of shoreline contains the shoreline type of interest.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Shoreline/channel structure	WdDeb	Wood debris in subestuary	Amount of wood within the subestuary's channels. Dimensions of what constitutes wood are defined here as pieces >0.1 m diameter and >2 meter in length. Wood ratings are the same as those applied in freshwater. Note: ratings are likely similar to or identical to those applied to the most downstream freshwater reaches.	A complex mixture of single large pieces and accumulations consisting of all sizes, decay classes, and species origins; cross-channel jams are present where appropriate vegetation and channel conditions facilitate their existence; large wood pieces are a dominant influence on channel diversity (e.g., pools, gravel bars, and mid-channel islands) where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 3-10 pieces/CW, 25-50 ft -- 3-10 pieces/CW, 50-150 ft -- 7-30 pieces/CW , 150-400 ft -- 20-50 pieces/CW in conjunction with large jams in areas where accumulations might occur, >400 ft -- 15-37 pieces/CW in conjunction with large jams in areas where accumulations might occur.	Complex array of large wood pieces but fewer cross channel bars and fewer pieces of sound large wood due to less recruitment than index level 1; influences of large wood and jams are a prevalent influence on channel morphology where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 2-3 pieces/CW, 25-50 ft -- 2-4 pieces/CW, 50-150 ft -- 3-7 pieces/CW , 150-400 ft -- 10-20 pieces/CW (excluding large jams) in conjunction with large jams in areas where accumulations might occur, >400 ft -- 8-15 pieces/CW (excluding large jams) in conjunction with large jams in areas where accumulations might occur.	Few pieces of large wood and their lengths are reduced and decay classes older due to less recruitment than in index level 1; small debris jams poorly anchored in place; large wood habitat and channel features of large wood origin are uncommon where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 1-2 pieces/CW, 25-50 ft -- 1-2 pieces/CW, 50-150 ft -- 1-3 pieces/CW , 150-400 ft -- 10-20 pieces/CW without large jams in areas where accumulations might occur, >400 ft -- 8-15 pieces/CW without large jams in areas where accumulations might occur.	Large pieces of wood rare and the natural function of wood pieces limited due to diminished quantities, sizes, decay classes and the capacity of the riparian streambank vegetation to retain pieces where channel gradient and flow allow such influences. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- 0.33-1 pieces/CW, 25-50 ft -- 0.33-1 pieces/CW, 50-150 ft -- 0.33-1 pieces/CW , 150-400 ft -- 3-10 pieces/CW without large jams in areas where accumulations might occur, >400 ft -- 2-8 pieces/CW without large jams in areas where accumulations might occur.	Pieces of LWD rare. Density of LWD (pieces per channel width CW) consistent with the following: channel width <25 ft -- <0.33 pieces/CW, 25-50 ft -- <0.33 pieces/CW, 50-150 ft -- <0.33 pieces/CW , 150-400 ft -- <3 pieces/CW with accumulations where they might occur, >400 ft -- <2 pieces/CW with no accumulations where they might occur.
3 Biological community								

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Competitors or predators	HatRel-sp	Hatchery salmonid releases	Relative magnitude of hatchery Chinook, coho, fall chum, summer chum, pink, steelhead and cutthroat that utilize the subestuary or estuarine segment.	Hatchery fish for the species designated have been rarely released over the past decade and any releases that have been made are very small in number compared to the number of wild fish for this species present.	Hatchery fish for the species designated are released at infrequently to at least every other year currently, are a small fraction of the abundance of wild conspecifics, and produce densities of total juveniles or adults for the species judged to be <20% of historic densities.	Hatchery fish for the species designated are released at least every other year currently, are 1/4 as abundant to more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species judged to be 20-50% of historic densities.	Hatchery fish for the species designated are released in most years, are more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species judged to be 50-75% of historic densities.	Hatchery fish for the species designated are released in most years, are more abundant than wild conspecifics, and produce densities of total juveniles or adults for the species that might approach densities expected historically.
Competitors or predators	MarFshStatua	Status of marine fish populations	Status of marine fish populations in the segment.	Predatory marine fish species not present.	Populations of predatory marine fish species at very low densities, reflecting marginal sustainability.	Densities of marine fish species correspond to stable, though depressed levels compared to healthy average levels that might be expected in the absence of fishing pressures and environmental change.	Densities of marine fish species correspond to healthy populations for the species under average conditions that might have prevailed prior to fishing pressures and environmental changes.	Extremely high densities of marine fish species present due to unusually favorable conditions or proximity to reproductive areas.
Competitors or predators	MarMamStatu s	Status of marine mammals	Status of marine mammals in the subestuary or estuarine segment.	Predatory marine mammal species not present.	Populations of predatory marine mammal species at very low densities, reflecting marginal sustainability.	Densities of marine mammal species correspond to stable, though depressed levels compared to healthy average levels that might have occurred in the absence of environmental changes and bans on capture or killing.	Densities of marine mammal species correspond to healthy populations for the species under average conditions that might have prevailed prior to environmental changes and bans on capture or killing.	Extremely high densities of marine mammal species present due to unusually favorable conditions or proximity to reproductive areas.
Competitors or predators	SeabirdStatus	Status of seabirds	Status of seabirds in the subestuary or estuarine segment.	Predatory seabird species not present.	Populations of predatory seabird species at very low densities, reflecting marginal sustainability.	Densities of seabird species correspond to stable, though depressed levels compared to healthy average levels that might be expected in the absence of environmental change.	Densities of seabird species correspond to healthy populations for the species under average conditions that might have prevailed prior to environmental changes.	Extremely high densities of seabird species present due to unusually favorable conditions or proximity to reproductive areas.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Competitors or predators	SalStatus-sp	Status of wild salmonids	Status of wild salmonids by species: Chinook, coho, fall chum, summer chum, pink, steelhead, cutthroat	Wild salmonid species of concern not present.	Population of wild salmonid species of concern at very low density, reflecting a population of marginal sustainability.	Density of wild salmonid species corresponds to a stable, though depressed level compared to the healthy average level associated with pristine condition due to watershed development.	Density of wild salmonid species corresponds to a healthy population for the species under average conditions that might have prevailed prior to watershed development.	Extremely high densities of the wild salmonid species present due to unusually favorable conditions or proximity to reproductive areas.
Food resources and/or refuge	EelgrAllPercent	Eelgrass - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous eelgrass; abundance classified as continuous, patchy, or not present in Washington ShoreZone.	> 87.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units. A value of 0 is assigned when 100% of the shoreline is identified as having either patchy or continuous eelgrass.	> 62.5% and < 87.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 37.5% and < 87.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 12.5% and < 37.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 0% and < 12.5% of segment's shoreline length contains patchy or continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units. A value of 4 is assigned when 0% of shoreline contains eelgrass.
Food resources and/or refuge	EelgrContPercent	Eelgrass - continuous percent	The total percent of the lineal shoreline within the segment containing continuous eelgrass; abundance classified as continuous, patchy, or not present in Washington ShoreZone.	> 52.5% of segment's shoreline length contains continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units. A value of 0 is assigned when 60% or more of the shoreline is identified as having continuous eelgrass.	> 37.5% and < 52.5% of segment's shoreline length contains continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 22.5% and < 37.5% of segment's shoreline length contains continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 7.5% and < 22.5% of segment's shoreline length contains continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units.	> 0% and < 7.5% of segment's shoreline length contains continuous eelgrass, where eelgrass abundance based on relative abundance within ShoreZone reach units. A value of 4 is assigned when 0% of shoreline contains continuous eelgrass.
Food resources and/or refuge	KelpAllPercent	Kelp - all percent	The total percent of the lineal shoreline within the segment containing patchy or continuous kelp (all species); abundance classified as continuous, patchy, or not present in Washington ShoreZone.	> 87.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units. A value of 0 is assigned when 100% of the shoreline is identified as having either patchy or continuous kelp.	> 62.5% and < 87.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 37.5% and < 87.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 12.5% and < 37.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 0% and < 12.5% of segment's shoreline length contains patchy or continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units. A value of 4 is assigned when 0% of shoreline contains kelp.

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Food resources and/or refuge	KelpContPercent	Kelp - continuous percent	The total percent of the lineal shoreline within the segment containing continuous kelp (all species); abundance classified as continuous, patchy, or not present in Washington ShoreZone.	> 52.5% of segment's shoreline length contains continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units. A value of 0 is assigned when 60% or more of the shoreline is identified as having continuous kelp.	> 37.5% and < 52.5% of segment's shoreline length contains continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 22.5% and < 37.5% of segment's shoreline length contains continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 7.5% and < 22.5% of segment's shoreline length contains continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units.	> 0% and < 7.5% of segment's shoreline length contains continuous kelp, where kelp abundance based on relative abundance within ShoreZone reach units. A value of 4 is assigned when 0% of shoreline contains continuous kelp.
Food resources and/or refuge	SalmCarcass	Salmon carcasses	Relative abundance of anadromous salmonid carcasses within the subestuary watershed.	Super abundant -- average number of carcasses per mile of main channel habitat within streams entering the segment (within an appropriately designated area) >800.	Very abundant -- average number of carcasses per mile of main channel habitat within streams entering the segment (within an appropriately designated area) >400 and < 800.	Moderately abundant -- average number of carcasses per mile of main channel habitat within streams entering the segment (within an appropriately designated area) >200 and < 400.	Not abundant -- average number of carcasses per mile of main channel habitat within streams entering the segment (within an appropriately designated area) >25 and <200.	Very few or none -- average number of carcasses per mile of main channel habitat within streams entering the segment (within an appropriately designated area) <25.
Food resources and/or refuge	NeriticZoo	Zooplankton within the upper water column	Index of average abundance of zooplankton within the segment during a month (in neritic waters). (Further work needed to define quantitative metrics.)	Relative density of neritic zooplankton at high level during peak of annual production cycle.	Relative density of neritic zooplankton at moderately high level during peak of annual production cycle.	Relative density of neritic zooplankton at moderate level during peak of annual production cycle. Density of Daphnia is moderate, > __ and < organisms per cubic meter. This density would provide a moderate ration to young salmonids under suitable temperatures producing positive, though significantly reduced growth than would occur with maximum ration.	Relative density of neritic zooplankton at low level during peak of annual production cycle..	Relative density of neritic zooplankton at extremely low level during peak of annual production cycle, representing the poorest conditions that occur naturally.
4 Water quality								
Chemistry	DisOxy	Dissolved oxygen	Average dissolved oxygen within the water column for the specified time interval.	> 8 mg/L (allows for all biological functions for salmonids without impairment at temperatures ranging from 0-25 C)	> 6 mg/L and < 8 mg/L (causes initial stress symptoms for some salmonids at temperatures ranging from 0-25 C)	> 4 and < 6 mg/L (stress increased, biological function impaired)	> 3 and < 4 mg/L (growth, food conversion efficiency, swimming performance adversely affected)	< 3 mg/L

Appendix Table C-1. Level 2 Attribute Index Definitions

Category	Code	Attribute	Definition	Index Value 0	Index Value 1	Index Value 2	Index Value 3	Index Value 4
Chemistry	MetWatCol	Metals in water column	The extent of dissolved heavy metals within the water column.	No toxicity expected due to dissolved heavy metals to salmonids under prolonged exposure (1 month exposure assumed).	May exert some low level chronic toxicity to salmonids (1 month exposure assumed).	Consistently chronic toxicity expected to salmonids(1 month exposure assumed).	Usually acutely toxic to salmonids (1 month exposure assumed).	Always acutely toxic to salmonids (1 month exposure assumed).
Chemistry	MedSedsSls	Metals/pollutants in sediments	The extent of heavy metals and miscellaneous toxic pollutants within the stream sediments and/or soils adjacent to the stream channel.	Metals/pollutants at natural (background) levels with no or negligible effects on benthic dwelling organisms or riparian vegetation (under continual exposure).	Deposition of metals/pollutants in low concentrations such that some stress symptoms occur to benthic dwelling organisms or riparian vegetation root/shoot growth is impaired (under continual exposure).	Stress symptoms increased or biological functions moderately impaired to benthic dwelling organisms; or few areas within the riparian zone present where no vegetation exists (slickens); ecotonal to these areas occupied only by tolerant species; horizons containing metals/pollutant concentrations influencing root growth and composition are common within the riparian corridor.	Growth, food conversion, reproduction, or mobility of benthic organisms severely affected; or large areas of the riparian zone devoid of vegetation; ecotonal areas occupied only by metals/pollutant-tolerant species; few areas in the riparian zones which are unaffected.	Metals/pollutant concentrations in sediments/soils are lethal to large numbers of the benthic species and/or riparian zone is practically devoid of vegetation.
Chemistry	MscToxWat	Misc toxic pollutants - water column	The extent of miscellaneous toxic pollutants (other than heavy metals) within the water column.	No substances present that may periodically be at or near chronic toxicity levels to salmonids.	One substance present that may only periodically rise to near chronic toxicity levels (may exert some chronic toxicity) to salmonids.	More than one substance present that may periodically rise to near chronic toxicity levels or one substance present > chronic threshold and < acute threshold (consistently chronic toxicity) to salmonids.	One or more substances present > acute toxicity threshold but < 3X acute toxicity threshold (usually acutely toxic) to salmonids.	One or more substances present with > 3X acute toxicity (always acutely toxic) to salmonids.
Temperature	TmpMonMx	Temperature - daily maximum	Maximum water temperatures within the stream reach during a month.	Warmest day < 10 C	Warmest day>10 C and <16 C	> 1 d with warmest day 22-25 C or 1-12 d with >16 C	> 1 d with warmest day 25-27.5 C or > 4 d (non-consecutive) with warmest day 22-25 C or >12 d with >16 C	> 1 d with warmest day 27.5 C or 3 d (consecutive) >25 C or >24 d with >21 C

Appendix D—Level 3 Survival Factors

Appendix Table D-1. Level 3 Survival Factors.

Factor	Definition
Channel stability	The effect of stream channel stability (within reach) on the relative survival or performance of the focus species; the extent of channel stability is with respect to its streambed, banks, and its channel shape and location.
Chemicals	The effect of toxic substances or toxic conditions on the relative survival or performance of the focus species. Substances include chemicals and heavy metals. Toxic conditions include low pH.
Competition (with hatchery fish)	The effect of competition with hatchery produced animals on the relative survival or performance of the focus species; competition might be for food or space within the stream reach.
Competition (with other species)	The effect of competition with other species on the relative survival or performance of the focus species; competition might be for food or space.
Flow	The effect of the amount of stream flow, or the pattern and extent of flow fluctuations, within the stream reach on the relative survival or performance of the focus species. Effects of flow reductions or dewatering due to water withdrawals are to be included as part of this attribute.
Food	The effect of the amount, diversity, and availability of food that can support the focus species on its relative survival or performance.
Habitat diversity	The effect of the extent of habitat complexity within a stream reach on the relative survival or performance of the focus species.
Harassment	The effect of harassment, poaching, or non-directed harvest (i.e., as can occur through hook and release) on the relative survival or performance of the focus species.
Key habitat	The relative quantity of the primary habitat type(s) utilized by the focus species during a life stage; quantity is expressed as percent of wetted surface area of the stream channel.
Obstructions	The effect of physical structures impeding movement of the focus species on its relative survival or performance within a stream reach; structures include dams and waterfalls.
Oxygen	The effect of the concentration of dissolved oxygen within the stream reach on the relative survival or performance of the focus species.
Pathogens	The effect of pathogens within the stream reach on the relative survival or performance of the focus species. The life stage when infection occurs is when this effect is accounted for.
Predation	The effect of the relative abundance of predator species on the relative survival or performance of the focus species.
Sediment load	The effect of the amount of the amount of fine sediment present in, or passing through, the stream reach on the relative survival or performance of the focus species.
Temperature	The effect of water temperature with the stream reach on the relative survival or performance of the focus species.
Withdrawals (or entrainment)	The effect of entrainment (or injury by screens) at water withdrawal structures within the stream reach on the relative survival or performance of the focus species. This effect does not include dewatering due to water withdrawals, which is covered by the flow attribute.

Appendix E—Associations Used in Translating Level 2 Environmental Attribute Values to Level 3 Survival Factor Values for Chum Salmon in Natal Subestuarine Waters

Appendix Table E-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for chum salmon in natal subestuarine waters (focus species here is assumed to be summer chum)

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Contributor	Contributor	Contributor	Contributor	Contributor	Contributor	Contributor
0-age transients (fry rearing and migration)	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals/Pollutants - in sediments/soils					
	Competition (with hatchery fish)	Hatchery chum releases – fall race	Hatchery pink releases	Hatchery Chinook releases				
	Competition (with other species)	Status of wild chum salmon – fall race	Status of wild pink salmon	Status of wild Chinook salmon				
	Flow	Flow - change in interannual variability in high flows (Flow - Intra daily (diel) variation)	Confinement - Hydromodifications	Channel complexity	Wood	Riparian function		
	Food	Channel complexity	Confinement - Hydromodifications	Riparian function	Salmon Carcasses	Ratio of emergent vegetation to watershed size	Ratio of emergent marsh-mud to watershed size	Accessibility to subestuary habitats
	Habitat diversity	Channel complexity	Confinement - Hydromodifications	Riparian function	Channel depth - tidal channels	Wood	Accessibility to subestuary habitats	
	Harassment	no effects						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration	Accessibility to subestuary habitats					
	Oxygen	Dissolved oxygen						
	Pathogens	no effects						
	Predation	Status of wild Chinook salmon	Status of wild coho salmon	Status of wild steelhead	Status of wild cutthroat	Status of seabirds	Status of wild cutthroat	Hatchery yearling Chinook releases
	- continued	Hatchery subyearling Chinook releases	Hatchery coho releases	Hatchery steelhead releases	Hatchery cutthroat releases			
	Sediment load	Turbidity (susp. sed.)						

Appendix Table E-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for chum salmon in natal subestuarine waters (focus species here is assumed to be summer chum)

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Contributor	Contributor	Contributor	Contributor	Contributor	Contributor	Contributor
	Temperature	Temperature - daily maximum (by month)						
	Withdrawals	no effects						
Prespawning migrant	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals/Pollutants - in sediments/soils					
	Competition (with hatchery fish)	no effects						
	Competition (with other species)	no effects						
	Flow	Channel depth - tidal channels	Flow - changes in interannual variability in low flows					
	Food	no effects						
	Habitat diversity	Channel complexity	Confinement - Hydromodifications	Riparian function	Channel depth - tidal channels	Wood	Accessibility to subestuary habitats	
	Harassment	no effects						
	KeyHabitat	All habitat types incorporated						
	Obstructions	Obstructions to fish migration						
	Oxygen	Dissolved oxygen						
	Pathogens	No effects						
	Predation	Status of marine mammals						
	Sediment load	Turbidity (susp. sed.)						
	Temperature	Temperature - daily maximum (by month)						
	Withdrawals	No effects						

Appendix F—Associations Used in Translating Level 2 Environmental Attribute Values to Level 3 Survival Factor Values for Chum Salmon in Estuarine and Marine Waters (excluding natal subestuaries)

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for chum salmon in estuarine and marine waters (excluding natal subestuaries).

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Contributor	Contributor	Contributor	Contributor	Contributor	Contributor	Contributor
0-age transients/migrants	Channel stability	no effects						
	Chemicals	Miscellaneous toxic pollutants - water column	Metals/Pollutants - in sediments/soils	Surface outflow average velocity	Wave exposure			
	Competition (with hatchery fish)	Hatchery chum releases – fall race	Hatchery pink releases	Hatchery Chinook releases				
	Competition (with other species)	Status of wild chum salmon – fall race	Status of wild pink salmon	Status of wild Chinook salmon				
	Flow	Surface outflow average velocity						
	Food	Ratio emerg veg to ITZ area	Ratio watershed areas to ITZ area	Density of subestuaries-marshes (by type)	Functional loss of subestuaries-marshes (by type)	Riparian vegetation	Wave exposure	Eelgrass - % shoreline with some
	-continued	Eelgrass - % shoreline with continuous	Kelp - % shoreline with some	Kelp - % shoreline with continuous	Neritic zooplankton	Salmon carcasses	ITZ bottom slope	
	Habitat diversity	ITZ bottom slope	% shoreline modifcations	Density of subestuaries-marshes (by type)	Functional loss of subestuaries-marshes (by type)	Wave exposure	Eelgrass - % shoreline with some	Eelgrass - % shoreline with continuous
	-continued	Kelp - % shoreline with some	Kelp - % shoreline with continuous					
	Harassment	no effects						
	KeyHabitat	All habitat types incorporated						
	Obstructions	no effects – included in functional loss						
	Oxygen	Dissolved oxygen						
	Pathogens	no effects						
	Predation	Status of wild Chinook salmon	Status of wild coho salmon	Status of wild steelhead	Status of wild cutthroat	Status of seabirds	Status of wild cutthroat	Hatchery yearling Chinook releases

Appendix Table F-1. Associations used in translating Level 2 Environmental Attribute values to Level 3 Survival Factor values through rule sets for chum salmon in estuarine and marine waters (excluding natal subestuaries).

Life stage	Level 3 Survival Factor	Level 2 Environmental Attribute						
		Contributor	Contributor	Contributor	Contributor	Contributor	Contributor	Contributor
	-continued	Hatchery subyearling Chinook releases	Hatchery coho releases	Hatchery steelhead releases	Hatchery cutthroat releases	Status of marine mammals		
	Sediment load	Turbidity (susp. sed.)						
	Temperature	no effects						
	Withdrawals	No effect						

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