Identification of Historical Populations of Coho Salmon *(Oncorhynchus kisutch)* in the Oregon Coast Evolutionarily Significant Unit

January 2007

Identification of Historical Populations of Coho Salmon (*Oncorhynchus kisutch*) in the Oregon Coast Evolutionarily Significant Unit

Peter W. Lawson, Eric P. Bjorkstedt[1], Mark W. Chilcote[2], Charles W. Huntington[3], Justin S. Mills[4], Kelly M.S. Moore[5], Thomas E. Nickelson[6], Gordon H. Reeves[7], Heather A. Stout, Thomas C. Wainwright, and Laurie A. Weitkamp

Northwest Fisheries Science Center
Newport Research Station
2032 Southeast OSU Drive
Newport, Oregon 97365

[1] Southwest Fisheries Science Center
HSU Telonicher Marine Laboratory
PO Box 690
Trinidad, California 95570

[2] Oregon Department of Fish and Wildlife
3406 Cherry Avenue Northeast
Salem, Oregon 97303

[3] Clearwater Biostudies, Inc.
23252 South Central Point Road
Canby, Oregon 97013

[4] Frank Orth and Associates
4040 Lake Washington Boulevard Northeast, Suite 208
Kirkland, Washington 98033

[5] Oregon Department of Fish and Wildlife
Corvallis Research Laboratory
28655 Highway 34
Corvallis, Oregon 97333

[6] Kisutch Consulting
75 Alydar Place
Paso Robles, California 93446

[7] US Forest Service
PNW Research Station, Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331

January 2007

Table of Contents

List of Figures

List of Tables

Executive Summary

In 2003 the Oregon Workgroup (Workgroup) of the Oregon Northern California Coast Technical Recovery Team (TRT) convened to review and analyze information that could shed light on historical populations of Oregon Coast coho salmon (*Oncorhynchus kisutch*). This document presents the preliminary conclusions of the Workgroup. A historical perspective describing how these populations functioned is an important first step in assessing the viability of present-day populations, in developing delisting criteria, and as an overall recovery strategy.

Documentation of life history traits, distribution, or abundance of Oregon Coast coho salmon prior to 1940 is limited. Considerable biological information has been gathered during the past 30 years, and particularly the past 12 years; however, it is difficult to relate the biological characteristics of modern populations to those that existed historically in the same basin. Human activities over the past 200 years have altered every aspect of salmon habitat on the coast, harvest has changed abundance patterns, and hatcheries may have blurred the distinctions among stocks. Coho salmon have adapted their behavior to many of these changes and, as a result, present-day Oregon Coast coho salmon populations function differently than they did historically. Nonetheless, we have tried to address where populations existed historically and how these historical populations functioned.

To establish historical population boundaries, we relied on geographical and ecological characteristics of the landscape that have not been greatly altered by human activities. Geographical information was used in calculating the distance between ocean-entry points. Ecological characteristics were utilized in partitioning the Umpqua Basin into four historical populations. A total of 56 historical populations were identified through this analysis.

Our view of the historical population structure of Oregon Coast coho salmon relies on a simple conceptual model of the spatial relationships of 56 populations. We used a rule-based approach to identify populations. Subsequently, we utilized a connectivity-viability model to classify these populations on the basis of two key characteristics: persistence (their relative abilities to persist without input from neighboring populations), and isolation (the relative degree to which they might have been influenced by adult fish from other populations migrating into their spawning areas). The interaction of these two factors across what we believe to have been the historical populations of Oregon Coast coho salmon gives us a measure of relative independence. This relative independence gives us a basis for classifying the populations as functionally independent, potentially independent, and dependent. Thirteen populations were identified as functionally independent, 8 as potentially independent, and 35 historical populations were identified as dependent populations. We will use this classification in the next step—analyzing the viability of populations and ultimately of the ESU in order to identify quantitative goals for recovery. Two other recovery groups (the Southern Oregon Northern California Coast Workgroup and the Central California Coast TRT) are also using the connectivity-viability model to classify their populations.

These proposed historical populations are intended to represent the range and diversity of populations of Oregon Coast coho salmon, not necessarily to be an exact reconstruction. In this representation of historical populations, we assume that ocean feeding areas were a shared resource and that, in the Umpqua River Basin, populations probably shared juvenile rearing and migration corridors. Understanding the historical structure of populations in addition to their abundance and life history characteristics provides a framework for comparing the historical to the present status of populations, the changes that have affected them, and the restoration of processes that may be necessary to recover them.

Acknowledgments

Introduction

The Oregon Coast Evolutionarily Significant Unit (ESU) of coho salmon (*Oncorhynchus kisutch*) was listed as threatened under the U.S. Endangered Species Act (ESA) (Fed. Reg. 63:42587–42591) in 1998. The ESA requires that a recovery plan be produced for listed species. As part of the recovery planning process, the National Marine Fisheries Service (NOAA Fisheries Service) has convened a group of scientists (NOAA 2003) to act as the Technical Recovery Team (TRT) for the Oregon and Northern California Coast (ONCC) recovery domains (Figure 1).[1] The two recovery domains are composed of the Oregon Coast Coho Salmon and Southern Oregon and Northern California Coast (SONCC) Coho Salmon ESUs. The ONCC TRT is made up of the Oregon Coast and Southern Oregon, Northern California Coho Workgroups. As a team, our goal was to provide a scientific context for identifying necessary actions to help the species recover. The TRT was asked to 1) identify population and ESU delisting goals; 2) characterize habitat/fish abundance relationships; 3) identify the factors for decline and limiting factors for the ESU; 4) identify early actions that are important for recovery; 5) identify research, evaluation, and monitoring needs; and 6) serve as science advisors to groups charged with developing measures to achieve recovery. This report is the first in a series providing the scientific foundation for biological delisting goals for the Oregon Coast Coho Salmon ESU. Subsequent reports will discuss population and ESU biological recovery criteria, factors limiting the recovery of the ESU, and research and monitoring needs.

Under the ESA, biological delisting goals define the biological conditions under which the listed species or ESU is no longer in danger of extinction nor likely to become endangered in the foreseeable future in any significant portion of its range. That is, these goals define the conditions necessary for the long-term persistence of the ESU as a whole. An ESU has, by definition, persisted as a unit on an evolutionary time scale. Knowledge of its structure (its component populations, their functions, and their interactions) under historical conditions before current threats became substantial provides a background against which to evaluate recent status and minimum conditions needed for long-term persistence. Because the persistence of the ESU depends on the aggregate performance of its component populations, an essential first step in developing delisting goals is to identify the historical populations of the ESU and define their interrelationships.

An ESU is composed of numerous constituent populations with varying features and behaviors. Some populations function essentially independently over moderate time scales, while others interact more strongly with nearby populations. In this report we describe what we believe were historical populations in the Oregon Coast Coho Salmon ESU. We draw on a variety of data sources and analyses to estimate the historical size, relative independence, and geographical range for each population.

---

[1] A complete description of TRT composition, tasks, and operating principles can be found in the NOAA Fisheries Service document "Recovery planning guidance for technical recovery teams" (online at http://www.nwfsc.noaa.gov/trt/about.htm).
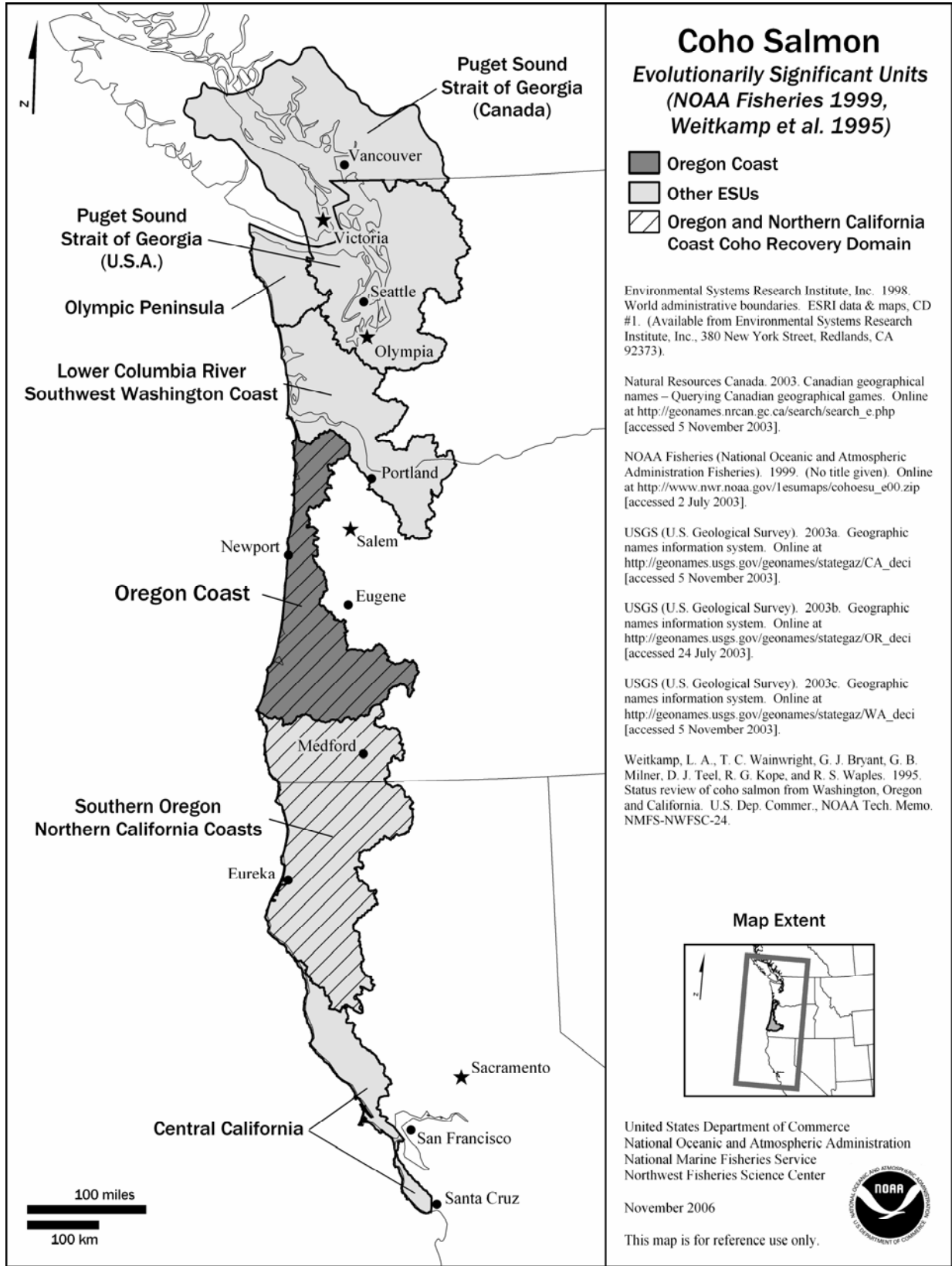
Figure 1. Coho salmon ESUs (NOAA 1999).

This document does not attempt to define current populations or what future populations will look like. It is our view that recovery will require a restoration of landscape processes that will enable fish to establish populations in whatever configuration suits them currently, not necessarily what has existed in the past.

The next part of the TRT deliberation will define population and ESU biological recovery criteria and delisting goals based initially on these historical populations. However, these proposed populations may change in the future, depending on this analysis. This process will continue to feed back to each step if changes are needed.

This document describes how the TRT divided the ESU into populations and further classified these populations into independent (functionally and potentially) and dependent populations and geographic strata. This identification and classification system assumes a model for delisting criteria that 1) uses geographic strata as a means for ensuring geographical, genetic, and ecological diversity of the recovered ESU, and 2) distinguishes between independent populations that are the focus of rigorous viability analyses and dependent populations, which may be less intensively monitored or managed. Under this model, ESA delisting goals would differ among the population classes, with rigorous quantitative productivity, abundance, and habitat goals for functionally and potentially independent populations and more qualitative goals such as presence and absence for dependent populations.

Population Concepts

In the biological literature, the term "population" often refers simply to a group of organisms of the same species that occur in the same area (such as McNaughton and Wolf 1973, Ehrlich and Roughgarden 1987). In a fishery research and management context, Ricker (1972) provided a more specific definition of a local population or "stock" as the "fish spawning in a particular lake or stream (or portion of it) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season." This definition has been widely used in assessments of salmon populations (such as WDF et al. 1993, Kostow 1995). McElhany et al. (2000) based their definition of "independent population" on Ricker's definition of "stock." They made the phrase "to a substantial degree" more specific and drew a distinction between independent and nonindependent populations. "Independent populations" were described as basic units for assessing population viability in the context of Pacific salmon (*Oncorhynchus* spp.) recovery planning. While we draw heavily from the review of population structure provided by McElhany et al. (2000), we found that their strict distinction between independent and nonindependent populations was overly simplistic when applied to the Oregon Coast Coho Salmon ESU. We therefore have taken a somewhat different approach to classifying populations, starting with Ricker's (1972) definition of a stock.

Definition of a Population

A population is group of fish of the same species that spawns in a particular locality at a particular season and does not interbreed substantially with fish from any other group.

Our purpose was to describe the historical population structure of the Oregon Coast Coho Salmon ESU. The structure and dynamics of the ESU populations in a historical context represent the conditions under which we are most certain that the ESU was not at risk of extinction. We are increasingly uncertain of the ability of the ESU to persist as the condition of the populations diverges from this baseline. We do not propose that historical conditions are the benchmark for population or ESU viability. Rather, we identify historical population structure as a template against which current and possible future population structures can be compared in the course of developing ESU biological recovery criteria. This document is concerned only with historical populations. There is no attempt to evaluate current population structure or compare current populations with historical populations.

Populations and ESUs

To develop conservation plans, planners must clearly define the organizational units of the organisms of concern (Meffe and Vrijenhoek 1988) and understand how those units behave and interact over time. Two biological units are considered in developing recovery plans for coho salmon listed under the ESA: ESUs and populations. In defining units for potential ESA listings of Pacific salmon, NOAA Fisheries Service adopted the concept of ESUs as the definition of listable "species" under the ESA (NMFS 1991, Waples 1991a).[2] ESUs are collections of local populations that share common demographic and genetic features. Over moderate time frames (1 to 10 generations), there may be periodic exchanges of individuals among the populations that make up an ESU, but there is little interaction with populations in other ESUs (Moritz et al. 1995). This document focuses on identifying the structure and relative independence of local populations within the Oregon Coast Coho Salmon ESU.

We acknowledge the link between biological structure and scales of space and time in our approach to identifying and classifying populations. The scale of ESUs was defined in terms of major patterns of genetic and life history diversity (Waples 1991b). Implicit in this definition is the idea that an ESU is made up of a number of populations, so the scales relevant to population structure are smaller than those for ESU structure. Populations are expected to exchange individuals at substantially higher rates within an ESU than between ESUs (Moritz et al. 1995). ESUs are defined primarily with respect to large genetic divergences (Waples 1991a). Populations are demographic units within which individuals interact at time scales of a few days to a few generations, whereas ESUs are genetic units in which relevant variation and structure change on time scales of tens to hundreds of generations.

The genetic structure of salmon ESUs is dynamic, at least on evolutionary time scales. There is no single array of genes (or combination of alleles) that can be said to make up an ESU. Rather, the integrity of an ESU is linked to maintaining the dynamic nature of natural evolutionary processes (gene flow, genetic drift, and adaptation) (Waples 1995). These processes are only imperfectly understood for salmon in general, and this applies as well to the Oregon Coast Coho Salmon ESU. Nevertheless, within most salmon ESUs a number of natural population units have persisted as largely independent entities for periods that are long on ecological time scales (100 years or more). The effort to identify historical populations of

---

[2] The term "species" included any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife that interbreeds when mature (ESA section 3).

Oregon Coast coho salmon has focused on such units, because they are natural units for assessing viability. In many ESUs, including Oregon Coast coho salmon, the role of small populations and their relationship to larger, historical populations is poorly understood. We would expect that our understanding of Oregon Coast coho salmon population genetics will improve as results from ongoing genetics research and other studies become available. Meanwhile, we consider that a population of any size may play a significant evolutionary role within the ESU.

Viability of an ESU is coupled with the viability and dynamics of its constituent populations. Our approach to these populations defines the relationships among the populations in terms of their interactions; this approach provides us with a basis for comparing historical populations with current populations and for assessing population viability and, subsequently, ESU viability, in a variety of restoration scenarios.

Conceptual Approach to Identifying and Classifying Historical Populations

In preparing for a coast-wide effort to develop recovery plans for all listed Pacific salmon ESUs, NOAA Fisheries Service developed a general approach to assessing the viability of ESUs (McElhany et al. 2000). The first step involves identifying the historical populations within an ESU and then classifying them in terms of their degree of historical independence. McElhany et al. (2000) acknowledged that the extinction risk of an entire ESU is a complex function of the dynamics of the ESU's component populations. They also considered that, although the population structure of ESUs is both complex and variable, the problem of ESU risk could be simplified by identifying "independent"[3] populations whose viability[4] could be assessed as individual units. ESU viability can be defined largely in terms of the viability of these independent components. To define and classify historical Oregon Coast coho salmon populations, we have followed the broad concepts outlined by McElhany et al. (2000). However, we recognize that population independence in this region is more complex, and is relative rather than absolute. We have, therefore, developed a population classification scheme that reflects the properties of individual populations and the interactions among populations. This proposed approach is intended to provide a uniform means of identifying the population structure of coho salmon for coastal ESUs south of the Columbia River. It was developed in collaboration with the Oregon Coast Workgroup of the ONCC TRT and the Central California Coast TRT, but has had additional input from the full ONCC TRT and staff from other coastal TRTs.

Identifying Populations

Our approach to identifying populations differs somewhat from the approach taken by other TRTs (Myers et al. 2006, Ruckelshaus et al. 2006) due to differences among the listed

---

[3] An independent population, according to McElhany et al. (2000, p. 3), is "any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period is not substantially altered by exchanges of individuals with other populations."

[4] A viable salmonid population (McElhany et al. 2000, p. 2) is "an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats for demographic variation (random or directional), local environmental variation, and genetic diversity changes (random or directional) over a 100-year time frame."

salmon species. Along the linear Oregon Coast, there are many basins of all sizes, each with a separate ocean entry point. This landscape contrasts with the river networks of the Columbia Basin, and with the hub-and-spoke geography of Puget Sound, where populations distribute themselves from a central basin or hub into contributing river basins or spokes. These differences in the geometric patterns of rivers result in different patterns of movement of fish between rivers and, therefore, different population structures and population dynamics. We sought a population definition that would be relevant to the geography and population dynamics on the Oregon Coast and would accommodate rivers and streams of vastly different sizes. While the role of large basins in ESU viability is obvious, it was also clear to the TRT that smaller basins are also an important part of the ESU. Our approach was designed to reflect this structure and to elucidate the historical role of each population in the demographic functioning of the ESU.

One of the problems in describing the historical population structure for Oregon Coast coho salmon was that this region of coast is composed of basins with a wide range of sizes. In this ESU, direct ocean tributaries range from less than 1 to greater than 4,600 stream miles (less than 1.6 to over 7,400 km). Large basins may have multiple populations. Smaller basins that drain directly into the ocean probably did not support enduring populations, but are not necessarily a part of a single larger unit. We had no basis for combining smaller basins with larger ones, and we thought it was important to reflect the full range of coho salmon habitats on the Oregon Coast. Spawners have a strong tendency to return home to their basin of origin, so each basin would naturally form a separate population. We have, therefore, defined historical populations based on their points of saltwater entry.

Classifying Populations

In order to classify historical populations of Oregon Coast coho salmon, we first had to explain our view of the population dynamics historically operating in this ESU. Because of the linear nature of the Oregon Coast, our approach to this problem is somewhat different from the other TRTs (Myers et al. 2006, Ruckelshaus 2006). We based our conceptual model of population dynamics for this ESU on existing literature regarding the functioning of complex populations in general and salmon populations in particular (Rieman and Dunham 2000). Two assumptions we made were 1) populations interact through the exchange of individuals, and 2) movement of individuals in salmon populations is strongly influenced by the physical relationship of ocean entry points (Figure 2). None of the published literature exactly matched the patterns of connectivity implied by the geography of the Oregon Coast or population interactions of coho salmon. Consequently, we adapted concepts from the published literature (see, for example, Hanski and Gilpin 1997) to develop our own population classification system, with quantitative support from the Bjorkstedt connectivity-viability model (Bjorkstedt et al. 2005) and estimates of historical population size based on a new synthesis of physical habitat features (intrinsic potential) and historical population abundance calculations (Appendix C).
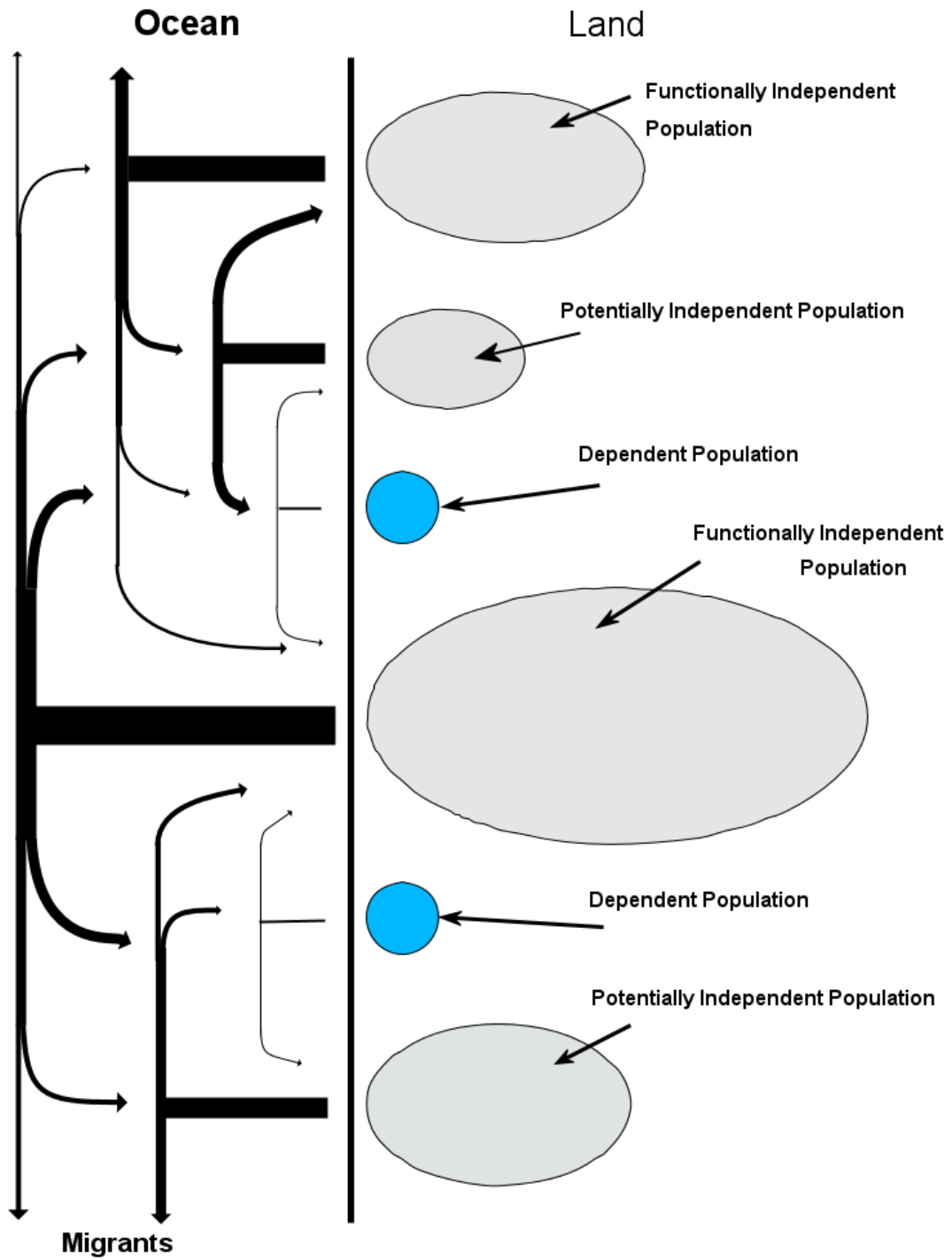
Figure 2. Conceptual model of ESU population structure. Arrow widths are proportional to number of migrants.

Persistence, isolation, and independence in population classification

In developing the classification system for historical Oregon Coast coho salmon populations, we utilized three key population characteristics: persistence, isolation, and independence.

Persistence is the ability of a population to sustain itself through time without inputs from other populations.

Isolation is the degree to which a population is unaffected by immigration to and from other populations: as the influence of immigration decreases, a population's isolation increases.

Independence reflects the interaction between isolation and persistence: a persistent population that is highly isolated is highly independent.

A population's persistence relies on the quantity and quality of habitat, which in turn influences potential population size. Habitat quantity and quality can be expressed in terms of the habitat's capacity to produce fish (in other words, the potential population size supported by the habitat). All else being equal, persistence is related to population size, with large populations tending to have a greater probability of persistence than small populations.

Processes that influence population dynamics affect small populations differently than large ones (McElhany et al. 2000). These processes include density effects, variation in environmental conditions, genetic processes, demographic stochasticity, and catastrophic events. Density effects can be positive or negative for small populations. As population numbers decline below carrying capacity, population production may increase because more resources are available to the remaining individuals. This gives a population resilience as productivity increases when numbers decline. If numbers decline below a critical point, reproduction may start to decline because individuals are unable to secure mates (Hilborn and Walters 1992). Environmental variation may result in periods of unfavorable conditions for a population. If the duration of unfavorable conditions persists longer than the reproductive cycle of the species, then populations may decline (Dennis et al. 1991, Lande 1993). Small populations may produce poor-quality offspring through the effects of genetic processes such as loss of diversity and inbreeding depression (accumulations of deleterious genes that reduce their ability to survive). Demographic stochasticity includes nongenetic changes in fecundity, mortality, and sex ratios. Changes in the reproductive potential and capacity that result from these factors are much more pronounced in small populations than in large ones (Lande 1998). Catastrophic events, either natural or man-made, may result in large mortality in a short time period. Through a combination of genetic and demographic factors, population numbers may be reduced below the level at which the population is able to maintain itself (Mangel and Tier 1994). Taken together, the various processes that cause small populations to lose productivity are termed "depensation."

Watershed size also influences population size. Larger watersheds in general will be expected to support more fish than smaller watersheds. Additionally, larger watersheds will be composed of smaller subwatersheds. Larger populations may, therefore, contain subunits. This resulting structure within larger systems provides a buffer against infrequent catastrophic events, which historically were fires and floods and the subsequent landslides on the Oregon Coast

(Reeves et al. 1995). These events generally affected only parts of the landscape. Some subunits may have been lost temporarily while unaffected subunits continued to produce fish. Smaller populations, without the buffering effect of subunits, may have been lost in such cases. Larger populations may also have a greater genetic diversity, which increases the potential for a population to respond to unfavorable or changing conditions (Waples 1990, Waples and Teel 1990).

There is a theoretical lower limit to the size of (or habitat required for) a persistent population (reviewed in Soulé 1987); below this minimum, random events and depensation cause the risk of extinction to increase substantially. This concept informs our consideration of independence; any extant population occupying a basin with sufficient habitat to support a minimum population size is likely to persist continuously. Populations with less habitat are likely to persist only if there is significant immigration from other populations. If we knew the minimum habitat capacity necessary to support a persistent population, we could separate those populations that can function independently in isolation from those that cannot simply on the basis of habitat capacity. Even if we do not know the theoretical lower limit to the population abundance or habitat capacity required to produce that minimum population size, we may be able to use habitat capacity as a proxy measure for the relative ability of a population to persist without immigration.

A population's isolation reflects the degree to which immigration from other populations affects its dynamics: as the influence of immigration decreases, a population's isolation increases. This concept can also be thought of in terms of the ratio of spawners hatched in that basin to spawners from other basins. This ratio is influenced by the rate that spawners from other populations migrate in, and the size of the other populations. A small population next to a large one is apt to have a high proportion of spawners from the larger population even if migration rates are low. It only takes a few fish from a large population spawning in a small population to lower the smaller population's degree of isolation. A simplifying assumption we are using here is that there is an underlying rate of dispersal among basins. We recognize that dispersal rates can be highly variable.

McElhany et al. (2000) suggest that, for the purposes of recovery planning, a particular population should be considered independent if exchanges of individuals with other populations do not substantially affect the dynamics of that population over a 100-year time frame. However, in our view, independence is relative and reflects the interactions between isolation (in other words, proportion of spawners hatched in that population returning to a population) and persistence. When we consider whether a population is independent in the context of this analysis, we do not base our consideration on the current state or predicted fate of that population (in other words, the population's historical persistence or whether the population has a high likelihood of persisting for 100 years into the future). Instead, we combine the degree of isolation of a population with the inferred historical abundance to compare the relative independence of each population in relation to others in the ESU, regardless of its likely persistence.

Categories of historical populations

As a specific criterion for relative persistence, we chose to define "high-persistence populations" as those that would have a high likelihood of persisting with no migrants from neighboring populations for 100 years. The boundary between high persistence and low persistence reflects the abundance (or habitat capacity) below which persistence begins to decline rapidly (Nickelson 2001). Those populations that did not meet this criterion were classified as "dependent populations." These low-persistence populations would probably not be in existence if they were not receiving migrants from neighboring populations. As a next step, high-persistence populations were further divided into two types ("potentially independent" and "functionally independent") on the basis of their historical interaction with other populations (isolation). The boundary between functionally and potentially independent populations reflects the likelihood of influence from other nearby populations (the proportion of native spawners returning to a population). Functionally independent populations on average provide more migrants to other populations than they receive, so their demographics are not greatly influenced by outside migrants.

We separated historical populations into three categories based first on their relative persistence and then on their degree of isolation:

Functionally independent populations: high-persistence populations whose population dynamics or extinction risk over a 100-year time frame is not substantially altered by exchanges of individuals with other populations. These populations are net "donor" populations that may provide migrants for other types of populations. This category is analogous to the "independent populations" of McElhany et al. (2000).

Potentially independent populations: high-persistence populations whose population dynamics may be substantially influenced by periodic immigration from other populations. In the event of the decline or disappearance of migrants from other populations, a potentially independent population could become a functionally independent population.

Dependent populations: low-persistence populations that rely upon immigration from other populations. Without these inputs, dependent populations would have a lower likelihood of persisting over 100 years. They are "receiving" populations that are dependent on sufficient immigration from surrounding populations to persist.

Isolation depends primarily on two factors: 1) the size and potential productivity of a population relative to nearby populations, and 2) the effective migration (migrants who contribute to the next generation) among nearby populations (Moilanen and Nieminen 2002, Bjorkstedt et al. 2005). The effective migration among nearby populations is a function of the size of the donor population, the distance from the donor to the receiving population, and the ability of the migrants to contribute offspring to the receiving population. The larger the donor population and the closer it is to the receiving population, the greater the rate of effective migration. Functionally independent populations, in that they are highly persistent and hence larger populations, are more likely to have individuals that stray to other populations. Thus populations closest to large functionally independent populations will have a greater potential for receiving migrants than will populations that are farther away from larger donor populations

(Figure 2). A population that is classified as potentially independent due to its proximity to a very large functionally independent population might function at some other time as functionally independent if the very large neighboring population experienced a significant population crash. Dependent populations are very likely to rely on immigration from both functionally and potentially independent populations. Seldom would dependent populations be expected to contribute directly to the long-term persistence of other population types by providing migrants.

Both functionally and potentially independent populations tend to be larger than dependent populations (Figure 2). Populations with larger numbers of individuals spread over a larger area are better buffered than are smaller populations from the impact of catastrophic flood and fire events (Reeves et al. 1995); catastrophic events on the scale of a large watershed are rare (Reeves et al. 1995). In addition, these larger populations often occur in larger watersheds with a greater variety of habitats, including areas of stable, lowland habitat that is most productive for coho salmon. Dependent populations are smaller and thus more vulnerable to periodic declines resulting from events in the freshwater and marine environments.

All population types, in varying degrees, contribute to the persistence and productivity of the ESU. Functionally independent populations are the foundation of the ESU. Because of their large size, these populations make the greatest contribution to the productivity and persistence of the ESU. The potentially independent populations are also important sources of productivity that may function as "giver" populations to the dependent populations. A potentially independent population may play an important role in the persistence of a functionally independent population if the productivity of that system declines due to disturbance in freshwater or estuarine habitats. Dependent populations contribute to the overall health of the ESU by increasing the total productive area, and may provide reservoirs of potentially adaptive diversity for the ESU (Buckling et al. 2003). They may also be important for maintaining the integrity of a given watershed. For example, returning adults provide nutrients that are used by a wide array of other aquatic and terrestrial organisms and vegetation (Cederholm et al. 1999).

One task of the TRT is to determine the modern population structure necessary to restore the aspects of life history diversity, distribution of populations, and abundance needed to provide for a sustainable Oregon Coast Coho Salmon ESU into the future. Understanding the number, abundance, life history diversity, and distributions of historical populations of Oregon Coast coho salmon is an important first step in determining biological recovery criteria and recovery scenarios. The organization and abundance of populations are dynamic (Hanski and Gilpin 1997). However, the static picture of historical structure we have reconstructed here provides a template for sustainable populations and a sustainable ESU.

Methods and Results

In developing the population identification and classification system that reflects the persistence, isolation, and independence of populations of Oregon Coast coho salmon, we sought an approach that had three desirable characteristics: consistency, reproducibility, and transparency. Consistency means that the same approach can be applied across ESUs over a broad geographic area and lead to comparable results in different areas. Reproducibility means that conclusions are predictable; in other words, another group of scientists could apply the same methods to the same information and reach essentially the same result. Transparency means that methods are reasonably simple and understandable, so that nonspecialists can understand the logical connection between information and conclusions. We chose a rule-based approach that we believe meets these criteria.

Criteria for Identifying the Distribution of Historical Populations

The task of identifying historical coho salmon populations within the Oregon Coast Coho Salmon ESU is challenging because anthropogenic factors such as hatchery operations, stock transfers, harvest effects, and habitat destruction and degradation have significantly influenced the population structure and interactions we observe today. There are no extant populations unaffected by these anthropogenic factors to provide information regarding historical population structure and number. Information about historical abundance and distribution of fish is available only for a few large basins. We have no alternative, therefore, but to examine a suite of characteristics of modern populations and their watersheds in our effort to identify the selective and isolating factors that may have lead to demographically independent historical populations. The factors we have considered include 1) historical use of habitat; 2) geographical isolation; 3) biological characteristics of populations; and 4) ecological characteristics of river, stream, and lake watersheds. This information was considered across the coastal river, stream, and lake basins that may have historically supported coho salmon (Figure 3).

Documented Historical Use

The extent of historical use of Oregon Coast coho salmon habitat (Figure 4) is not very different from the extent of present use in most basins within the ESU. There are areas, such as the Smith River (Figure 5), that have had a major barrier removed. There are also new barriers that restrict access to historical habitat. However, large areas of lowland habitat have been cut off or restricted from access by dikes, tidegates, and other hydrologic changes. Therefore, the extent of Oregon Coast coho salmon use does not show much restriction, but what is not shown is the loss of very significant areas that were historically the core of the populations. Because of these changes, the core of many Oregon Coast coho populations has subsequently persisted only in more marginal, less productive areas (IMST 2002).
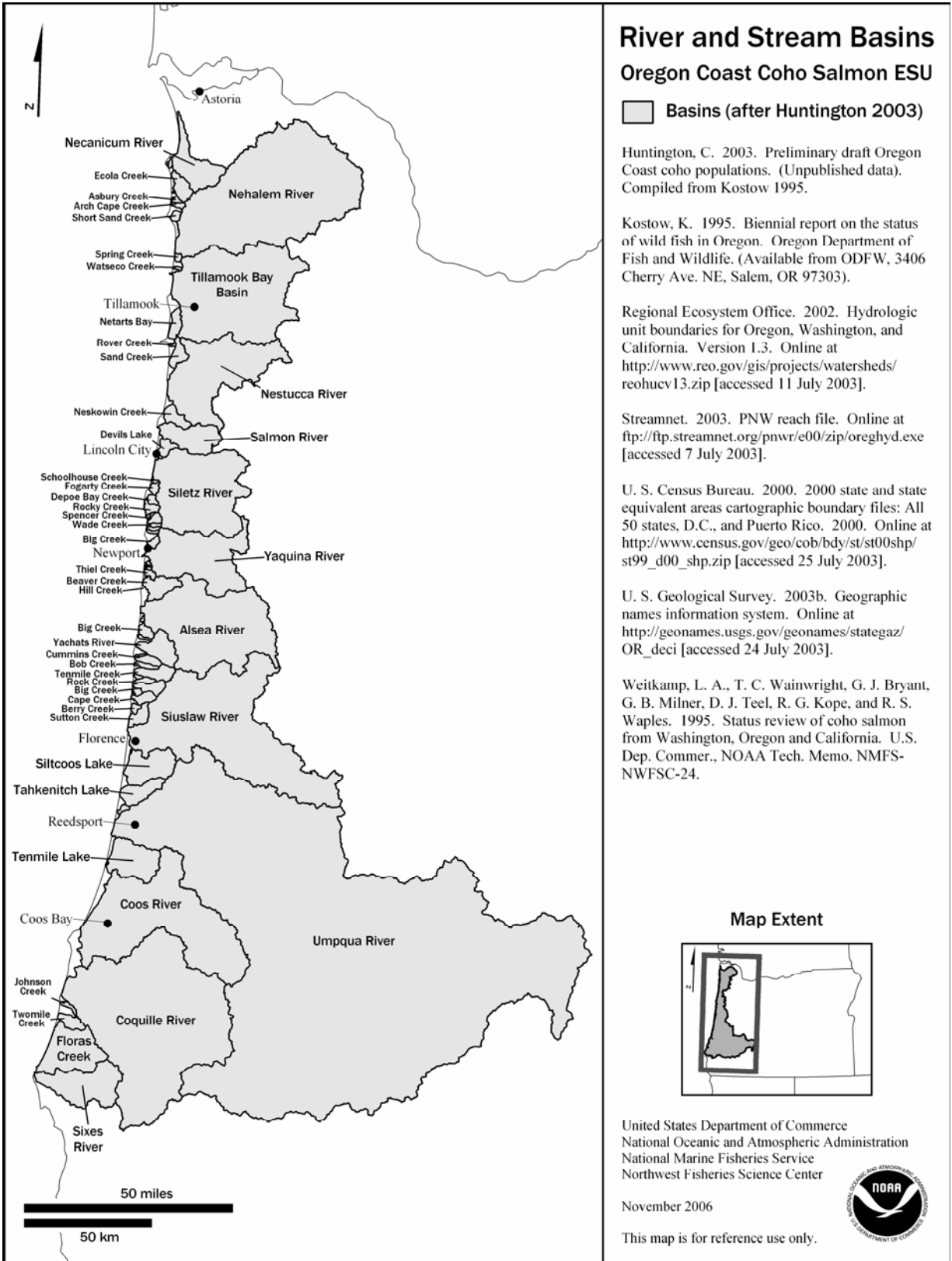
Figure 3. River and stream basins in the Oregon Coast Coho Salmon ESU.

Potential Historical Coho Distribution

Oregon Coast Coho Salmon ESU

⌇⌇ Coho Distribution (after ODFW 2003a)

⌇⌇ Streams (Streamnet 2003)

▭ Oregon Coast ESU (Weitkamp et al. 1995)

ODFW (Oregon Department of Fish and Wildlife). 2003a. Distribution of Oregon anadromous salmon and steelhead habitat: Coho salmon. Eleventh Edition. Natural Resources Information Management Program. Online at ftp://rainbow.dfw.state.or.us/pub/gis/k100/shape/coho/coho_v11.zip [accessed 16 July 2003].

Streamnet. 2003. PNW reach file. Online at ftp://ftp.streamnet.org/pnwr/e00/zip/oreghyd.exe [accessed 7 July 2003].

U. S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files: All 50 states, D.C., and Puerto Rico. 2000. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

U. S. Geological Survey. 2003b Geographic names information system. Online at http://geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure 4. Potential historical coho salmon distribution in the Oregon Coast Coho Salmon ESU.
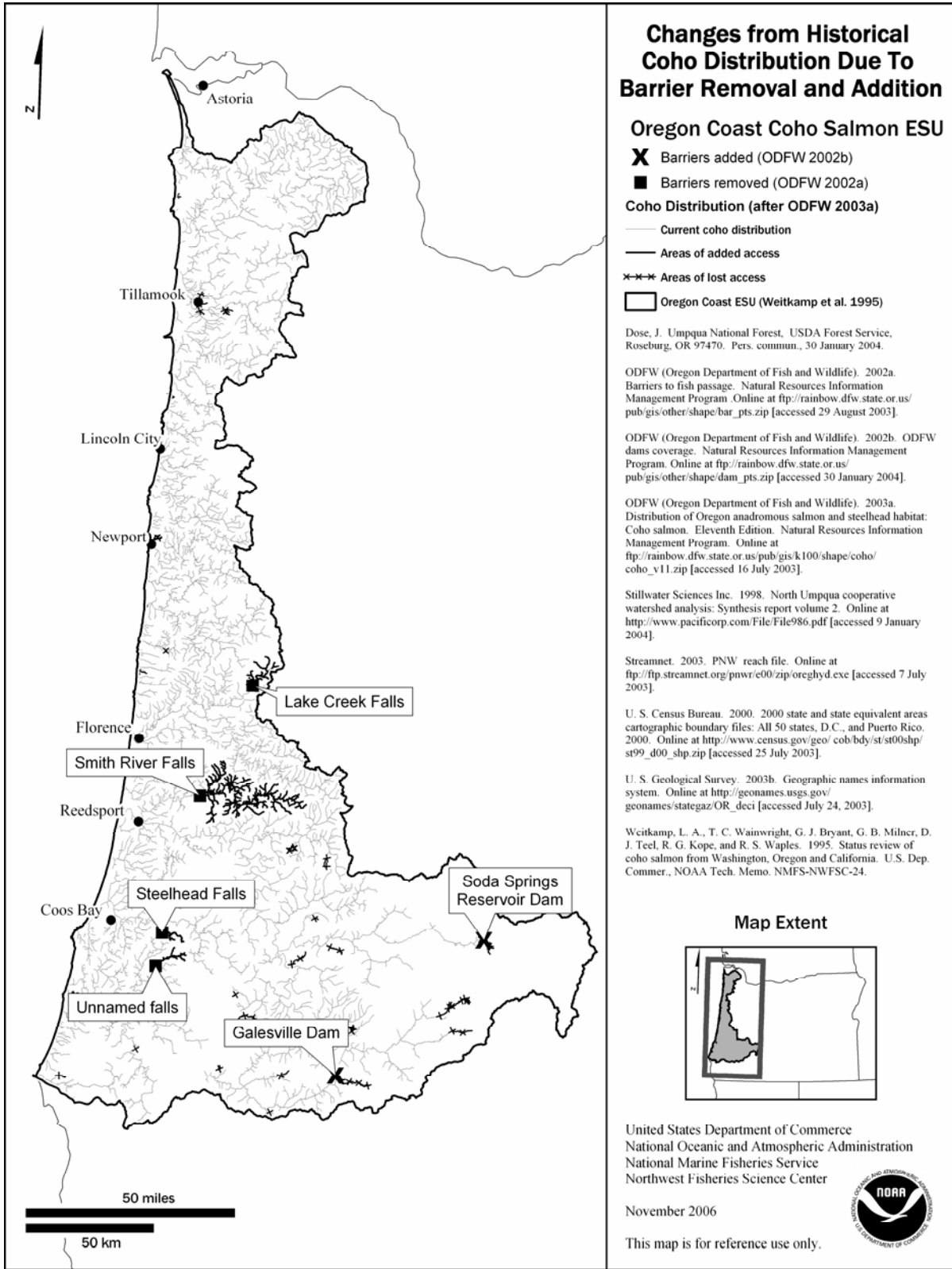
Figure 5. Changes from historical distribution of Oregon Coast coho salmon due to the addition (✖) or removal (■) of passage barriers.

Geographical Isolation

Geographical isolation is an important factor in the evolution of separate populations within a basin or between basins. The Oregon Coast Coho Salmon ESU, in general, is made up of relatively small basins (Figure 3). The exception to that general rule is the Umpqua River Basin, which is quite large and drains areas of very different vegetation, geology, and distance from the marine influence. Table 1 lists the ocean entry basins discussed in Kostow (1995) with their stream lengths and basin areas. We utilized this list as our starting point in defining historical coho salmon populations on the Oregon Coast.

The distance between saltwater entry points of each basin may have a significant effect on the degree of migration among populations. Table 2 shows the locations of the basins and the distances between each successive basin. Some populations may be significantly affected by migrants from larger or more productive systems. Long-term sustainability as a population may be affected by the distance from these larger or more productive systems.

Biological Characteristics

The first step in the process of identifying historical population patterns in the Oregon Coast Coho Salmon ESU was to consider several types of biological evidence. We examined life history traits for naturally spawning coho salmon populations, including smolt size and outmigration timing, age at spawning, river entry and spawn timing, ocean migration patterns based on marine coded-wire-tag (CWT) recoveries, homing fidelity, and genetics. The primary objective of this analysis was to discover patterns in these traits that might indicate how historical populations were structured. Interpretation of this evidence is complicated by the presence of life history variations within and between basins, and by the opportunistic behavior of coho to different configurations of habitat. Only recently have we begun to recognize and document these life history variations. For example, in the Coos Basin, it has been demonstrated by Miller and Sadro (2003) that fry who migrate out of their natal streams and enter the estuary and other tidal habitats during their first spring and summer are not necessarily lost from production at that time, and may survive to spawn. Because the traits we examined are believed to have both genetic and environmental bases, similarities among populations could indicate either shared genetic heritage or similar responses to shared environmental conditions.

Several factors make compiling and comparing life history trait information on a basin scale difficult. First, these traits vary greatly over time and space, presumably due in large part to the highly variable environment. Fish examined in different years or from different locations or habitats within a basin may display different life history characteristics, making it difficult to estimate values that characterize historical or basin-wide populations. Because traits also vary greatly from year to year, study results may be sensitive to the period over which they were conducted. For example, measurements of many life history traits for Oregon coho salmon during the 1983 El Niño were very different from those in the years before and after that event (Johnson 1988). A second factor that has confounded our analysis is the lack of information on life history traits, especially the lack of long-term data sets, from most naturally spawning populations. A third complication is that anthropogenic activities such as land-use practices (Hartman et al. 1984, Holtby 1987) and artificial propagation (Steward and Bjornn 1990, Flagg et al. 1995) may alter life history traits. To help limit this bias, life history trait comparisons in

Table 1. Ocean entry basin areas with stream lengths (1:100,000 scale data set) (Kostow 1995 and Streamnet 2003).

Basin name	Basin size			
	Approx. stream miles	Approx. stream km	Acres	Hectares
Necanicum River	93	150	53,320	21,578
Indian Creek	1	2	262	106
Canyon Creek	2	4	1,127	456
Ecola Creek	19	30	13,538	5,479
Red Rock Creek	1	2	149	60
Austin Creek	1	2	203	82
Asbury Creek	4	6	1,574	637
Arch Cape Creek	3	5	2,317	938
Short Sands Creek	6	10	2,950	1,194
Nehalem River	932	1,502	545,738	220,853
Spring Creek	4	6	1,874	758
Watseco Creek	2	4	845	342
Tillamook Basin	622	1,002	358,830	145,214
Netarts Bay	17	27	9,705	3,927
Rover Creek	2	3	634	257
Sand Creek	20	32	10,825	4,381
Nestucca River	381	613	204,119	82,605
Neskowin Creek	24	38	12,355	5,000
Salmon River	104	168	47,742	19,321
Devils Lake	20	31	7,799	3,156
Siletz River	548	882	235,531	95,316
Schoolhouse Creek	2	3	743	301
Fogarty Creek	8	12	3,324	1,345
Depoe Bay Creek	8	12	2,985	1,208
Rocky Creek	8	13	5,047	2,043
Johnson Creek* (near Siletz)	2	4	712	288
Spencer Creek	8	13	3,807	1,541
Wade Creek	4	7	1,709	692
Coal Creek	4	6	1,527	618
Moolack Creek	3	6	1,311	530
Big Creek (near Yaquina)	8	13	3,429	1,388
Yaquina River	351	566	160,658	65,016
Henderson Creek	2	3	604	244
Grant Creek	2	3	366	148
Moore Creek	2	3	554	224
Theil Creek	6	10	2,767	1,120
Beaver Creek	42	68	21,532	8,714

Table 1 continued. Ocean entry basin areas with stream lengths (1:100,000 scale data set) (Kostow 1995 and Streamnet 2003).

	Basin size			
Basin name	Approx. stream miles	Approx. stream km	Acres	Hectares
Alsea River	530	854	301,778	122,126
Little Creek	1	2	646	262
Big Creek (near Alsea)	14	22	5,740	2,323
Vingie Creek	4	6	1,264	511
Yachats River	59	94	27,845	11,268
Gwynn Creek	2	4	800	324
Cummins Creek	11	17	6,282	2,542
Bob Creek	6	10	3,669	1,485
Tenmile Creek	24	38	14,963	6,055
Squaw Creek	3	4	1,086	439
Rock Creek	6	10	3,648	1,476
Big Creek (near Siuslaw)	17	28	10,125	4,097
China Creek	6	9	2,128	861
Blowout Creek	2	3	290	118
Cape Creek	15	24	7,340	2,971
Berry Creek	6	9	2,442	988
Sutton Creek (Mercer Lake)	18	29	10,692	4,327
Siuslaw River	916	1,474	496,047	200,744
Siltcoos Lake	84	135	48,632	19,681
Tahkenitch Lake	39	63	23,276	9,420
Threemile Creek	5	8	2,105	852
Umpqua River Basin (Total)	4,611	7,424	2,998,976	1,213,647
Tenmile Lakes	99	159	57,569	23,297
Coos River	760	1,223	384,393	155,559
Coquille River	1,222	1,968	676,342	273,707
Johnson Creek (near Coquille)	6	9	2,656	1,075
Twomile Creek	24	38	9,704	3,927
Floras Creek/New River	133	215	81,414	32,947
Sixes River	130	209	85,832	34,735

* Not included in future discussions due to falls at ocean, impassable to coho historically.

Table 2. Locations of ocean entries for basins along the Oregon Coast.*

Basin name	Latitude	Longitude	Distance (km) from Columbia River
Columbia River	46.244	124.057	0.0
Necanicum River	46.012	123.926	27.7
Indian Creek	45.930	123.978	37.6
Canyon Creek	45.930	123.977	37.6
Ecola Creek	45.899	123.962	41.2
Red Rock Creek	45.845	123.961	47.3
Austin Creek	45.819	123.964	50.2
Asbury Creek	45.815	123.962	50.6
Arch Cape Creek	45.804	123.966	51.9
Short Sands Creek	45.760	123.963	56.8
Nehalem River	45.658	123.933	68.4
Spring Creek	45.620	123.937	72.6
Watseco Creek	45.589	123.984	77.6
Tillamook Bay	45.488	123.901	90.5
Netarts Bay	45.403	123.944	100.6
Rover Creek	45.328	123.967	109.1
Sand Creek	45.290	123.937	113.9
Nestucca River	45.184	123.956	125.8
Neskowin Creek	45.100	123.986	135.4
Salmon River	45.047	124.005	141.5
Devils Lake	44.968	124.016	150.3
Siletz River	44.904	124.010	157.4
Schoolhouse Creek	44.873	124.041	161.6
Fogarty Creek	44.839	124.053	165.5
Depoe Bay	44.806	124.058	169.2
Rocky Creek	44.779	124.071	172.4
Spencer Creek	44.729	124.059	178.0
Wade Creek	44.716	124.060	179.5
Coal Creek	44.708	124.061	180.4
Moolack Creek	44.703	124.063	180.9
Big Creek (near Yaquina)	44.659	124.058	185.8
Yaquina River	44.613	124.017	191.9
Henderson Creek	44.589	124.068	196.7
Grant Creek	44.581	124.068	197.6
Moore Creek	44.572	124.069	198.6
Theil Creek	44.565	124.070	199.4
Beaver Creek	44.524	124.075	204.0

Table 2 continued. Locations of ocean entries for basins along the Oregon Coast.*

Basin name	Latitude	Longitude	Distance (km) from Columbia River
Alsea River	44.423	124.080	215.2
Little Creek	44.393	124.088	218.6
Big Creek (near Alsea River)	44.371	124.088	221.0
Vingie Creek	44.341	124.098	224.5
Yachats River	44.309	124.107	228.1
Gwynn Creek	44.271	124.110	232.3
Cummins Creek	44.266	124.108	232.9
Bob Creek	44.244	124.110	235.3
Tenmile Creek	44.226	124.110	237.3
Squaw Creek	44.208	124.113	239.3
Rock Creek	44.183	124.114	242.1
Big Creek (near Suislaw River)	44.177	124.114	242.8
China Creek	44.169	124.115	243.7
Blowout Creek	44.157	124.117	245.0
Cape Creek	44.134	124.123	247.6
Berry Creek	44.095	124.122	251.9
Sutton Creek (Mercer Lake)	44.060	124.127	255.9
Siuslaw River	44.017	124.136	260.7
Siltcoos Lake	43.874	124.153	276.6
Tahkenitch Lake	43.815	124.165	283.3
Threemile Creek	43.748	124.180	290.8
Umpqua River Basin	43.669	124.204	299.8
Tenmile Lakes	43.562	124.231	311.9
Coos River	43.429	124.229	326.6
Coquille River	43.124	124.429	364.2
Johnson Creek	43.093	124.431	367.6
Twomile Creek	43.044	124.441	373.1
Floras Creek/New River	42.913	124.496	388.3
Sixes River	42.854	124.543	395.9
Elk River	42.810	124.533	400.9

* Columbia and Elk rivers are included to locate the ESU boundary. Tributaries to Tillamook Bay are assumed to harbor a single population.

this document have focused on naturally spawning populations. However, because of the practice of releasing hatchery fry and smolts in widespread locations, often outside the basin where the parents originated, many studies of naturally spawning populations probably include first- or second-generation hatchery fish. Information on life history traits from hatchery populations was used only when there was insufficient information available from naturally spawning populations, as in the case of ocean migration patterns. As with environmental variability, the effects of anthropogenic activities may confuse the determination of average life history traits and are difficult to factor out.

Because of these potential sources of variability, data were collected from as many sources as possible to give some indication of average results. We especially sought older data sets to indicate coho salmon population traits prior to the 1960s, when technological advances in hatchery practices made it possible to raise large numbers of salmon to juvenile or smolt stages. The resulting proliferation of hatchery release programs has probably decreased local variability among coho populations (Weitkamp et al. 1995, Ford et al. 2004).

The generalized coho salmon life cycle is summarized in Figure 6. Adult coho salmon begin migrating into coastal streams and rivers with the first freshets in the fall. Spawning begins in November, peaks in December or January, and may continue into March. Wild spawners typically migrate and spawn later than hatchery fish in the same area. Eggs hatch in the spring and fry grow rapidly to parr stage by summer or early fall. Parr then seek out areas protected from high flows and spend a second winter in freshwater before migrating to the ocean as smolts in March through June. About 20% of males mature at age 2 and return to freshwater as "jacks" in the same year they entered the ocean as smolts. The remainder of juveniles rear in the ocean for 18 months and return as 3-year-old adults in the following fall (Lawson et al. 2004). Other life history variations do occur, particularly in the timing of life history changes between fry and smolts (Miller and Sadro 2003).

Smolt size and outmigration timing

Recent data do not suggest any population-based pattern for either smolt outmigration timing (Table 3) or smolt size (Table 4) in modern Oregon Coast coho salmon. Regardless of the basin of origin, peak outmigration timing generally occurs in May, with some runs earlier or later, and with most smolts measuring 90–115 mm (3.5–4.5 inches) fork length.

Smolt outmigration timing and smolt size appear to respond to small-scale habitat variability. Smolts residing in ponds or lakes often have different outmigration timing and are a different size than smolts residing in streams within the same basin (Rodgers et al. 1993, Nielsen 1994). For example, large smolts observed in Tenmile Lakes were thought to have resulted from a productive lake-rearing environment (McGie 1970). Both smolt outmigration timing and size exhibit considerable interannual variation; mean smolt sizes from a single system can vary substantially between years (Table 4), whereas peak outmigration timing can vary by several weeks to a month (Table 3).

Because of their responses to small-scale habitat variability, smolt size and outmigration timing have also been shown to be affected by anthropogenic activities, including habitat degradation (Moring and Lantz 1975, Holtby 1987) and habitat restoration (Johnson et al. 1993,
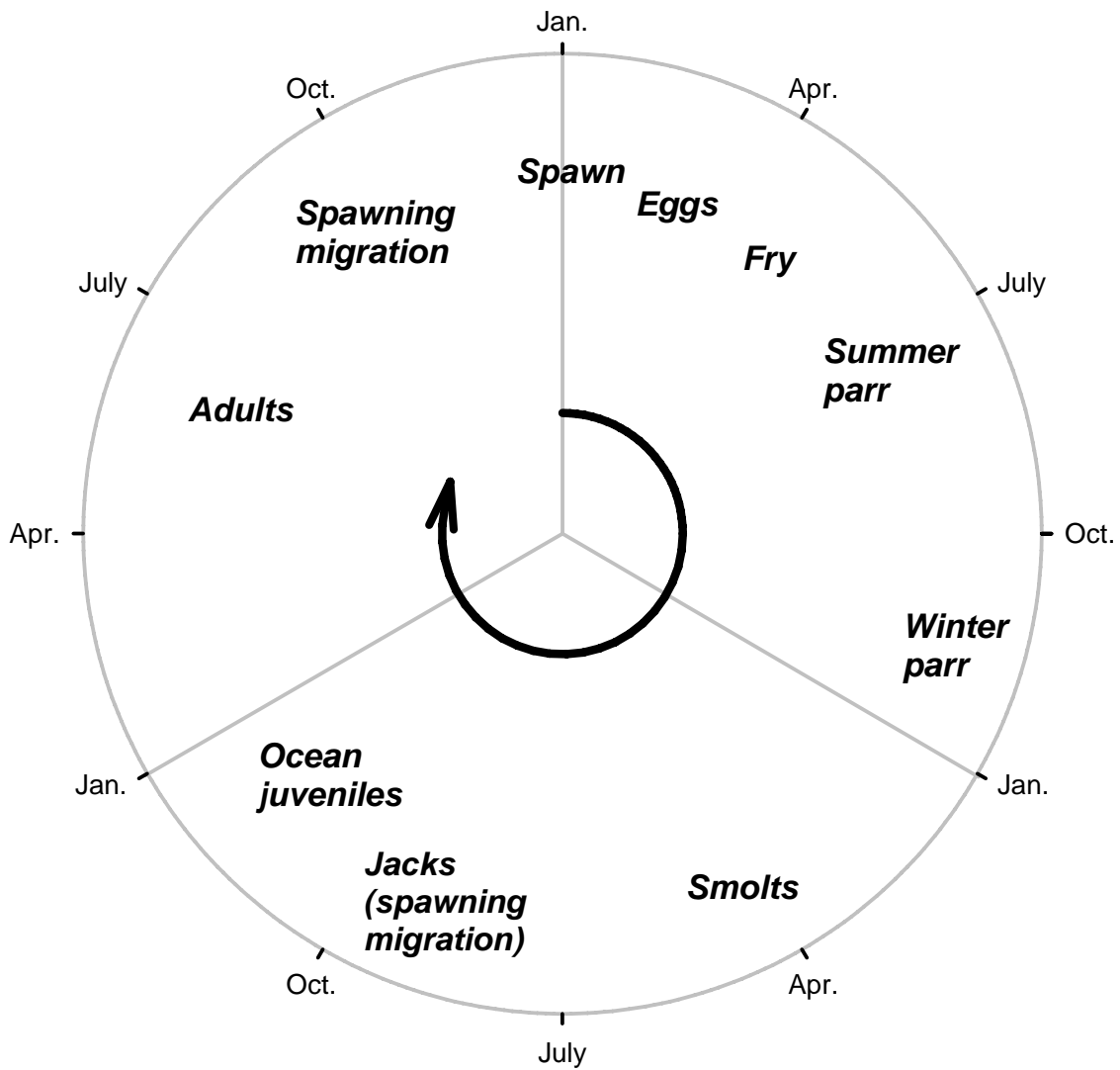
Figure 6. Generalized life cycle of the coho salmon in Oregon (modified from Lawson et al. 2004).

Table 3. Oregon Coast coho salmon smolt outmigration peak timing and duration (after Weitkamp et al. 1995). Asterisks (**) indicate no data.

Basin (tributary)	Smolt outmigration duration	Peak smolt outmigration	Years covered	Source
Wilson River (Spring Creek)	Feb–June	April	1949–1958	Skeesick 1970
Tillamook River (Sand Creek)	Mid Mar–mid June	Early May	1946–1949	Sumner 1953
Nestucca River (East Creek)	**	Late April	1988–1991	Johnson et al. 1993, Rodgers et al. 1993, Weeks 1994
Nestucca River (Moon Creek)	**	Late April–early May	1988–1991	Rodgers et al. 1993
Salmon River	**	May	1975–1976	McGie 1977
Alsea River	Mar–May	Mar–April	1959–1973	Moring and Lantz 1975
Alsea River (Lobster Creek)	Feb–June	Late Mar–early April	1988–1993	Johnson et al. 1993, Rodgers et al. 1993, Weeks 1994
Alsea River (Drift Creek)	Feb–May			Chapman 1965
Alsea River (Crooked Creek)	**	May	1973–1979	Weeks 1994
Tenmile Creek	**	May	1992–1993	Johnson et al. 1993, Weeks 1994
Cummins Creek	**	Late April–early May	1992–1993	Johnson et al. 1993, Weeks 1994
Siuslaw River	Feb–June	Mid-May	1983	Rodgers et al. 1993
Siuslaw River (Triangle Lake)	**	Early May	1973	Weeks 1994
Tenmile Lakes	**	Mid-May	1970–1975	McGie 1970–73, 1975
Floras Creek/New River	**	Mid-May	1973	Weeks 1994
Coquille River	**	Late April–early May	1979	Weeks 1994
Sixes River	Mar–June	Early–mid May	1969	Reimers 1971
Nehalem River (N. fork)	**	Late April–early May	1998–2002	Solazzi et al. 2003
Tillamook (LS fork Kilchis)	**	Late March–early May	1998–2002	Solazzi et al. 2003
Tillamook (LN fork Wilson River)	**	Late April–late May	1998–2002	Solazzi et al. 2003
Siletz River (Mill Creek)	**	Late April–mid-May	1998–2002	Solazzi et al. 2003
Siletz River (Bales Creek)	**	Late March–mid-May	1998–2002	Solazzi et al. 2003
Yaquina River (Mill Creek)	**	Late April–early May	1998–2002	Solazzi et al. 2003
Yaquina River (Cascade Creek)	**	Mid–late April	1998–2002	Solazzi et al. 2003

Table 3 continued. Oregon Coast coho salmon smolt outmigration peak timing and duration (after Weitkamp et al. 1995). Asterisks (**) indicate no data.

Basin (tributary)	Smolt outmigration duration	Peak smolt outmigration	Years covered	Source
Alsea River (UM Lobster)	**	Early April–mid-May	1998–2002	Solazzi et al. 2003
Alsea River (E. fork Lobster)	**	Early–late April	1998–2002	Solazzi et al. 2003
Tenmile Creek	**	Late April–early June	1998–2002	Solazzi et al. 2003
Smith River (W. fork)	**	Mid April–mid-May	1998–2002	Solazzi et al. 2003
Smith River (Fall Creek)	**	Early April–mid-May	1998–2002	Solazzi et al. 2003

Table 4. Oregon Coast coho salmon smolt sizes. Note that there is more variation between years than between systems (after Weitkamp et al. 1995). Asterisks (**) indicate no data.

Basin (tributary or location)	Smolt size range (mm)	Mean smolt size (mm)	Avg. length at peak migration (mm)	Years covered	Source
Tillamook (Wilson River)	**	100	**	1949–1958	Skeesick 1970
Tillamook (Sand Creek)	41–184	105–110	**	1946–1949	Sumner 1953
Nestucca River (East Creek)	**	100	**	1988–1990	Rodgers et al. 1993
Nestucca River (East Creek)	**	116	**	1991–1992	Rodgers et al. 1993
Nestucca River (Moon Creek)	**	97–102	**	1988–1992	Rodgers et al. 1993
Yaquina River	88–160	118	**	1980	Nicholas et al. 1982
Alsea River (Lobster Creek)	**	86	**	1988–1991	Rodgers et al. 1993
Alsea River (Lobster Creek)	**	91	**	1992–1993	Rodgers et al. 1993, Weeks 1994, Johnson et al. 1993, Johnson et al. 1993
Alsea River (E. fork Lobster Creek)	**	82–83	**	1988–1992	Rodgers et al. 1993
Alsea River (Drift Creek)	**	80–90	**	1959–1962	Chapman 1965
Alsea River (Deer Creek)	**	97	**	1960–1973	Knight 1979
Alsea River (Flynn Creek)	**	95	**	1960–1973	Knight 1979
Alsea River (Needle Creek)	**	93	**	1960–1973	Knight 1979
Siuslaw River	**	100–107	**	1983	Rodgers et al. 1987
Umpqua River	**	100	**	1991	Roper 1994
Tenmile Lakes	**	152	**	1970–1975	McGie 1970–73, 1975
Sixes River	88–150	120	**	1969	Reimers 1971
Nehalem River (N. fork)	**	**	101–122	1998–2002	Solazzi et al. 2003
Tillamook (LS fork Kilchis River)	**	**	99–118	1998–2002	Solazzi et al. 2003
Tillamook (LN fork Wilson River)	**	**	102–111	1998–2002	Solazzi et al. 2003
Siletz River (Mill Creek)	**	**	95–117	1998–2002	Solazzi et al. 2003
Yaquina River (Bales Creek)	**	**	98–101	1998–2002	Solazzi et al. 2003
Yaquina River (Mill Creek)	**	**	122–157	1998–2002	Solazzi et al. 2003
Alsea River (Cascade Creek)	**	**	100–140	1998–2002	Solazzi et al. 2003
Alsea River (UM Lobster Creek)	**	**	81–98	1998–2002	Solazzi et al. 2003
Alsea River (E. fork Lobster Creek)	**	**	77–100	1998–2002	Solazzi et al. 2003
Cummins Creek	**	**	105–115	1998–2002	Solazzi et al. 2003
Tenmile Creek	**	**	111–121	1998–2002	Solazzi et al. 2003
Umpqua River (W. fork Smith)	**	**	102–116	1998–2002	Solazzi et al. 2003
Coos (Fall Creek)	**	**	100–123	1998–2002	Solazzi et al. 2003

Rodgers et al. 1993). These factors thoroughly complicate the assessment of any basin-linked pattern that may exist for either trait because these activities have occurred throughout the range of Oregon Coast coho salmon. Sampling design may also influence reported smolt sizes and outmigration timing. It is impossible to discern the historical patterns of smolt size and outmigration timing from the modern patterns cited here. We are unable to predict the effects of anthropogenic activities on these patterns and from this describe the historical condition. Therefore, these characteristics do not appear to be useful in defining historical populations within the Oregon Coast Coho Salmon ESU.

Age at spawning

In the Oregon Coast Coho Salmon ESU, the vast majority of adult fish are 3-year-olds, having spent approximately 18 months in freshwater and 18 months in salt water (Gilbert 1912, Pritchard 1940, Loeffel and Wendler 1968). Exceptions to this pattern are jacks—sexually mature males that return to freshwater to spawn after only 5–7 months in the ocean. A small fraction of adults return at age 4, having spent an extra year in freshwater before spawning (Moring and Lantz 1975).

Drucker (1972) suggested that there is a latitudinal cline in the proportion of jacks in coho salmon populations, with populations in California having more jacks and those in British Columbia having almost none. Although the production of jacks is a heritable trait in coho salmon (Iwamoto et al. 1984), it is also strongly influenced by environmental factors (Silverstein and Hershberger 1992). The proportion of jacks in a given coho salmon population appears to be highly variable through time (Figure 7) (Zhou 2000), likely as a response of the population to environmental variation.

Some systems have also shown long-term changes in the proportion of jacks produced. The Tenmile Lakes system (Oregon) historically produced large numbers of jacks (Morgan and Henry 1959) but no longer does so (Ursitti 1989), presumably because of altered freshwater predation pressures (Reimers et al. 1993). Because of the high level of variability in the relative production of jacks in a population and its sensitivity to environmental change, the proportion of jacks appeared to be a poor indicator of historical population patterns and was not pursued further.

River entry and spawn timing

In general, river entry and spawn timing show considerable spatial and temporal variability. Most modern Oregon Coast coho salmon enter rivers in October (Mullen 1981a). Spawning occurs from November through January and occasionally into February, depending on the population (Figures 8a–e). Some coho may spend one or two months in freshwater before spawning (Flint and Zillges 1980).

Coho salmon river entry timing is influenced by many factors; one of the most important appears to be river flow (Sumner 1953). Coho salmon wait for freshets before entering rivers, so a delay in fall rains delays river entry and spawn timing. Delays in river entry of over a month are not unusual (Eames et al. 1981). Several small Oregon Coast coho salmon systems have sandbars that block their mouths for most of the year except during winter (such as Devils Lake,
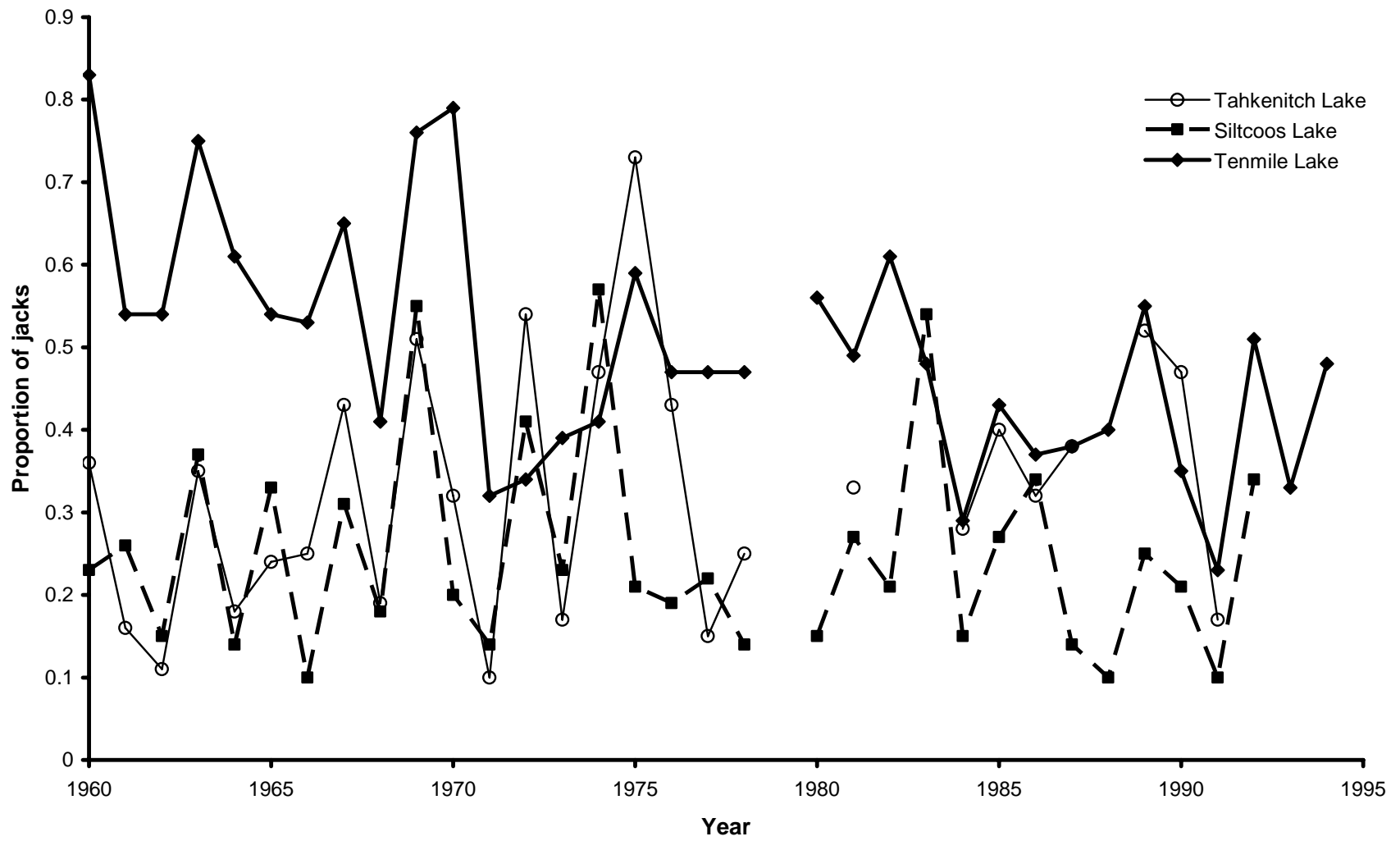
Figure 7. Coho salmon freshwater proportion of jacks caught in Tahkenitch, Siltcoos, and Tenmile lakes basins 1960–1994 (after Zhou 2000).
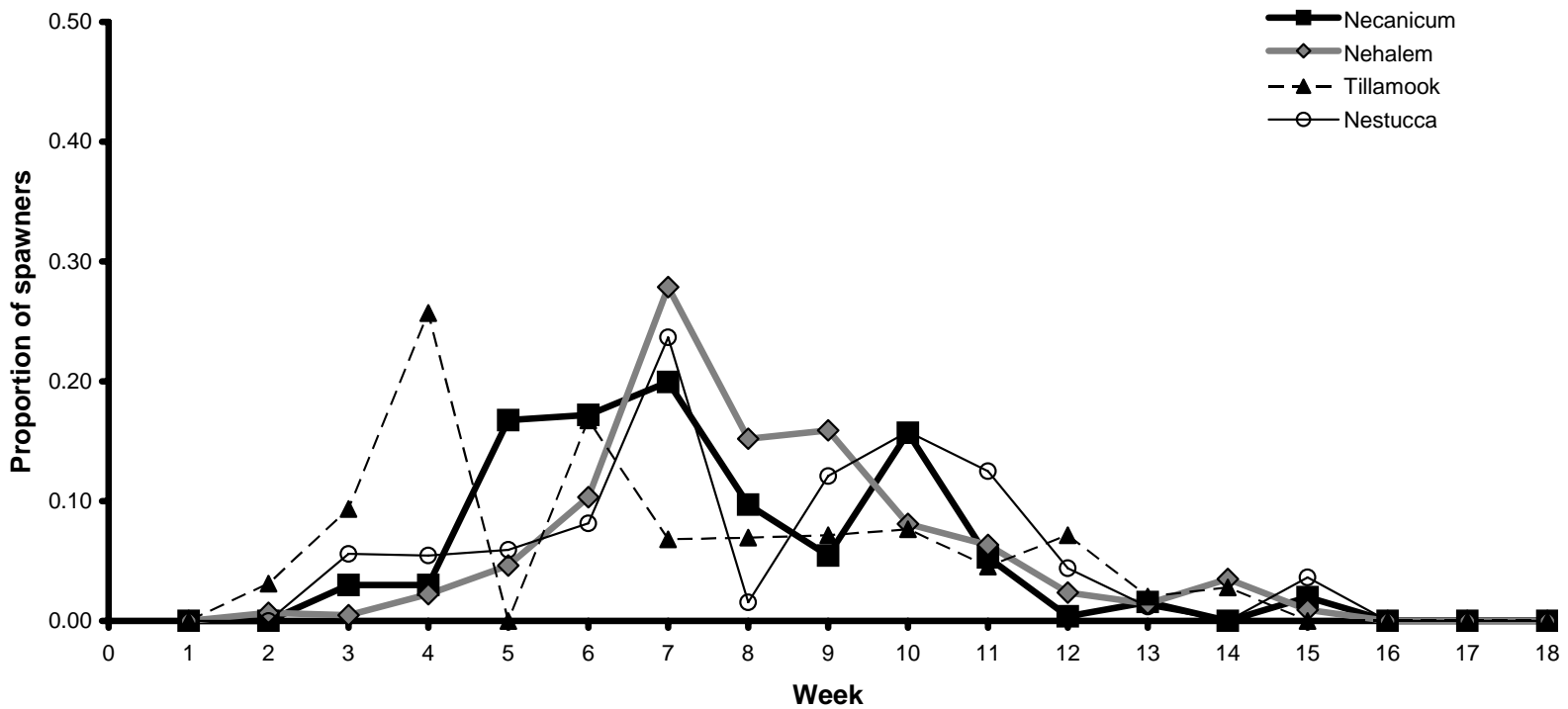
Figure 8a. North Coast Monitoring Area spawn timing for Oregon Coast coho salmon for 2001 (NOAA 2004). To convert weeks to calendar dates: week 1 = Oct. 15–21; week 3 = Oct. 29–Nov. 4; week 7 = Nov. 26–Dec. 2; week 11 = Dec. 24–31; week 16 = Jan. 29–Feb. 4; and week 18 = Feb. 12–18.
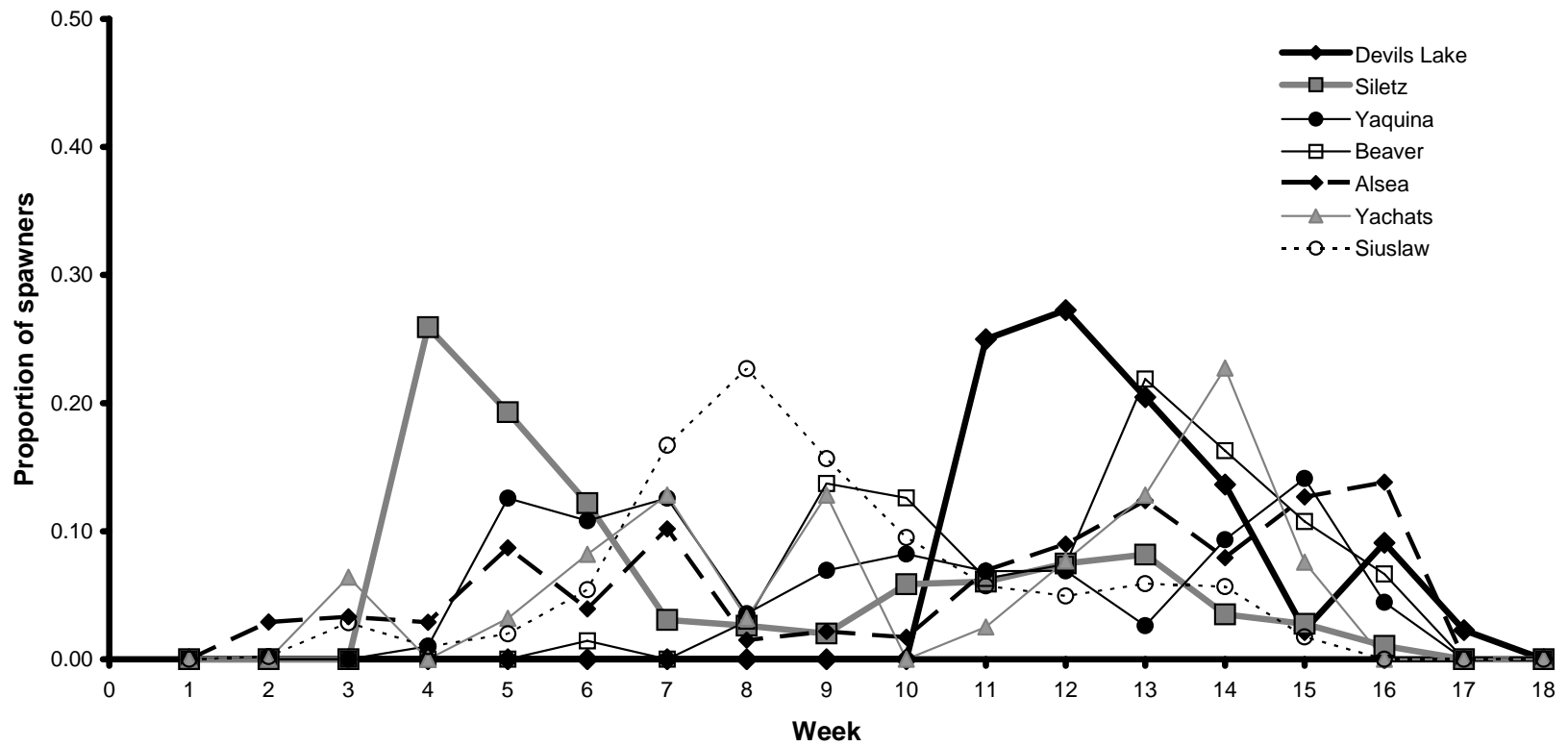
Figure 8b. Mid-Coast Monitoring Area spawn timing for Oregon Coast coho salmon for 2001 (NOAA 2004). To convert weeks to calendar dates: week 1 = Oct. 15–21; week 3 = Oct. 29–Nov. 4; week 7 = Nov. 26–Dec. 2; week 11 = Dec. 24–31; week 16 = Jan. 29–Feb. 4; and week 18 = Feb. 12–18.
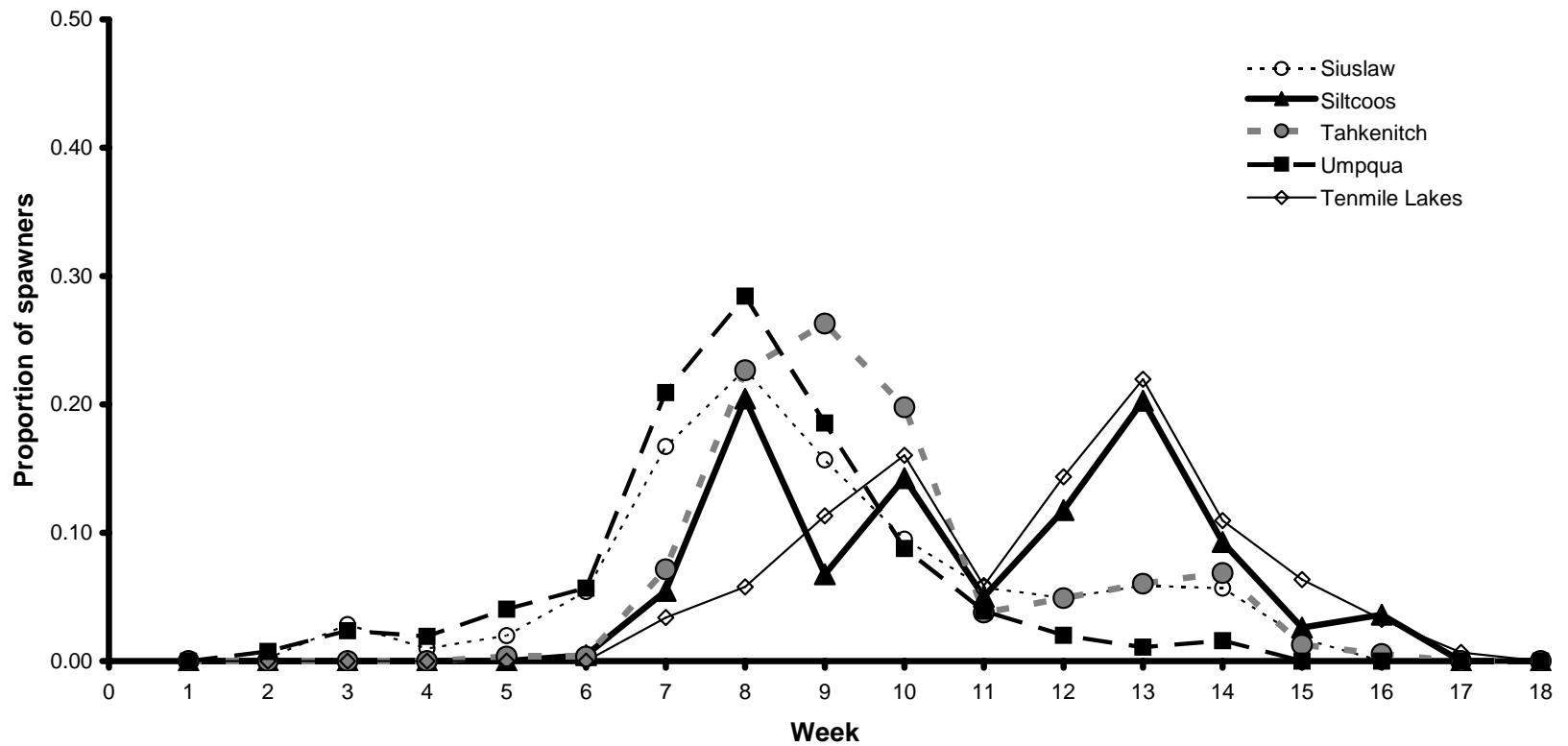
Figure 8c. Suislaw River to Tenmile Lakes spawn timing for Oregon Coast coho salmon for 2001 (NOAA 2004). To convert weeks to calendar dates: week 1 = Oct. 15–21; week 3 = Oct. 29–Nov. 4; week 7 = Nov. 26–Dec. 2; week 11 = Dec. 24–31; week 16 = Jan. 29–Feb. 4; and week 18 = Feb. 12–18.
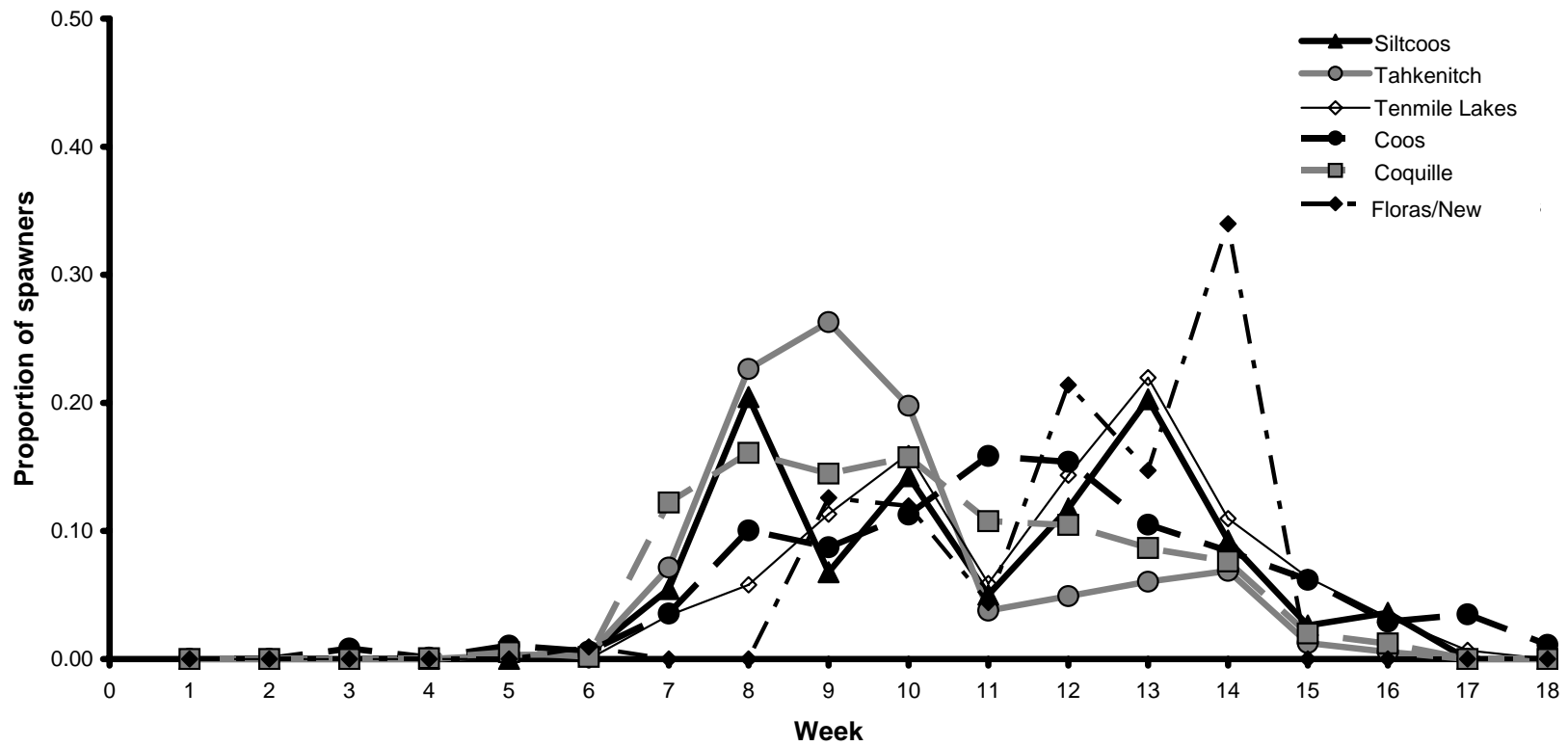
Figure 8d. Mid-South Coast Monitoring Area spawn timing for Oregon Coast coho salmon for 2001 (NOAA 2004). To convert weeks to calendar dates: week 1 = Oct. 15–21; week 3 = Oct. 29–Nov. 4; week 7 = Nov. 26–Dec. 2; week 11 = Dec. 24–31; week 16 = Jan. 29–Feb. 4; and week 18 = Feb. 12–18.
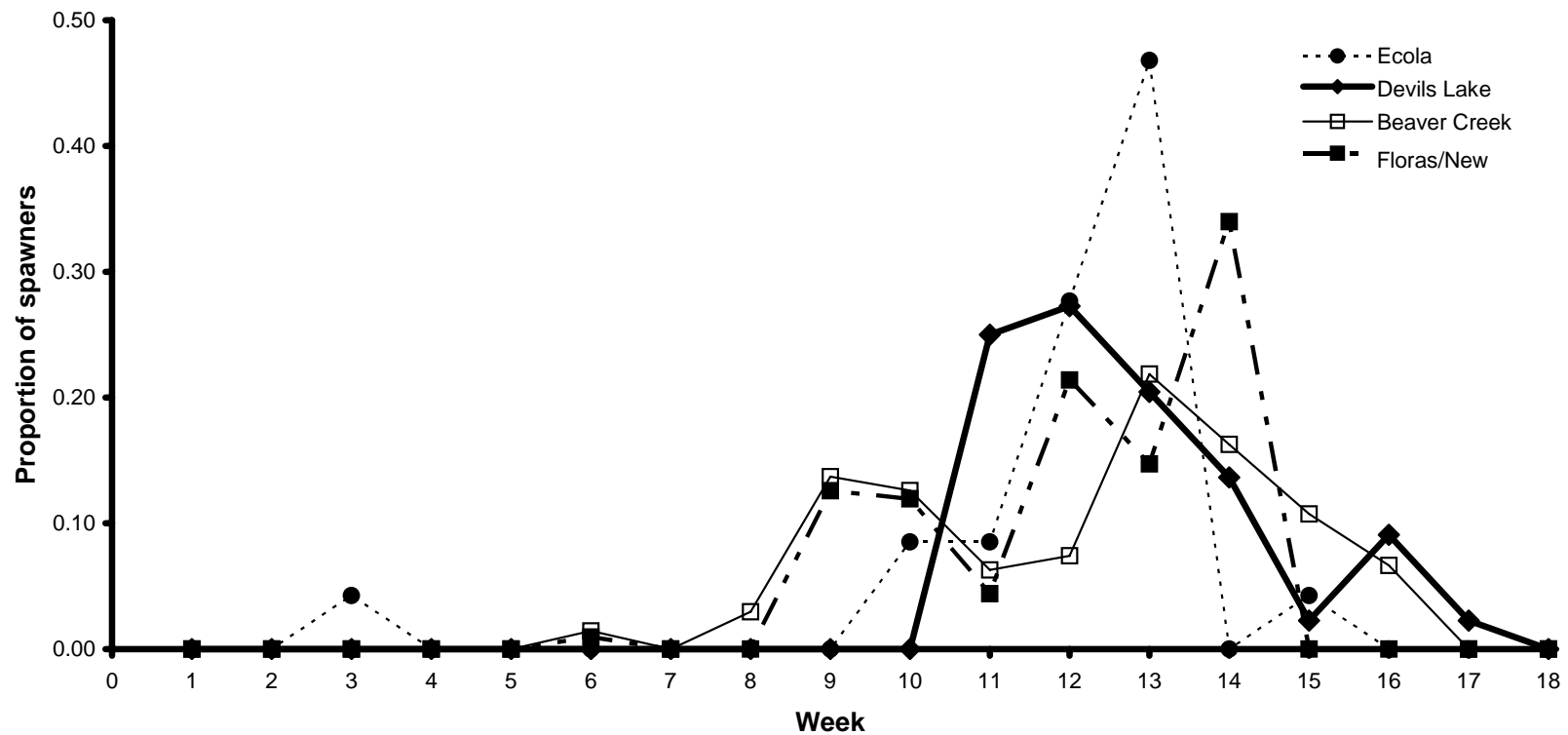
Figure 8e. Small systems spawn timing for Oregon Coast coho salmon for 2001 (NOAA 2004). To convert weeks to calendar dates: week 1 = Oct. 15–21; week 3 = Oct. 29–Nov. 4; week 7 = Nov. 26–Dec. 2; week 11 = Dec. 24–31; week 16 = Jan. 29–Feb. 4; and week 18 = Feb. 12–18.

Sixes River, New River). In these systems, coho and other salmon species are unable to enter the rivers until sufficiently strong freshets breach the sandbars (Sandercock 1991).

These factors make determining and comparing average or peak river entry and spawn timing difficult because of the high spatial and temporal variability exhibited within basins. Compared to normal run times, river entries of some coho salmon populations are exceptionally early or late. It was originally thought that this might be helpful in delineating historical populations. However, the relationship between populations with unusually timed runs is not well understood and exceptional run timing is found in numerous geographical areas. The strongest pattern evident from these data is the later run timing in small systems. Historically, the range of variation might have given clues to population structure in the basins. However, because of the effect of stock transfer and hatchery programs, as well as other anthropogenic effects, it is impossible to discern historical patterns from modern observations. Because there is no evidence to suggest that all runs of a certain type are closely related, we now consider differently timed modern runs to be a component of overall life history diversity within each area and not an indication of historical population structure.

Marine distribution

Coho salmon smolts from the Oregon Coast enter the ocean in the spring and usually encounter a southward-flowing coastal current. Once in the coastal ocean they tend to swim north, but depending on the strength of the currents, may initially be displaced to the south (Pearcy 1992). As juveniles grow larger, swimming speed increases, resulting in a net northward movement. By late summer, juveniles from the coast are distributed off the mouth of the Columbia River and the Washington Coast (Pearcy and Fisher 1988, Brodeur et al. 2004). In the fall, early maturing males (jacks) return to their natal streams.

Fall and winter distribution of Oregon coastal coho salmon are less well-known. Hartt and Dell (1986) report results of tagging experiments conducted from 1956 to 1968. Juvenile salmon in the Gulf of Alaska were tagged at sea and recovered as adults the following year. They estimated that up to 37% of the fish they tagged returned to Oregon and California, with 20% of tags recovered south of the Columbia River. Recent sampling efforts in British Columbia and the Gulf of Alaska confirm the presence of juvenile coho salmon from the Oregon Coast in northern British Columbia (Welch et al. 2004) and the Gulf of Alaska (Weitkamp 2004). However, it does not appear that they are as abundant as Hartt and Dell (1986) observed. Pearcy (1992) postulates that ocean conditions may have changed, altering migration patterns. Alternatively, the shift from predominantly wild to predominantly hatchery fish may have affected migration patterns, because the wild fish tend to enter the ocean earlier and migrate farther north.

There is a southward migration during the winter or early spring. Maturing fish first appear in ocean salmon fisheries in May off the coast of northern California, as far south as Monterey (Weitkamp and Neely 2002). There is a northward migration in late spring and summer, with fish arriving in the Coos Bay area in June, and in the ocean off Yaquina Bay and Tillamook Bay in July. A few adults are caught as far north as northwest Vancouver Island (Canada), but the majority are caught south of the Columbia River. By August adults are starting to home to their natal systems, returning to freshwater in September through November.

Coded-wire tags (CWTs) can provide information on marine distribution of specific hatchery populations. They are primarily recovered from marine fisheries or when the salmon return to hatcheries. Consequently, CWT recovery patterns only indicate ocean migration patterns during the last few months of a 1½-year-long migration. Although patterns of movement during earlier stages of ocean migration have been studied (such as Loeffel and Forster 1970, Hartt 1980, Miller et al. 1983, Hartt and Dell 1986, Pearcy and Fisher 1988), the studies are not broad enough in scope to adequately compare early migration patterns for coho salmon released from different areas of the Oregon Coast.

CWT recoveries show distinctive differences between regions, as is observed between the SONCC and the Oregon Coast Coho Salmon ESUs (Weitkamp and Neely 2002). Within the Oregon Coast there is a tendency for north coast fish to be caught in more northerly fisheries, while south coast fish contribute more heavily to southern fisheries. However, the tendency is not strong enough for us to draw conclusions about neighboring populations within regions, such as between the Yaquina and the Siuslaw rivers. The CWT recovery data provide information at the ESU scale, but are not useful for distinguishing between historical populations.

Genetics

Weitkamp et al. (1995) reviewed the genetics studies available at the time and presented a new analysis of samples collected by NOAA Fisheries Service. In allozyme studies, coho salmon from the Oregon Coast Coho Salmon ESU consistently showed genetic differences from other groups, including the Columbia River to the north and the Rogue and Klamath rivers to the south (Olin 1984, Solazzi 1986, Hjort and Schreck 1982). One study (Hjort and Schreck 1982) also found that hatchery populations from the north coast of Oregon were distinct from the natural spawners. Studies of DNA patterns concluded there was a unique stock unit south of the Columbia River to Cape Blanco (Currens and Farnsworth 1993, Forbes et al. 1993).

Samples of DNA from California to Alaska (Johnson et al. 1991, Milner 1993) were analyzed for allele frequencies and genetic distances at six gene loci (Weitkamp et al. 1995). Cluster analysis identified two overlapping groups on the Oregon Coast: a north-central group (with samples from Alsea, Trask, Siletz, and Nehalem basins) and a central to south-central group (with samples from the Rogue, Sixes, Eel, Tenmile, New, Coos, Tahkenitch, Alsea, Beaver, Siletz, Salmon, Smith, and Coquille basins). The Umpqua River Basin was in a third group along with Trinity, Rogue, and Elk basins. The same analysis also grouped Washington Coast and Puget Sound coho salmon separately from Columbia River fish.

Recently, NOAA Fisheries Service (Ford et al. 2004) analyzed seven microsatellite loci in DNA extracted from coho salmon scales collected from 12 systems on the south-central and central Oregon Coast in 2000 and 2001. Additional fin and muscle samples from nearby systems collected between 1991 and 1997 were also used in the analysis. Samples were selected to examine variability within and between three groups of fish. On the central coast, samples from three large basins and one small basin (Siletz, Yaquina, and Alsea rivers and Beaver Creek) were compared in an attempt to see if the small system (Beaver Creek) had a particular affinity to one of its larger neighbors (see Figure 9). Within the Umpqua River, samples were compared from Calapooya Creek, Elk Creek, Smith River, South Fork Umpqua River, and mainstem
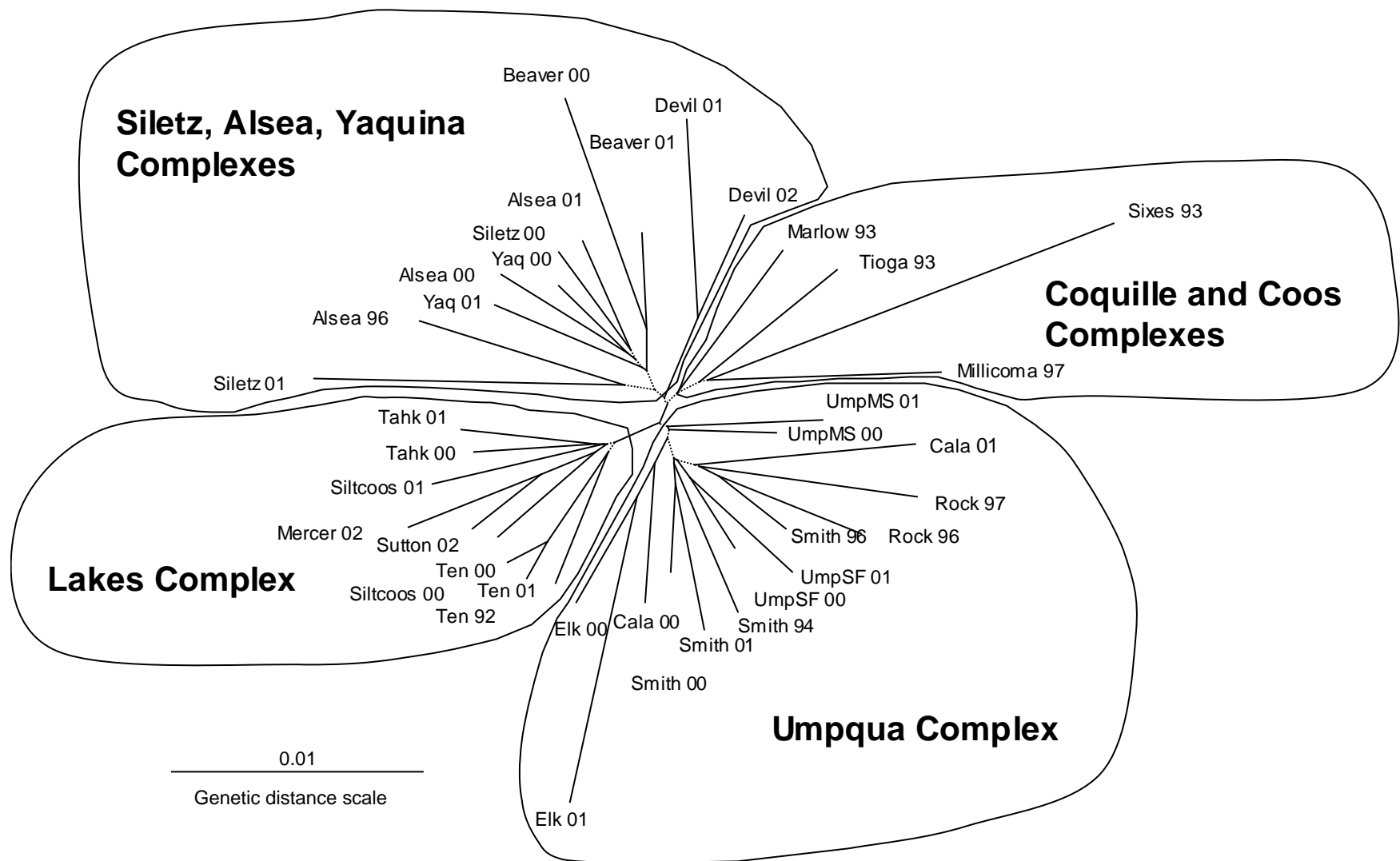
Figure 9. A maximum likelihood tree of Oregon Coast coho salmon genetic samples. Branches not significantly greater than zero are shown with thin dotted lines. Clusters are outlined by heavy curved line. Analysis by M. Ford based on data from Ford et al. 2004.

Umpqua River. The objective was to look for population structure within this large river basin. The third group of scales was sampled from fish returning to four coastal lakes: Devils Lake, Siltcoos Lake, Tahkenitch Lake, and Tenmile Lake. The lake habitats are distinct from the rivers, and coho salmon from these lakes are thought to be distinct from the coastal river runs.

A phylogenetic tree based on these data (Figure 9) showed some obvious geographic structure, although the internal branches connecting the geographic groups were relatively short compared to the terminal branches (branch length is proportional to genetic differences). The samples from the lakes formed a coherent group, as did the samples from the Umpqua River Basin. There was some suggestion of structure within each of these groups. The Siletz, Yaquina, and Alsea rivers and Beaver Creek also grouped together. There was no population structure identified within this group, although the authors stressed that this was not a strong conclusion. More generally, there is no strong evidence whether or not there are independent populations within these groups. Despite sample size limitations, this study was able to use modern genetic techniques to show a finer scale of population structure than had been demonstrated in earlier studies. In particular, this study supports Siltcoos, Tahkenitch, and Tenmile lakes as at least one independent group. Devils Lake clustered with mid-coast rivers rather than the other lakes. The study also supports dividing the modern populations within the Umpqua River Basin into more than one population. There was no clear discrimination among the mid-coast basins. This may be due to recent hatchery practices and stock transfers blurring the boundaries between historical populations.

Homing fidelity

The rate of migration between basins is an important component of our population model. For an indication of stray rates, we utilized the Uremovich (1977) study, which found that, over the 7-year period of 1970–1976, 6.5% of the Chinook salmon (*Oncorhynchus tshawytscha*) carcasses in the Sixes River came from the Elk River hatchery, about 5 km to the north. However, he had no data to indicate the proportion of Elk River fish that were straying. Shapovalov and Taft (1954) found that an average of about 20% of coho spawners in two neighboring streams on the California Coast were migrants from the other stream. These two streams, Waddell and Scott creeks, are small systems with ocean entry points about 8.5 km apart. They saw a pattern in migration rates that suggested variability between years in response to abundance. Such variability certainly occurs on the Oregon Coast, but we have no way at present to identify this variability or incorporate it in our isolation models (Labelle 1992).

We examined freshwater CWT recoveries on the Oregon Coast to test assumptions about patterns of migration between basins. For the period of 1990–2003, 52 tagged coho from 17 Columbia River hatcheries were recovered in freshwater areas of coastal basins. Of the 52 tagged fish, 32 were recovered in 2001, including 4 fish from 3 Oregon hatcheries and 28 fish from 9 Washington hatcheries. Twenty-three of these fish were found in basins from the Umpqua River to the Rogue River. Surprisingly, 6 of the 52 fish were Cowlitz River stock, which is typically considered a north-migrating stock. These data would suggest that migration of Columbia River fish in 2001 was episodic and irregular. Because most of the migrants were found in the largest systems on the coast, it may be that fish originating from large systems prefer other large systems.

Migration patterns between hatcheries on the Oregon Coast may be more relevant to the historical behavior of natural fish. For the period 1990–2003, there were 71 CWTs from 4 Oregon coastal hatcheries recovered outside the basin of hatchery origin. This represents 0.5% of the CWTs recovered. The actual migration rate is almost certainly higher because CWTs are much more likely to be recovered at the hatchery than on the spawning ground or from freshwater fisheries. In any case, modeling with a 0.5% vs. 5% rate would have no effect on our isolation results. More importantly, the pattern of recoveries showed that most fish were recovered from neighboring basins, falling off rapidly with increasing distance. This supports the negative exponential migration distribution assumed in our connectivity-viability model (Bjorkstedt et al. 2005).

Summary of biological characteristics

In conclusion, data for comparison of life history traits of coho salmon populations on the Oregon Coast are not usually collected at the broad geographic scale that would be useful for distinguishing populations. The data that are available show high variability in run timing, smolt outmigration and spawner returns, jacking rate, and homing fidelity that are largely attributable to environmental variation or alternative life histories. Genetic data indicate modern population differences on the scale of regions and, to a lesser extent, individual basins. Lake populations (Tahkenitch, Siltcoos, Tenmile, and Sutton) appear different from river populations, and the large Umpqua River Basin shows genetic differentiation within the basin. However, due to the significant anthropogenic impacts to the landscape, none of these biological characteristics were able to shed light on population structure in historical Oregon Coast coho salmon populations.

Ecological Characteristics

Hydrology

North of Cape Blanco, all coastal Oregon rivers with the exception of the Umpqua River drain only the west side of the Oregon Coast Range. The range is relatively low, with peaks at 500–1,000 m (1,640–3,280 feet) high. Interior portions of the Umpqua River Basin, however, drain the east slope of the Coast Range and the west side of the Cascade Range, which has peaks from 1,000 to 2,000 m (3,280–6,560 feet) high.

Stream flows in this region follow a similar pattern, with seasonal highs typically experienced in December or January (Figure 10). Mean annual flows are relatively similar for the basins draining the west slope of the Coast Range. Where they have been measured, these flows have ranged from 0.027 to 0.080 m^3/s per sq. km (Figure 11). Mean annual flows for the interior drainages within the Umpqua River Basin have ranged from 0.009 to 0.042 m^3/s per sq. km. Lowest flows generally occur in summer and fall and are a small percentage of the peak flows. Expressed as a percentage of mean flow during the month of greatest runoff, low flows during the month of least runoff range between 1.0% and 5.1% (Figure 12). The exception to this is the North Umpqua River (3.5% and 42.3%). The difference in this basin is related to the strong influence of high Cascades geology and hydrology. Duration of high flows range from 4 to 6 months in basins proximal to the coast. In the interior drainages of the Umpqua River Basin, high flows can persist for as long as 7 months in unregulated systems (Figure 13).
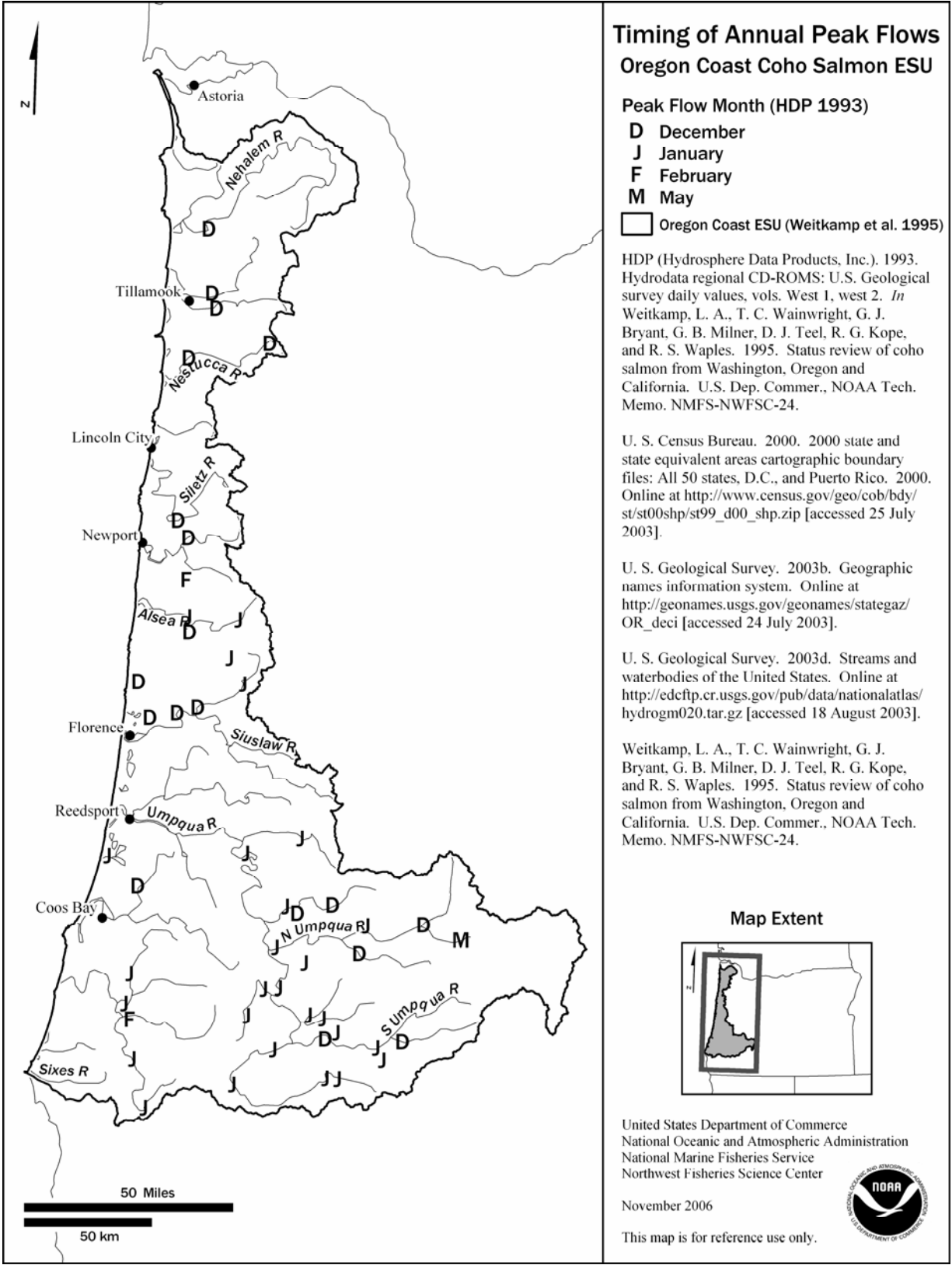
Figure 10. Timing of annual peak flows in rivers of the Oregon Coast Coho Salmon ESU.
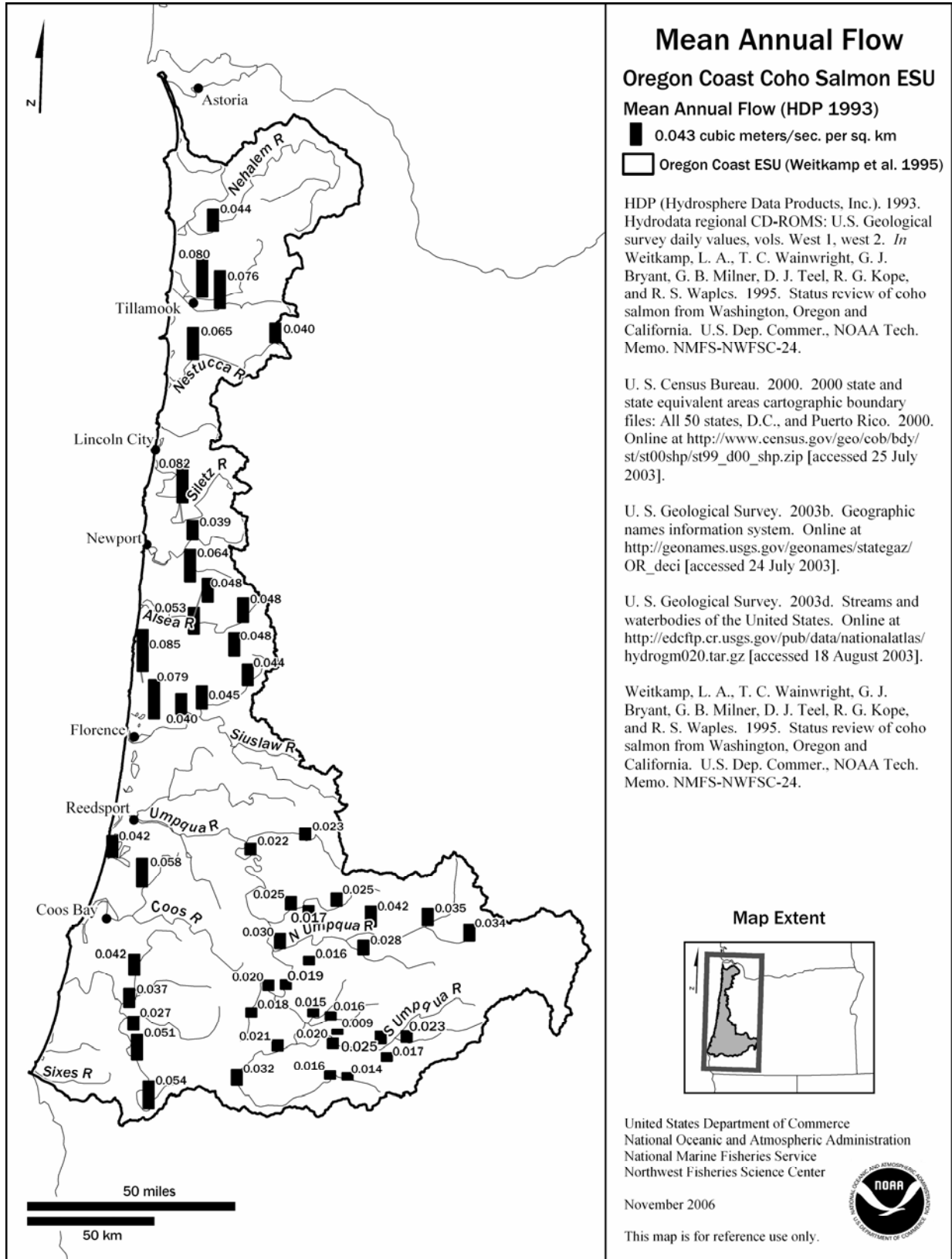
Figure 11. Mean annual flow in rivers of the Oregon Coast Coho Salmon ESU.
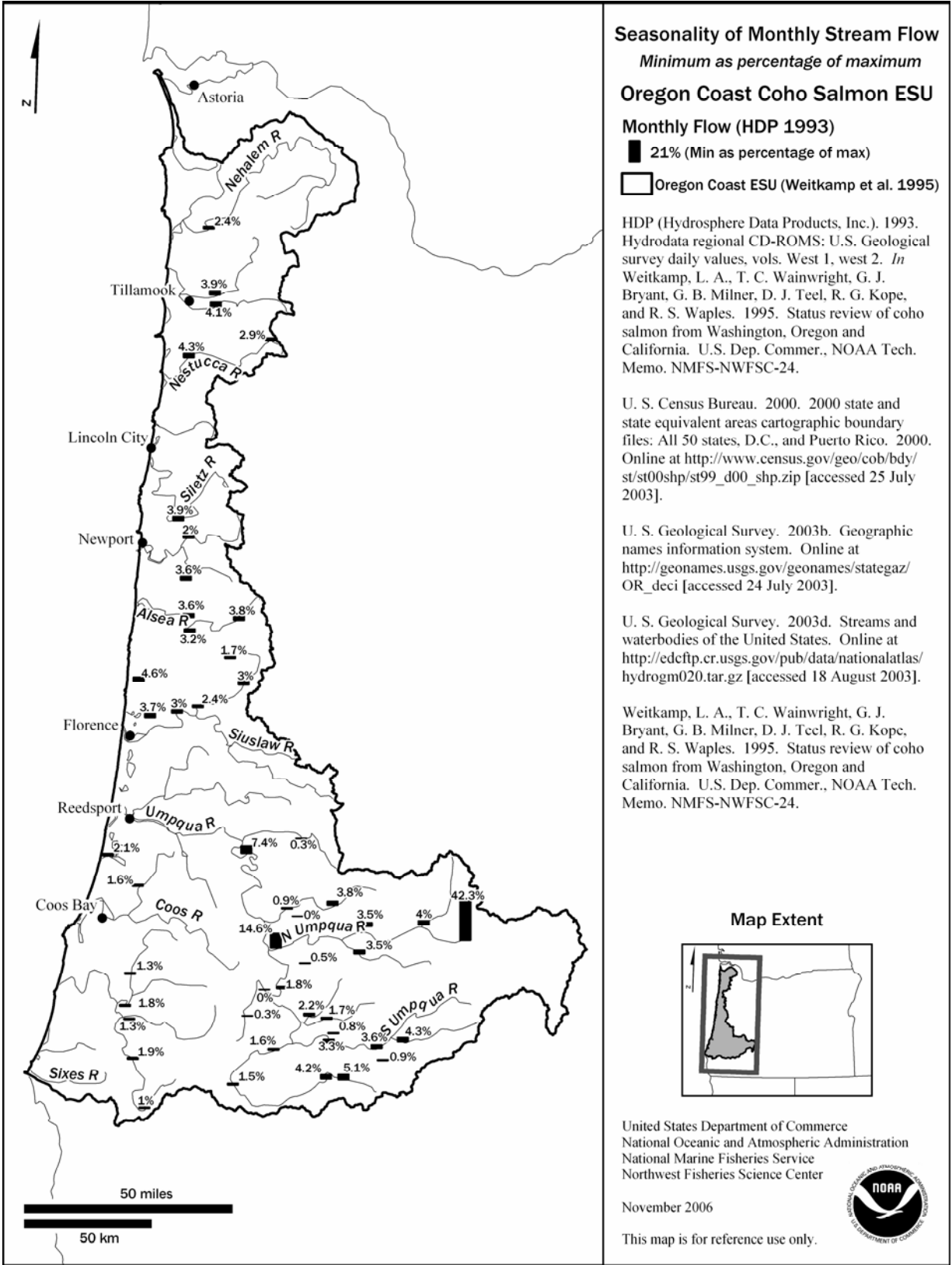
Figure 12. Seasonality of monthly stream flow in rivers of the Oregon Coast Coho Salmon ESU.
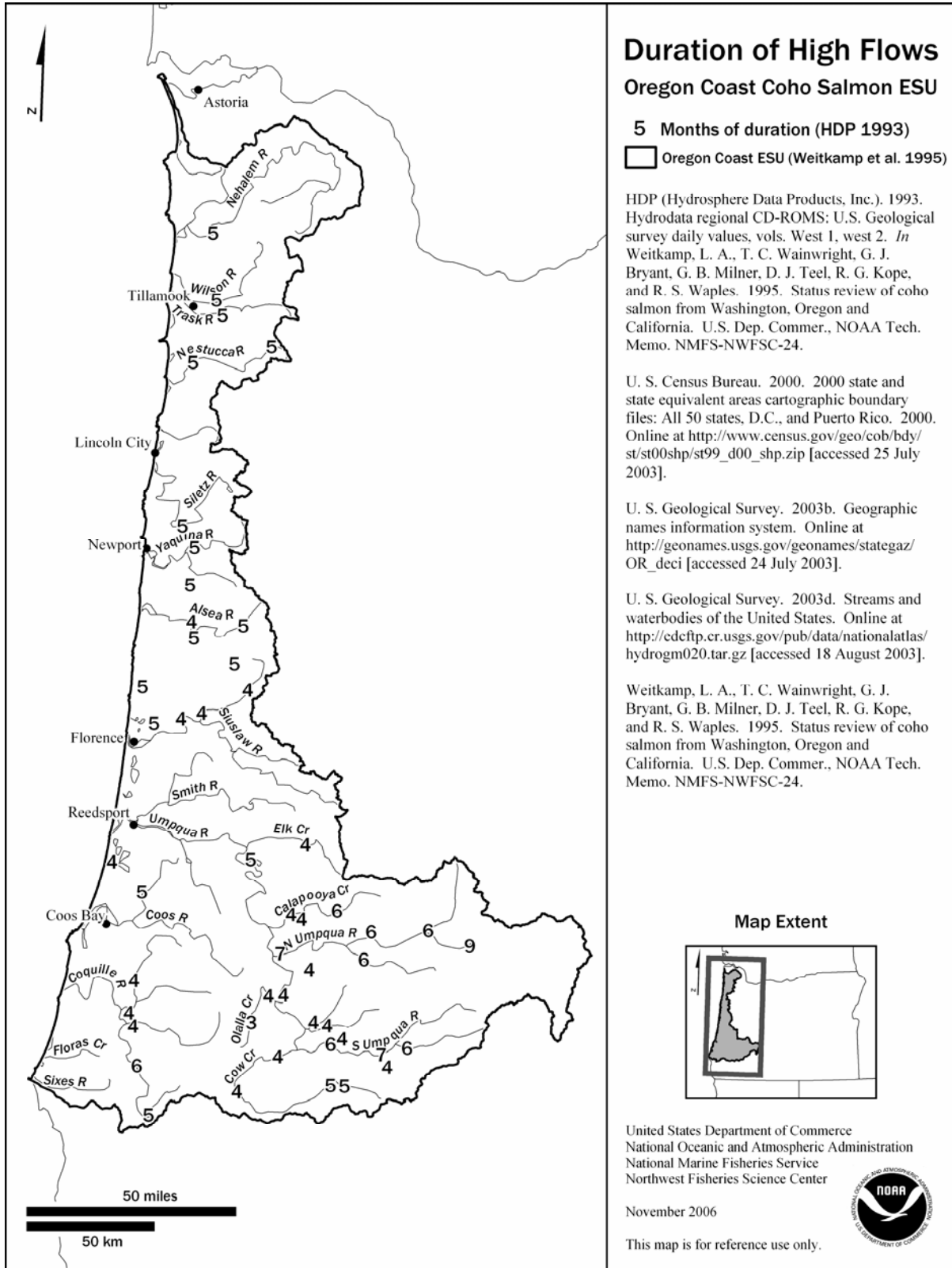
Figure 13. Duration of high flows in the Oregon Coast Coho Salmon ESU. The number of months of duration of peak flow is shown at gauging stations.

Air and stream temperatures

There are few clear broad-scale differences in air or stream temperatures from north to south within coastal areas occupied by the historical Oregon Coast Coho Salmon ESU. Minimum average winter air temperatures are typically around 4ºC (39ºF), whereas minimum average stream temperatures have a range of 4–8ºC (39–46ºF). Maximum average air temperatures are typically around 21ºC (70ºF) and maximum average stream temperatures at selected sites in coastal basins have been observed to range from 15ºC to 21ºC (59–70ºF). Higher maximum stream and air temperatures have been observed in the South Umpqua River, which is an interior basin.

Precipitation

The Oregon Coast receives high rainfall (120–305 cm [47–120 inches] per year) compared to areas east of the Coast Range (60–120 cm [24–47 inches] per year). Generally, however, it receives less rainfall than the Olympic Peninsula, Washington, farther north (>240 cm [95 inches] per year). The exceptions to this are in the Nehalem River Basin, the upper areas of the five rivers of the Tillamook Basin, and the upper Salmon River and Siletz River basins (Figure 14). Much of the Umpqua River Basin receives considerably less rainfall than the areas proximal to the coast, with precipitation averages between 102 cm (40 inches) and 152 cm (60 inches). Because of the relatively low elevation, snowfall in the Coast Range is low, averaging 30–60 cm (12–24 inches) annually, while the higher Cascade Range receives from 250 cm (98 inches) to 760 cm (300 inches) annually. This difference in snowfall is important for the Umpqua River Basin, as the North and South Umpqua rivers drain a portion of the west slope of the Cascade Range (Oregon Climate Service 2000a).

Vegetation

Dominant vegetation types are a valuable indicator of relative precipitation, temperature, soil type, solar radiation, and altitude because of the specific requirements of different forest communities. Consequently, changes of vegetation types can indicate differences in the physical environment, which may affect the freshwater habitat of salmon. (A more detailed discussion of vegetation has been compiled in Appendix A.) Potential vegetation is similar in most of the basins of the Oregon Coast Coho Salmon ESU with the exception of the Siuslaw and Umpqua river basins, which extend into the interior away from marine influence (Figure 15).

Ecoregion

Ecoregions as shown in Figures 16 and 17 are representations of the integrations of vegetation, geology, soils, precipitation, and evaporation potential (ONHP 2001). Level 3 ecoregions of the Oregon Coast Coho Salmon ESU from south of the Columbia River to Cape Blanco show large-scale geologic provinces. Level 4 ecoregions show a finer scale of differences, reflecting areas such as coastal lowlands and volcanics, which often indicate differing potential for development of good coho salmon habitat. Descriptions of each type of level 3 and 4 ecoregion are found in Appendix B.

Average Annual Precipitation
(Oregon Climate Service 2000a)
Oregon Coast Coho Salmon ESU

< 100 cm   200 - 300 cm
100 - 200 cm   > 300 cm

Oregon Coast ESU (Weitkamp et al. 1995)

Oregon Climate Service. 2000a. 103-year high-resolution precipitation climate data set for the coterminous United States. Online at ftp://ftp.ftw.nrcs.usda.gov/pub/ams/prism/data/natl_atlas/prism_shp.zip [accessed 1 August 2003].

U. S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files: All 50 states, D.C., and Puerto Rico. 2000. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

U. S. Geological Survey. 2003b. Geographic names information system. Online at http://geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

Astoria
Tillamook
Lincoln City
Newport
Florence
Reedsport
Coos Bay

50 miles
50 km

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure 14. Average annual precipitation in watersheds of the Oregon Coast Coho Salmon ESU.

Vegetation Zones
(after Franklin and Dyrness 1973)
Oregon Coast Coho Salmon ESU

Sitka spruce
Western hemlock
Umpqua Valley
Mixed evergreen & hardwood
Subalpine
Willamette Valley
Oregon Coast ESU (Weitkamp et al. 1995)

Franklin, J. F., and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service General Tech. Rep. PNW-8. U.S. Gov. Printing Office, Washington, DC.

U. S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files: All 50 states, D.C., and Puerto Rico. 2000. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

U. S. Geological Survey. 2003b. Geographic names information system. Online at http://geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

U.S. Geological Survey. 2003d. Streams and waterbodies of the United States. Online at http://edcftp.cr.usgs.gov/pub/data/nationalatlas/hydrogm020.tar.gz [accessed 18 August 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure 15. Vegetation zones in the watersheds of the Oregon Coast Coho Salmon ESU.

Astoria

Tillamook

Lincoln City

Newport

Florence

Reedsport

Coos Bay

Nehalem R

Nestucca R

Siletz R

Yaquina R

Alsea R

Siuslaw R

Umpqua R

N Umpqua R

S Umpqua R

Sixes R

Coast Range

Willamette Valley

Cascades

Klamath Mountains

50 Miles

50 km

Figure 16. Level 3 ecoregions of the Oregon Coast Coho Salmon ESU.

Level 4 Ecoregions
(ONHP 2001)
Oregon Coast Coho Salmon ESU

Legend:
- Mid-Coastal Sedimentary
- Umpqua Cascades
- Volcanics
- Umpqua Interior Foothills
- Coastal Uplands
- Inland Siskiyous
- Coastal Lowlands
- Other < 5% of total area

Oregon Coast ESU (Weitkamp et al. 1995)

Oregon Natural Heritage Program. 2001. ORNHP/ODFW ecoregions of Oregon. Online at http://www.sscgis.state.or.us/data/shapefile/k250/ecoregion.zip [accessed 24 July 2003].

U. S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files: All 50 states, D.C., and Puerto Rico. 2000. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

U. S. Geological Survey. 2003b. Geographic names information system. Online at http://geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

U.S. Geological Survey. 2003d. Streams and waterbodies of the United States. Online at http://edcftp.cr.usgs.gov/pub/data/nationalatlas/hydrogm020.tar.gz [accessed 18 August 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure 17. Level 4 ecoregions of the Oregon Coast Coho Salmon ESU.

The ecological information shows a relative uniformity of conditions throughout the Oregon Coast Coho Salmon ESU (Weitkamp et al. 1995). This is not surprising, given the dominant effect of the ocean on coastal climate. Differences relate to the effects of topography on rainfall and of geology on vegetation and slope stability. Inland areas of the Umpqua River Basin are drier, with more extreme temperatures than the coastal areas. Ecoregions integrate a variety of biotic and abiotic factors to show patterns of habitat variation that may be important to coho salmon.

Summary of potential isolating ecological characteristics

We reviewed a wide range of factors of potential use in distinguishing among populations of coho salmon on the Oregon Coast. Most of the data indicated differences on a broad scale, but there were few data sets useful at the finer scale of individual basins. The most recent genetic analysis indicated that modern populations are probably structured at a smaller scale than broad regions (north coast to south coast). Geographic isolation is potentially useful for defining the degree of interactions among populations, and ecoregions may define habitat divisions significant to life history adaptations that could potentially become isolating factors in population structure. These more enduring ecological characteristics (which include geological history, vegetation, and climate) appear to be more informative when considering the historical population structure of Oregon Coast coho salmon. We used ecological characteristics specifically when considering population structure within the Umpqua River Basin.

Methods for Population Identification and Classification

We identified two steps for defining populations and their structure: 1) identifying population units, and 2) classifying the units into categories. Identification delineates populations and defines where they occur. Classification categorizes those populations into groups. Based on our conceptual model, we defined three groups: functionally independent populations, potentially independent populations, or dependent populations. Both steps are based on simple rules.

Identification Method

We used two rules for identifying populations. The first identifies all main basins that encompass the range of one or more populations.

Rule 1: No population will span salt water; in other words, populations are divided at saltwater entry such that each direct ocean tributary wholly encompasses the range of any populations that spawn within the freshwater basin. For purposes of this rule, estuaries are considered part of the freshwater system, so multiple streams entering a single bay may contain a single population.

This rule is based on two postulates regarding salmon populations. First, population structure is largely determined by the structure of freshwater spawning and rearing habitats and the migration pathways connecting these habitats. Second, saltwater entry/exit is a major break point in migration pathways, so migration among habitats within a basin is more likely than migration through salt water among basins. Coho salmon spawn and rear in freshwater, which

allows periods of migration for juveniles before saltwater entry and for adults during spawning migrations.

Applying Rule 1, we initially identified 67 direct ocean entry basins with coho salmon habitat within the range of the Oregon Coast Coho Salmon ESU (Table 1). These are basins greater than 2 km (≈1 mile) in stream length and at least minimally accessible to coho salmon. These basins range in size from Rover Creek (60 ha [148 acres]) to the Umpqua River Basin (1.2 million ha [3 million acres]).

The second rule describes when a basin contains more than one persistent population.

Rule 2: To be considered separate populations, two breeding groups within a basin must be sufficiently isolated to be considered functionally or potentially independent.

Evidence for isolation may include major ecological differences among subbasins, large spatial separation of spawning and rearing habitats, or noteworthy life history or genetic differences. Under Rule 2, we considered subdividing several of the larger basins into multiple populations. These are discussed from north to south below.

Identification Results

Nehalem River

We considered defining two populations within the basin divided just below the confluence of the mainstem and Humbug Creek (Figure 18). In favor of this split is the geological distinctness of the upper basin, which is largely in the Willapa Hills Ecoregion (Figure 17). However, there was no apparent isolating mechanism to limit migrations between spawning areas in the upper and lower basins, and the upper basin is ecologically similar to the north fork, which would have been included in the lower population.

Tillamook Basin

The Tillamook Basin drains several moderate-sized rivers (Figure 19)—Miami, Kilchis, Wilson, Trask, and Tillamook—each of which could have supported an independent coho salmon population. We considered subdividing the basin into multiple populations. However, we ultimately concluded that historically there probably were not separate populations in this basin. Considerations leading to this conclusion included 1) habitat is ecologically similar across the rivers; 2) most historical production was in lowland areas, where tributaries are close together and likely merged during floods (Coulton et al. 1996); and 3) most coho habitat is in the Tillamook, Trask, and Wilson rivers, which are all close together. The Miami River is somewhat separated geographically from the other main tributaries, but was probably not large enough to support a functionally or potentially independent population without input from its neighbors. At present, coho habitat is widely dispersed in the upper reaches of the tributaries; however, this appears to be largely a result of loss of higher quality lowland habitats rather than the historical structure of the population.
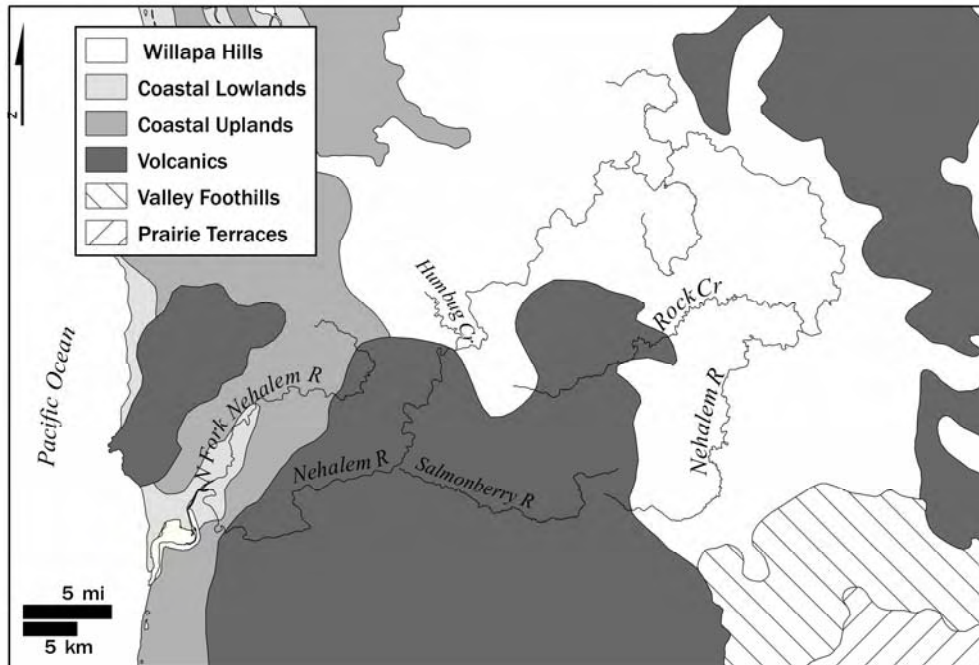
Figure 18. Level 4 ecoregions in the Nehalem River Basin and the surrounding area.
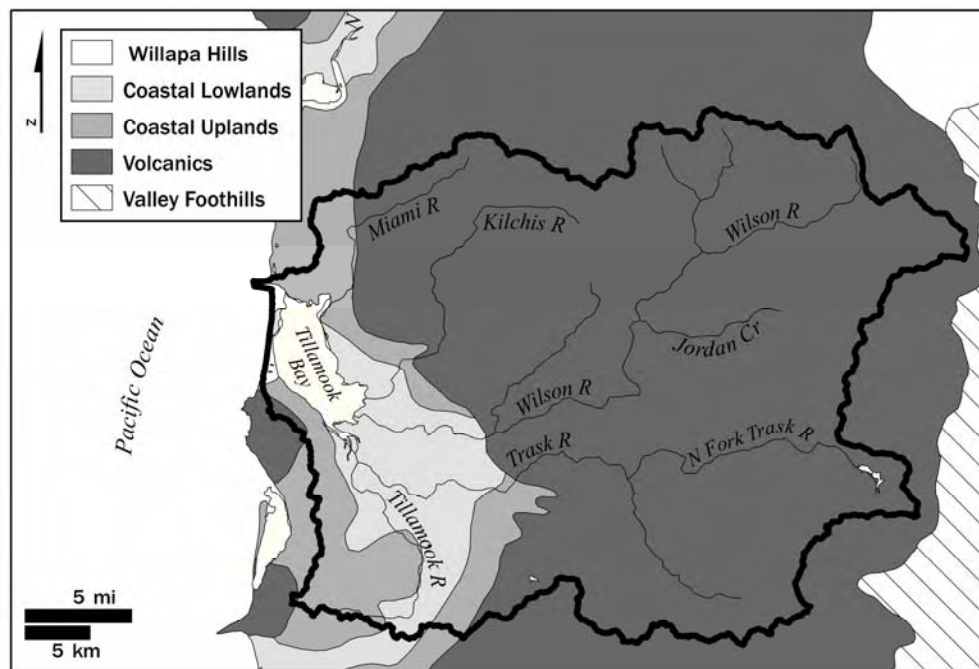
Figure 19. Level 4 ecoregions of the Tillamook Basin and the surrounding area.

Nestucca River

Kostow (1995) identified two tributary populations (Nestucca and Little Nestucca rivers). We found no significant ecological differences or isolating mechanisms between the two tributaries to justify subdividing the population.

Siletz River

Kostow (1995) identified three populations entering Siletz Bay. We found no significant ecological differences or isolating mechanisms among the tributaries to justify subdividing the population.

Siuslaw River

Two populations (Siuslaw and North Fork Siuslaw) were identified by Kostow (1995). We considered separating the north fork from the main river, but found no significant ecological differences and noted likely historical lowland habitat connections between the two rivers.

Umpqua River Basin

This is a large basin (Table 1) draining a diverse region (Figure 20). We considered several possible population scenarios with between one and five populations in the basin. The single population scenario was eliminated because of the size of the basin, its ecological diversity as indicated by multiple level 3 and level 4 ecoregions (Figures 16 and 17), and the apparent genetic diversity within the basin (Figure 9) (Ford et al. 2004). The finest-scale divisions we considered included independent populations in the North Umpqua River, South Umpqua River, mainstem Umpqua River, lower Umpqua Basin (lower mainstem and bay tributaries), and Smith River. The Smith River, a large tributary entering the Umpqua River below tidewater, was eliminated from consideration as a historically independent population because until 1930 most of the habitat in the basin was inaccessible due to an impassable falls low in the basin. In addition, the lower reaches of the Smith River are geographically close and ecologically similar to other lower basin streams.

Given these considerations, we initially reduced the likely scenarios to two: 1) three populations based on fourth-field Hydrologic Units (HUC) (Smith River and mainstem to the forks, north fork, and south fork), and 2) two populations based on dominant level 3 ecoregions (Figure 16) within subbasins. The HUC-based approach is appealing for simplicity and recognizes that major tributary branches within basins are possible isolating points for migrating adults. The ecoregion approach focuses more on potential isolation via local adaptation to geology, hydrography, and vegetation differences among regions. The Umpqua River Basin spans four level 3 ecoregions: Coast Range, Klamath Mountains, Willamette Valley, and Cascades. However, the latter two historically had little coho salmon habitat (Figures 4 and 16). The two dominant ecoregions are the Coast Range, which spans the lower tributaries and main stem, except for Elk and Calapooya creeks, and the Klamath Mountains, which span upper Elk Creek, Calapooya Creek, and the lower portions of the North and South Umpqua rivers.
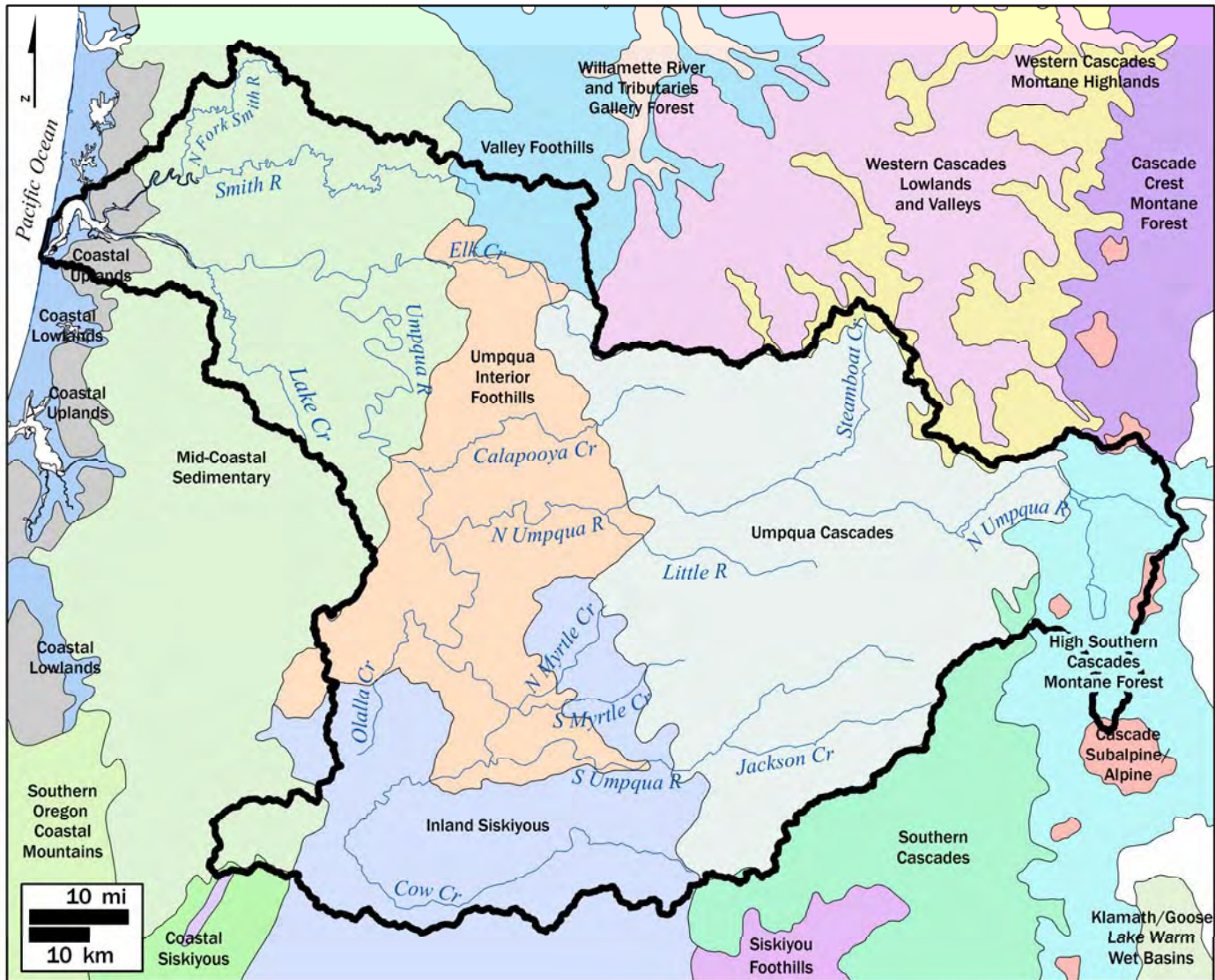
Figure 20. Level 4 ecoregions of the Umpqua River Basin and the surrounding area.

There are large uncertainties inherent in reconstructing historical population patterns, and there is no clear support favoring one of these scenarios over the other. Recent genetic analysis (Figure 9) (Ford et al. 2004) supports some division within the basin, but patterns of genetic variation are ambiguous and we do not know to what extent they reflect recent management rather than historical population structure. Pending further evidence, we provisionally identified two historical populations based on ecoregion differences within the Umpqua River Basin: Lower Umpqua and Upper Umpqua (Figure 16), with the division in the mainstem immediately below the confluence of Elk Creek. The Lower Umpqua population occupies the Coast Range Ecoregion, while the Upper Umpqua population inhabits primarily the Klamath Mountains Ecoregion, with some habitat in the Cascades and Coast Range ecoregions.

Subsequently, on the advice of ONCC TRT members and in response to several comanager comments, we revisited the identification of independent populations in the Umpqua River Basin. In order to be consistent with the population identification process in the SONCC, we performed a principal components analysis (Appendix D) utilizing the methods in Williams et al. (2006). After assessing the results of the analysis, we decided that the configuration that made the most sense was one with lower, middle, north, and south Umpqua populations. This reflects our observation that the temperatures, rainfall, hydrology, and ecoregions are quite different between the North and the South Umpqua rivers. We decided to include a Middle Umpqua population due to the presence of the Willamette Valley Ecoregion in the Elk Creek system and the significant hydrological differences from the North and South Umpqua river populations. The Lower Umpqua is substantially different from all three of the other populations, based on its landscape position and its proximity to marine climate influence. More recently, Johnson (2006) has shown that the Lower Umpqua is quite different genetically and has its affinities with the nearby lake populations. The upper Umpqua populations are less distinct, with high migration rates and substantial gene flow mediated by jacks. The Workgroup decided that, with the substantial differences in biogeography and hydrology between the North, South, and Middle Umpqua basins, in the face of uncertainty it is more conservative in terms of risk to define three upper Umpqua populations instead of one. Therefore, the Umpqua River Basin has four historical populations defined: lower, middle, north, and south.

Coos River

We considered splitting the south fork of the Coos River and Millicoma River (Figure 21) as separate populations, following the lead of Kostow (1995). However, this was rejected because of lowland habitat connections in the lower basin where much historical production likely occurred, similar to the situation in Tillamook Bay and Siuslaw Bay.

Population Classification

We classified historical populations into the three population categories: functionally independent, potentially independent, and dependent, based on relative persistence and degree of isolation. Because no direct measure of persistence was available, we used historical potential population size as a proxy. We reconstructed historical population potential from a landscape-based model (Appendix C, Burnett et al. 2003). We then used a connectivity-viability model based on the distances between the ocean entry points of basins (Bjorkstedt et al. 2005). These models are described in the following subsections.
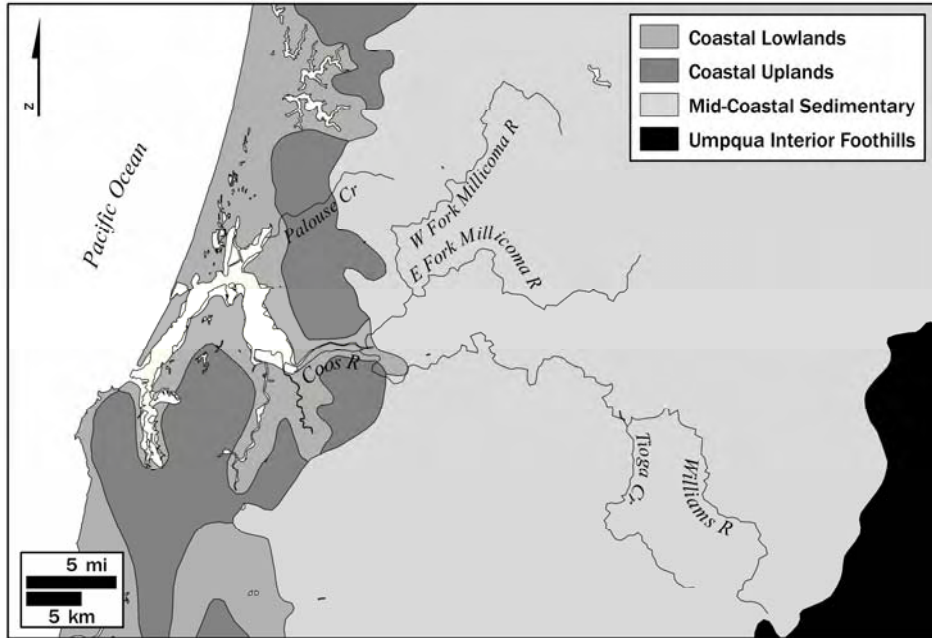
Figure 21. Level 4 ecoregions of the Coos Basin and surrounding area.

Classification Methods

Historical population size (persistence)

We used habitat metrics and recent studies of relationships between habitat and juvenile production to estimate historical abundance. Of course, using current habitat metrics to derive an index of historical abundance requires measuring habitat features that are relatively stable over time. Therefore, we used geomorphic measures of stream conditions that can be calculated from current GIS databases (Coastal Landscape Analysis and Modeling Study [CLAMS]) and digital elevation models (DEMs), adjusted for known changes in the landscape (such as construction or removal of migration barriers) (Burnett et al. 2003). To estimate historical abundance, we combined key geomorphic measures (gradient, valley width, and active channel width) from the DEMs with habitat intrinsic potential (an integrated measure of habitat quality described in Burnett et al. 2003 and illustrated in Figures C-2 through C-5 in Appendix C), smolt capacity estimates for different types of habitat, and a smolt-to-adult survival rate based on a good marine survival year. We compared these habitat-based estimates with estimates derived from cannery records from the turn of the century to confirm that our estimates were reasonable (Lichatowich 1989). Appendix C presents a detailed description of the methods used to estimate these potential historical population sizes.

The advantage of calculating adult abundance from computed GIS data is that estimates can be made for basins where there are no historical fishery data. Table 5 lists the estimated potential historical abundance of coho salmon for the 56 populations in the Oregon Coast Coho Salmon ESU delineated by the process of identification described above. Total adult abundance derived from smolt numbers and a 10% marine survival rate was about 3.3 million adults if all populations peaked in the same year.

Table 5. Potential historical smolt and adult abundance for 56 putative populations of coho salmon in the Oregon Coast Coho Salmon ESU (Appendix C, Table C-2).

Population	Potential smolts	Adults at 10% marine survival	Population	Potential smolts	Adults at 10% marine survival
Necanicum	685,000	68,500	Alsea	1,628,000	163,000
Ecola	72,000	7,000	Big (near Alsea)	34,000	3,000
Arch Cape	3,000	300	Vingie	3,000	300
Short Sands	4,000	400	Yachats	110,000	11,000
Nehalem	3,330,000	333,000	Cummins	10,000	1,000
Spring	5,000	500	Bob	6,000	600
Watseco	5,000	500	Tenmile Creek	28,000	3,000
Tillamook Bay	3,288,000	329,000	Rock	6,000	600
Netarts	15,000	1,500	Big	18,000	2,000
Rover	2,000	200	China	5,000	500
Sand	123,000	12,000	Cape	15,000	2,000
Nestucca	1,037,000	104,000	Berry	54,000	5,000
Neskowin	49,000	5,000	Sutton (Mercer Lake)	84,000	8,000
Salmon	168,000	17,000	Siuslaw	2,674,000	267,000
Devils Lake	85,500	9,000	Siltcoos	771,000	77,000
Siletz	1,217,000	122,000	Tahkenitch	228,000	23,000
Schoolhouse	2,000	200	Threemile	22,000	2,000
Fogarty	18,000	2,000	Umpqua (Total)	8,199,000	820,000
Depoe Bay	7,000	700	Lower Umpqua	1,293,000	129,000
Rocky	10,000	1,000	Middle Umpqua	2,420,000	242,000
Spencer	11,000	1,000	North Umpqua	1,180,000	118,000
Wade	5,000	500	South Umpqua	3,310,000	331,000
Coal	4,000	400	Tenmile	525,000	53,000
Moolack	4,000	400	Coos	2,058,000	206,000
Big (near Yaquina)	26,000	3,000	Coquille	4,169,000	417,000
Yaquina	1,217,000	122,000	Johnson	8,000	800
Theil	20,000	2,000	Twomile	134,000	13,000
Beaver	265,000	27,000	Floras/New	396,000	34,000
			Sixes	372,000	37,000

Figure 22. Historical coho population potential versus basin area for Oregon Coast basins (data sources: Appendix C, Streamnet 2003).

Our GIS-based modeling of the historical capacity of Oregon Coast basins to produce coho salmon shows considerable between-basin variation in the ability to produce these fish. Large coastal basins have a greater absolute capacity to produce coho than do smaller basins because they contain a greater abundance of suitable habitat (Figure 22). However, the potential of Oregon Coast basins to produce coho salmon is influenced by habitat quality as well as quantity. Some basins are inherently more productive for these fish than others because they have the capacity to form disproportionate quantities of the kinds of complex, low-gradient habitats most favored by coho salmon. These basins, including the Tillamook Basin, Yaquina River, Beaver Creek, the lake basins (Siltcoos Lake, Tenmile Lakes, Tahkenitch Lake), and others once produced more coho salmon than would be expected on the basis of their size alone because they contain disproportionately large lowland areas (or lakes) that can provide highly productive rearing environments for juvenile coho.

When compared in terms of their historical capacity to produce coho salmon per unit of basin area, larger basins on the Oregon Coast appear to have been generally more productive than smaller basins because they were more likely to contain relatively extensive lowland areas and complex low-gradient habitats (Figure 23). Though there were exceptions to this pattern, as indicated earlier, the lower inherent productivity of the smaller basins tended to make the coho salmon populations within them even smaller than expected on the basis of basin size alone. This made the coho populations within these smaller basins particularly vulnerable to periodic local extinctions unless there was a consistent influx of stray spawners from larger basins. The relatively higher vulnerability of these populations is attributable to demographic risks associated with small population size, increased sensitivity to fluctuations in marine survival due to lower freshwater productivity, and the vulnerability of small natal basins to single catastrophic disturbances.

Isolation (proportion of native spawners)

One of the defining properties of salmon is their propensity to undergo a long ocean migration and return with high fidelity to their natal spawning grounds. This is what isolates salmon populations from one another. However, homing is not perfect and the movement of migrant salmon between populations is also a defining property of salmon populations. The degree of isolation between populations is determined by the proportion of salmon adults that are migrants from another population and the effectiveness of these migrant salmon at placing competitive offspring into the habitat to which they stray. The proportion of migrants into a population also affects the demographic independence of each population. Our rules for classifying a population are based on a calculation of historical abundance and on the proportion of nonmigrant or native spawning adults based on distances between populations and the relative sizes of these populations.

We used a connectivity-viability model developed by Bjorkstedt et al. (2005) to calculate the relative isolation of each population on the Oregon Coast. Quantitative data on coho salmon dispersal rates are lacking, so the model is relatively simple, reducing the number of assumptions at the risk of reducing the descriptive power of the model. Dispersal of migrants among basins separated by salt water is modeled as a function of distance between the mouths of ocean tributaries. All basins were treated as single units. Thus the Umpqua River Basin, where four populations were delineated, was treated as a single population from the perspective of its neighbors.

In this model, fidelity to native basins (proportion of native spawners) was assumed a constant 95% of potential returning adults. We used our estimates of historical abundance as the number of returning adults for each population. The remaining 5% of the returning population dispersed as migrants along the coast with an exponential decline with distance (Bjorkstedt et al. 2005). After they were dispersed along the coast, they entered the basin nearest to their final location. Distances among watersheds along the Oregon Coast were calculated using the latitude-longitude coordinates for the mouths of each river. The distance between each pair of neighboring river mouths was calculated "as the crow flies." Distances between nonneighboring rivers were calculated as the sum of all intervening neighbor-pair distances. In this way, the curvature of the coast was included in the distance calculations. Tributaries of Tillamook Basin were considered as a single watershed. Two out-of-ESU systems, the Columbia River to the north and Elk River to the south were included to allow estimation of migrants across the ESU boundaries. Elk River historical abundance was estimated from intrinsic potential. Columbia River abundance was based on Chapman (1986).

In early drafts of this document, we modeled the influence of the Umpqua River Basin as one large system. This system dominated the southern portion of the ESU. However, the SONCC Workgroup, in applying the connectivity-viability model, considered that most out-of-basin migrants originated from the lower reaches in large systems. For consistency, we reanalyzed the Oregon Coast Coho Salmon ESU using only the Lower Umpqua River population metrics to represent the contribution of the Umpqua River Basin for the connectivity-viability analysis.
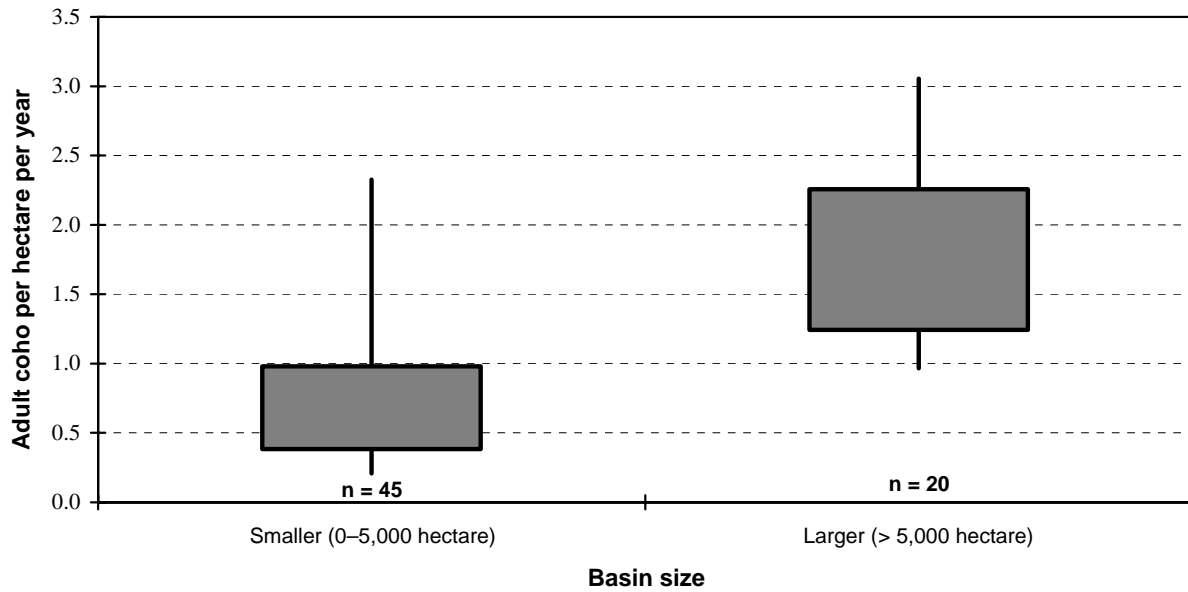
Figure 23. Box-whisker plots of estimated historical coho salmon productivity (adults per hectare of basin area per year) for Oregon Coast basins smaller and larger than 5,000 hectares. Boxes depict the 25th to 75th percentile productivity values for basins of a given size; whiskers extend to the 10th and 90th percentile values (data sources: Appendix C, Streamnet 2003).

Classification Results

The connectivity-viability model reports the proportion of spawners in each stream that originated from that stream (proportion of native return). Streams with a higher proportion of native return are more isolated. Figure 24 is an analysis of relative independence based on the isolation of each population in the ESU and the historical population size (persistence). It shows a continuum from small, dependent populations to large, independent populations. Defining the relative roles of populations on this continuum required us to create divisions that were, to some extent, artificial and arbitrary. We focused on understanding the axes of isolation and historical population size in terms of the analytical techniques used and the population dynamics. We were concerned with finding criteria for these break points that were realistic and defensible in terms of existing analyses.

Establishing a horizontal line to distinguish the functionally independent populations was straightforward because of the model structure. The native return rate used in the model was 95%. Thus all populations with greater than 95% proportion native return were net donors, and those with fewer than 95% proportion native return were net receivers. The horizontal line at 0.95 in Figure 24 depicts this division.
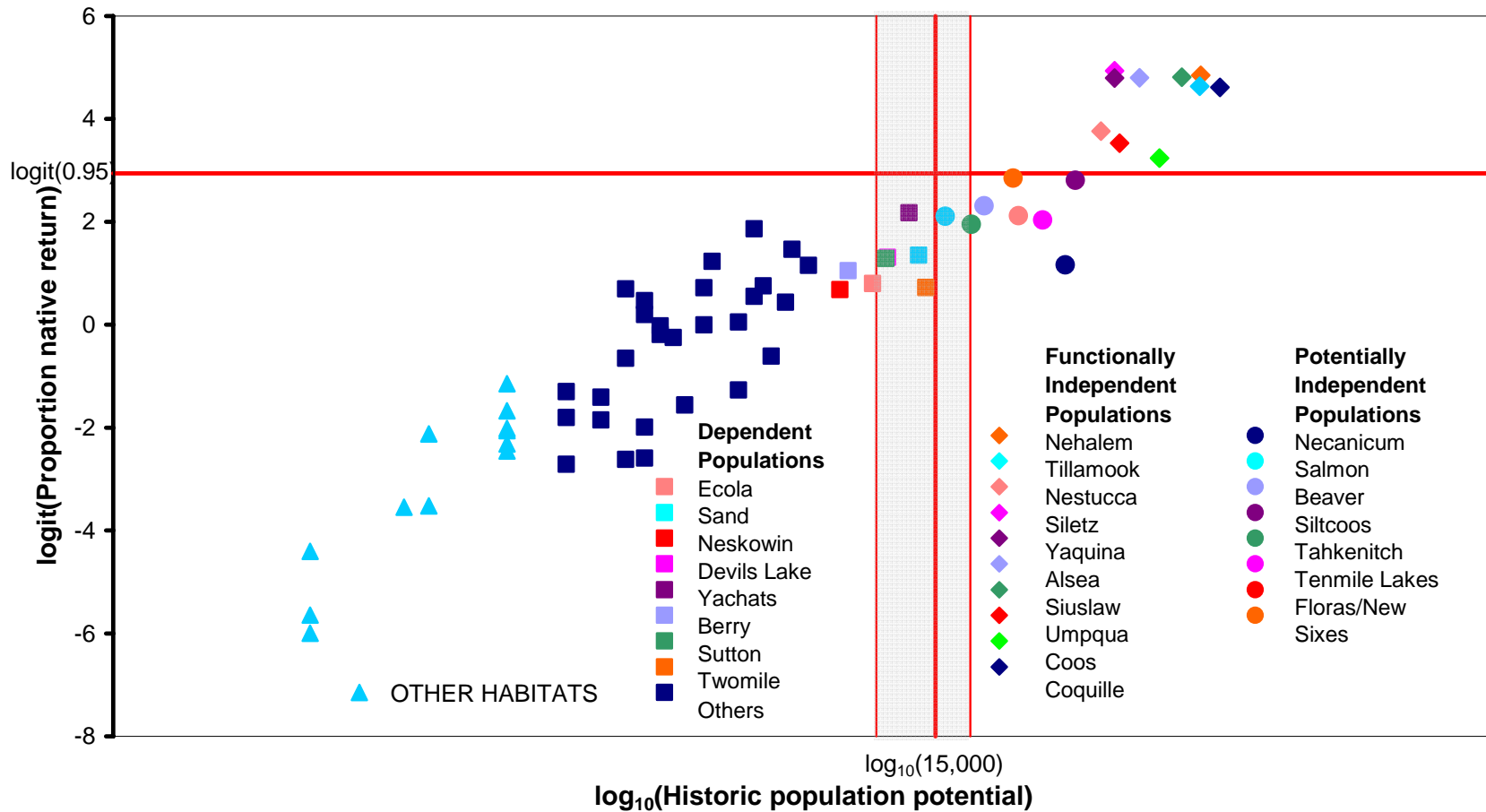
Figure 24. Connectivity-viability analysis for Oregon Coast coho salmon using estimates of potential historical coho salmon abundance and a dispersal model in which fidelity is fixed at 95% and dispersers are spread across neighboring watersheds according to an exponential decline with distance (decay parameter = 0.05). This analysis includes the influence of the Columbia and Elk rivers. The solid horizontal line represents the isolation criterion of 95% native spawners. The solid vertical line represents the persistence criterion of 15,000 adult coho at 10% marine survival. The shaded area represents ± 50% of 15,000. The logit transformation is used to linearize proportional data when many of the proportions are near 0 or 1. The horizontal line at 0.95 represents 95% native spawners. The model specified that 5% of spawners stray, so points below this line received a net influx of spawners. The location of this line is determined by the model input. The relative position of points on the y-axis do not change if this value is varied.

Establishing a vertical line to distinguish between persistent and nonpersistent populations was more difficult. As population abundance or their habitat areas (or capacity) gets smaller, the probability of extinction rises. It is, however, harder to quantify that probability than it is to characterize the functional relationship between habitat size and extinction probability. The stochastic life cycle model (Nickelson and Lawson 1998) can be used to produce quantitative extinction probabilities. However, these probabilities are sensitive to many of the model parameters, including patterns of freshwater production, density dependence, straying, and marine survival. As a consequence, we were unwilling to use the absolute extinction probabilities from the model to define the vertical line criterion. We were, however, more comfortable with the qualitative model result; as habitat quantity decreases, extinction probability increases exponentially. We chose as our criterion for persistence the point where the probability of extinction started to increase rapidly (Figure 25). We considered 24 km (≈15 miles) of habitat as the break point. The resulting habitat quantity would be expected to produce 15,000 adult spawners at 10% marine survival, so we set the vertical line in Figure 24 at 15,000 adult spawners on the historical population potential axis. This does not mean that populations to the left of this point would necessarily go extinct in 100 years without input from other populations. It does mean that the probability of such extinctions is high enough so that on an evolutionary time scale of tens to thousands of years, we expect such extinctions to be a normal part of the populations' dynamics and reflected in the genetic population structure.
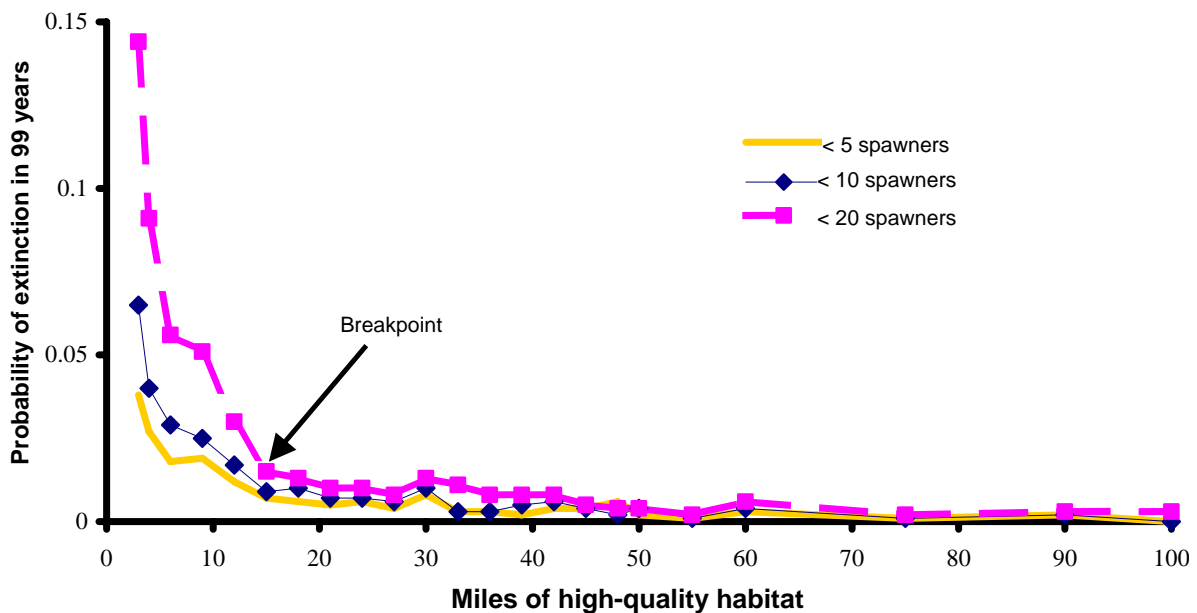
Figure 25. The relationship between the quantity of high-quality habitat (habitat that will support populations of coho salmon when marine survival is 3%) and probability of extinction defined as the number of spawners less than 5, 10, or 20 per mile of high quality habitat (from Nickelson 2001).

We explored the effect of increasing or decreasing this number by 50% (7,500 or 22,500), as represented by the vertical shaded area in Figure 24. If our estimate is low only one population, the Salmon, would be reclassified as dependent. With a high estimate, five of the larger dependent populations (Twomile, Sand, Yachats, Devils Lake, and Sutton [Mercer Lake])

would be reclassified as potentially independent. We wanted to portray a zone of likely scenarios.

Fifteen thousand adult spawners sounds, at first, like a high threshold for persistence. However, the historical population potential was calculated as a maximum, assuming 10% marine survival. In years with 1% marine survival, as we have experienced recently, these populations would have been below 1,500 adults. These estimates assume the best possible production from these populations, a condition that probably occurred only rarely. The smallest populations were probably composed of 10 to 100 spawners during periods of poor ocean conditions.

Using Figure 24, we can assign each population a classification according to our conceptual model. All populations to the left of the vertical line had a relatively low probability of persistence and were classified as dependent. Their long-term existence depended on input from larger neighboring populations. Populations to the right of the vertical line were capable of persistence over longer periods. The populations above the horizontal line were considered functionally independent, with demographics not greatly influenced by neighboring populations. Those persistent populations below the horizontal line were classified potentially independent, capable of sustaining themselves without input from neighboring populations, but with demographics influenced by their larger neighbors. Populations in the upper-left quadrant would be both isolated from other populations and unlikely to persist over a time frame of 100 years. These could be considered ephemeral populations. Such populations would experience periodic extinctions with low probability of recolonization from other populations. None of our historical populations fell into this category. This lends some support to the break points we chose for the horizontal and vertical lines.

In the previous two drafts of this document, we relied on geographical and ecological characteristics of the landscape to establish historical population boundaries. Geographical information was used in calculating the distance between ocean-entry points. Ecological characteristics were utilized in partitioning the Umpqua River Basin into two historical populations. A total of 67 historical populations were originally identified through this process.

As we proceeded with the analyses for recovery criteria, comments from several sources, including the SONCC Workgroup, spurred us to take another look at the reasons for including some of the smallest populations in the dependent populations list. We determined that dependent populations are important to the recovery of the ESU based on their reflection of the robustness of nearby independent populations and also for their potential to provide a place where new alleles can be "fixed." New alleles that confer a selective advantage can then be transferred into larger populations. This is thought to be an important mechanism for long-term ESU viability. The dependent populations in previous drafts of this document are made up of a large size range of basins from those with less than a mile of coho salmon habitat to as much as 18 miles. Some of the very small basins would have abundances that would be at quasi-extinction (50 fish) levels under ocean conditions as great as 3% marine survival. This level of marine survival is one that is often seen over a 100-year time series. We felt that those very small populations would not persist long enough to fix alleles and to provide that function for the ESU. Therefore, we chose a threshold of historical production potential of less than 2,000 smolts as tabulated in Table 5 for exclusion from the designation of dependent population. These are

shown in Table 6. This threshold results in 11 fewer populations than were presented initially. In addition, a reviewer pointed out that Johnson Creek near the Yaquina River has a waterfall into the ocean at its mouth and, therefore, probably never had a coho salmon population. The historical populations total 56 with these new configurations. The final list of populations is shown in Table 7.

Thirty-five (about 65%) of the 56 populations we identified were classified as dependent populations. Altogether they inhabited less than 6% of the coho salmon habitat in the Oregon Coast Salmon ESU. Based on our models, these populations probably would have experienced periodic extinction and recolonization events on a time frame of 10 to 1,000 years. There is a wide range of basin sizes in this category, ranging from Twomile Creek, supporting up to 13,000 adults at 10% marine survival, to Schoolhouse Creek and Rover Creek, estimated to produce only 200 adults under good marine survival. The larger dependent populations are expected to be occupied most of the time, while many of the smaller systems probably do not have spawning coho salmon in most years. Some of the smaller systems we have identified may seldom have supported coho salmon, while there may be other small systems not on our list where coho occasionally spawn.

Figure 26 is a map of proposed populations and Table 7 is the list of populations and their proposed classification. Table 8 allows a comparison between population classification and the distance to the nearest functionally independent population. Thirteen of the 56 populations were classified as functionally independent, including the four in the Umpqua River Basin. An additional eight populations were classified as potentially independent, including the populations in the three large lake basins. The Coos River, which had been classified as potentially independent in early analyses becomes functionally independent if only the Lower Umpqua is utilized in modeling connectivity-viability as exchanging migrants with neighboring basins. Using only the Lower Umpqua River population in the model run was an assumption made to be consistent with the SONCC Workgroup, which utilized this approach for the Rogue, Klamath, and Eel basins. Their reasoning was because of the greater distances to the upper basins on these rivers, the most likely source and receivers of strays would be the lower basins in these systems, and the similarity of the habitat in the lower basin to the habitat in the other smaller coastal basins. This reasoning was therefore also applied to the Umpqua Basin. In addition, Johnson's (2006) analysis has shown a genetic difference between the fish of the upper Umpqua Basin and a genetic affinity of the Lower Umpqua with the nearby lakes populations.

Table 6. Other basins originally included as historical dependent populations (Table 1).

Basin	Basin size		Potential smolts
	Acres	Hectares	
Indian Creek	262	106	100
Canyon Creek	1,127	456	400
Red Rock Creek	149	60	100
Johnson Creek (near Siletz River)	Not accessible		
Austin Creek	203	82	300
Henderson Creek	604	244	1,000
Grant Creek	366	148	400
Moore Creek	554	224	1,000
Little Creek	646	262	1,000
Gwynn Creek	800	324	1,000
Squaw Creek	1,086	439	100
Blowout Creek	290	118	1,000

Table 7. Proposed historical populations, listed north to south, with classification (Appendix C, Bjorkstedt et al. 2005).

Population	Population type	Population	Population type
Necanicum	Potentially independent	Alsea	Functionally independent
Ecola	Dependent	Big (near Alsea)	Dependent
Arch Cape	Dependent	Vingie	Dependent
Short Sands	Dependent	Yachats	Dependent
Nehalem	Functionally independent	Cummins	Dependent
Spring	Dependent	Bob	Dependent
Watseco	Dependent	Tenmile Creek	Dependent
Tillamook Bay	Functionally independent	Rock	Dependent
Netarts	Dependent	Big	Dependent
Rover	Dependent	China	Dependent
Sand	Dependent	Cape	Dependent
Nestucca	Functionally independent	Berry	Dependent
Neskowin	Dependent	Sutton (Mercer Lake)	Dependent
Salmon	Potentially independent	Siuslaw	Functionally independent
Devils Lake	Dependent	Siltcoos	Potentially independent
Siletz	Functionally independent	Tahkenitch	Potentially independent
Schoolhouse	Dependent	Threemile	Dependent
Fogarty	Dependent	Lower Umpqua	Functionally independent
Depoe Bay	Dependent	Middle Umpqua	Functionally independent
Rocky	Dependent	North Umpqua	Functionally independent
Spencer	Dependent	South Umpqua	Functionally independent
Wade	Dependent	Tenmile	Potentially independent
Coal	Dependent	Coos	Functionally independent
Moolack	Dependent	Coquille	Functionally Independent
Big (near Yaquina)	Dependent	Johnson	Dependent
Yaquina	Functionally independent	Twomile	Dependent
Theil	Dependent	Floras/New	Potentially independent
Beaver	Potentially independent	Sixes	Potentially independent

Historical Coho Populations

Oregon Coast Coho Salmon ESU

☐ Functionally Independent
▨ Potentially Independent
■ Dependent

Huntington, C. 2003. Preliminary draft Oregon Coast coho populations. (Unpublished data). Compiled from Kostow 1995.

Kostow, K. 1995. Biennial report on the status of wild fish in Oregon. Oregon Department of Fish and Wildlife. (Available from ODFW, 3406 Cherry Ave. NE, Salem, OR 97303).

Regional Ecosystem Office. 2002. Hydrologic unit boundaries for Oregon, Washington, and California. Version 1.3. Online at http://www.reo.gov/gis/projects/watersheds/reohucv13.zip [accessed 11 July 2003].

Streamnet. 2003. PNW reach file. Online at ftp://ftp.streamnet.org/pnwr/e00/zip/oreghyd.exe [accessed 7 July 2003].

U. S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files: All 50 states, D.C., and Puerto Rico. 2000. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

U. S. Geological Survey. 2003b. Geographic names information system. Online at http://geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Map labels: Astoria, Necanicum, Ecola, Arch Cape, Short Sand, Nehalem, Spring, Watseco, Tillamook Bay, Tillamook, Netarts, Rover, Sand, Nestucca, Neskowin, Salmon, Devils Lake, Lincoln City, Schoolhouse, Fogarty, Depoe, Rocky, Spencer, Wade, Coal, Moolack, Big (near Yaquina), Siletz, Newport, Yaquina, Theil, Beaver, Alsea, Big (near Alsea), Vingie, Yachats, Cummins, Bob, Tenmile Creek, Rock, Big (near Siuslaw), China, Cape, Berry, Sutton (Mercer Lk.), Siuslaw, Florence, Siltcoos, Tahkenitch, Threemile, Reedsport, Lower Umpqua, Tenmile, Middle Umpqua, Coos Bay, Coos, North Umpqua, Johnson, Twomile, Coquille, Floras/New, South Umpqua, Sixes

50 miles / 50 km

Figure 26. Proposed historical coho salmon populations in the Oregon Coast Coho Salmon ESU. Dependent-population basins are identified in Figure 3.

Table 8. Locations of ocean entry and distance to the nearest functionally independent (FI) population ocean entry point for basins along the Oregon Coast.[a]

Basin name	Latitude	Longitude	Population type[b]	Distance (km) from Columbia River	Distance (km) to nearest FI population
Columbia River	46.244	124.057	N/A	0.0	–
Necanicum River	46.012	123.926	PI	27.7	40.7
Ecola Creek	45.899	123.962	D	41.2	27.2
Red Rock Creek	45.845	123.961	D	47.3	21.1
Arch Cape Creek	45.804	123.966	D	51.9	16.5
Short Sands Creek	45.760	123.963	D	56.8	11.6
Nehalem River	45.658	123.933	FI	68.4	0.0
Spring Creek	45.620	123.937	D	72.6	4.2
Watseco Creek	45.589	123.984	D	77.6	9.2
Tillamook Basin	45.488	123.901	FI	90.5	0.0
Netarts Bay	45.403	123.944	D	100.6	9.9
Rover Creek	45.328	123.967	D	109.1	18.6
Sand Creek	45.290	123.937	D	113.9	23.4
Nestucca River	45.184	123.956	FI	125.8	0.0
Neskowin Creek	45.100	123.986	D	135.4	9.6
Salmon River	45.047	124.005	PI	141.5	15.7
Devils Lake	44.968	124.016	D	150.3	7.1
Siletz River	44.904	124.010	FI	157.4	0.0
Schoolhouse Creek	44.873	124.041	D	161.6	4.2
Fogarty Creek	44.839	124.053	D	165.5	8.1
Depoe Bay Creek	44.806	124.058	D	169.2	11.8
Rocky Creek	44.779	124.071	D	172.4	15.0
Spencer Creek	44.729	124.059	D	178.0	13.9
Wade Creek	44.716	124.060	D	179.5	12.4
Coal Creek	44.708	124.061	D	180.4	11.5
Moolack Creek	44.703	124.063	D	180.9	11.0
Big Creek (near Yaquina)	44.659	124.058	D	185.8	6.1
Yaquina River	44.613	124.017	FI	191.9	0.0
Theil Creek	44.565	124.070	D	199.4	7.5
Beaver Creek	44.524	124.075	PI	204.0	11.0
Alsea River	44.423	124.080	FI	215.2	0.0
Big Creek (near Alsea River)	44.371	124.088	D	221.0	5.8

Table 8 continued. Locations of ocean entry and distance to the nearest functionally independent (FI) population ocean entry point for basins along the Oregon Coast.[a]

Basin name	Latitude	Longitude	Population type[b]	Distance (km) from Columbia River	Distance (km) to nearest FI population
Vingie Creek	44.341	124.098	D	224.5	9.3
Yachats River	44.309	124.107	D	228.1	12.9
Cummins Creek	44.266	124.108	D	232.9	17.7
Bob Creek	44.244	124.110	D	235.3	20.1
Tenmile Creek	44.226	124.110	D	237.3	22.1
Rock Creek	44.183	124.114	D	242.1	18.6
Big Creek (near Suislaw)	44.177	124.114	D	242.8	17.9
China Creek	44.169	124.115	D	243.7	17.0
Cape Creek	44.134	124.123	D	247.6	13.1
Berry Creek	44.095	124.122	D	251.9	8.8
Sutton Lake	44.060	124.127	D	255.9	4.8
Siuslaw River	44.017	124.136	FI	260.7	0.0
Siltcoos Lake	43.874	124.153	PI	276.6	15.9
Tahkenitch Lake	43.815	124.165	PI	283.3	16.5
Threemile Creek	43.748	124.180	D	290.8	9.0
Umpqua River	43.669	124.204	FI	299.8	0.0
Tenmile Lakes	43.562	124.231	PI	311.9	12.1
Coos River	43.429	124.229	FI	326.6	37.6
Coquille River	43.124	124.429	FI	364.2	0.0
Johnson Creek	43.093	124.431	D	367.6	3.4
Twomile Creek	43.044	124.441	D	373.1	8.9
Floras Creek/New River	42.913	124.496	PI	388.3	24.1
Sixes River	42.854	124.543	PI	395.9	31.7
Elk River	42.810	124.533	N/A	400.9	–

[a] Columbia and Elk rivers are included to locate the ESU boundary. Tributaries to Tillamook Bay are assumed to harbor a single population.
[b] D = dependent; FI = functionally independent; PI = potentially independent.

Discussion

Our view of the historical population structure of Oregon Coast coho salmon relies upon a simple conceptual model of the spatially dependent demographics of the 56 populations we consider likely to have been present within the ESU. This model classifies populations on the basis of two key characteristics: persistence (their relative abilities to persist in isolation from one another), and isolation (the relative degree to which they might have been influenced by adult fish from other populations straying into their spawning areas). The interaction of these two factors across what we believe to have been the historical populations of Oregon Coast coho salmon gives us a measure of relative independence.

Our model of the interplay between the persistence and isolation of historical coho populations within the Oregon Coast ESU provided us a clear method for classifying the relative independence of individual populations. We classified historical populations into three distinct groups: functionally independent, potentially independent, and dependent. In general, Oregon Coast drainage basins of intermediate to large size (whose coho salmon populations fell to the right of a persistence threshold in Figure 24) are thought to have each supported a coho population capable of persisting indefinitely in isolation, though some of them (seen below a horizontal line representing an isolation threshold in Figure 24) may have been demographically influenced by adult coho straying into spawning areas from elsewhere in the ESU. Those persistent populations with minimal demographic influence from adjacent populations were classified as functionally independent (13 populations), while populations that appeared likely to have been capable of persisting in isolation but were demographically influenced by adjacent populations were classified as potentially independent (8 populations). Small coho salmon populations would have been found in smaller coastal basins (seen falling both to the left of the persistence line and below the isolation line in Figure 24) and may not have been able to maintain themselves continuously for periods as long as hundreds of years without the demographic boost provided by migrating spawners from other populations. For this reason, these populations were classified as dependent.

We believe that the dependent populations relied at times upon the strength of adjacent larger populations for their continuous historical presence in the Oregon Coast's smaller basins. As long as the larger persistent populations within the ESU remained strong, the smaller (dependent) populations would rarely if ever have disappeared from their basins. However, if some form of broad-scale environmental change triggered a substantial decline in one or more of the larger populations, the reduction in migrants would have increased the possibility that the same environmental change, perhaps coupled with local disturbances, would have resulted in the intermittent disappearances of the dependent populations found in some of the smaller basins.

Uncertainties

Despite the simplicity of the conceptual model we used to classify the connectivity-viability of historical coho salmon populations within the Oregon Coast Coho Salmon ESU, it should be emphasized that analytical components of our model are no different from those of other mathematical models of populations or habitat. Our model produces results that we consider a reasonable but uncertain approximation of an imperfectly understood biological phenomenon: the interactions of historical Oregon Coast coho salmon populations.

We are confident in the way our modeling has arrayed 56 historical populations of Oregon Coast coho salmon on the basis of their potential abundance. The abundance levels assigned to the populations reflect what is known about how the species uses its habitat and are consistent with patterns evident in both recent and historical data on coho abundance. However, the specific coho population size we used to define our persistence (threshold) line in Figure 24 was based on results from a simple habitat-based model of coastal coho populations developed by Nickelson and Lawson (1998). That model fits data on the recent performance of Oregon Coast coho salmon populations, but habitat available to these populations has been substantially altered from that which supported historical populations, and is of lower quality (IMST 2002). Historical habitats may have been somewhat more stable and productive than those we can study today, raising the possibility that historical coho populations may have been able to persist on smaller quantities of relatively higher quality habitat than recent data on coho salmon abundance and population performance might suggest. There are also inherent between-basin differences in the stability or aggregate productivity of coho salmon habitat that could affect the persistence of some smaller populations but that were only weakly accounted for when we used absolute coho abundance as a proxy for population persistence. Taking these things into account, we assessed the sensitivity of our population classifications to a 50% reduction in the coho salmon population size used as a persistence threshold and found that only 5 of 35 coho populations otherwise classified as dependent (Twomile, Sand, Devils Lake, Sutton [Mercer Lake], and Yachats) would be reclassified as potentially independent. Similarly, a 50% increase in the persistence threshold would have resulted in only one potentially independent population (Salmon) being reclassified as dependent. Most of our classifications of populations would thus be unaffected by what we might consider as reasonable changes to our persistence threshold.

Another area of uncertainty within our classification model is the dispersal pattern used to simulate migration between coho salmon populations, and thus to distinguish between functionally independent and potentially independent populations in the historical ESU. The pattern that we used assumes an exponential decline in migration rate with increasing distance from the natal basin and does not account for a variety of environmental gradients that may (or may not) affect the relative attractiveness of nonnatal basins to straying coho salmon. A more complex pattern might be more realistic, but we are not aware of any data or studies that would provide us a sufficient basis for structuring such a pattern. This simplification creates uncertainty about the degree to which the results of our model reflect the true isolation of individual coho populations. Sensitivity analyses by Bjorkstedt et al. (2005) have shown that changes in the assumed dispersal pattern of migrant coho salmon tend to have only minor effects on the apparent isolation of the larger coho populations within the historical Oregon Coast Coho

Salmon ESU, but variable effects on the apparent isolation of intermediate-sized to smaller populations. This is a topic worthy of further investigation.

Other Applications of the Connectivity-Viability Model

Our model-based approach to classifying the connectivity-viability (relative independence) of coho salmon populations within the Oregon Coast Coho Salmon ESU may be of interest to other NOAA Fisheries Service TRTs because it provides a structured way to delineate independent salmon populations within geographically linked coastal areas. At present, the general model is being used to help identify historically independent coho salmon populations within two additional ESUs, both along the California coast (Bjorkstedt et al. 2005, Williams et al. 2006). The model may also prove useful in examining recent changes in the interactive demographic behavior of geographically linked salmon populations and establishing a conceptual framework for the development of ESU recovery goals.

In addition to identifying and classifying historical populations of the Oregon Coast Coho Salmon ESU, we have examined the ESU for evidence of genetic and geographic structure. These patterns will be used in developing biological recovery criteria that conserve diversity and avoid loss of critical diversity components of the ESU through catastrophe.

Definition of Biogeographic Strata in the Oregon Coast Coho Salmon ESU

Within the Oregon Coast Coho Salmon ESU, there is substantial genetic and geographic structure, with genetic similarities clustering into a few geographic units. For our analyses, we have designated these clusters as "biogeographic strata" or "strata." These biogeographic strata represent both genetic and geographic similarities, and we assume that preserving sustainable populations in each of them will conserve major genetic diversity in the ESU as well as spread risks to the maintenance of genetic and geographic diversity due to catastrophes. Each of these strata must be secure for the entire ESU to be sustainable. Development of the information needed for the Workgroup to develop the concept of biogeographic strata has occurred over the last two decades. There have been substantial advances, particularly in genetic analysis.

Utilizing allozyme loci, Olin (1984) identified three major genetic groupings within what was subsequently described as the ESU. These groupings are 1) the Nehalem River south to the Coos River (just north of Cape Arago), 2) the Nehalem River south to the Alsea River, and 3) the Siuslaw River south to Morton Creek (just north of Cape Blanco). Geographic coverage of groups 1 and 2 overlapped and also were the most genetically similar (see Figure 27).

Subsequently, Kostow (1995) defined 82 coho salmon populations within the ESU based on geographic similarity, adjacency, and unpublished genetics data.[5] Kostow described three gene conservation groups (GCG) (see Figure 28) that are also based on geographic proximity as well as the somewhat poorly defined genetic structure. At the time of the Kostow work, allozyme analyses in coho salmon was not very revealing of finer scale genetic structure.

After Kostow (1995), ODFW scientists, in the process of defining the Environmental Monitoring and Assessment Program (EMAP) (Stevens and Olsen 2002) sampling stratification for the Oregon Coast Coho Salmon ESU, decided that the North/Midcoast GCG was very large and included areas that were geographically and ecologically different from north to south. They therefore defined north coast and mid-coast monitoring areas in order to be able to have higher resolution due to increased sampling in the North/Mid Coast GCG (see Figure 29). The monitoring areas were defined as following the former ODFW "Fish Districts" with four areas defined. These are north coast, mid-coast, Umpqua River, and mid-south coast monitoring areas.[6]

In the Workgroup deliberations on historical Oregon Coast coho salmon populations, we examined information on ecoregions, hydrology, precipitation, and other ecological and physical differences in the basins that drain directly to the ocean or to Tillamook Bay. In addition, we had a newly completed genetic study (Ford et al. 2004) that showed four genetic clusters within the ESU (Figure 9). The most northerly basins of the ESU were not sampled by Ford due to

---

[5] D. Teel, NWFSC, Manchester Laboratory, Port Orchard, WA. Pers. commun., 8 July 2005.
[6] T. Nickelson, ODFW, Corvallis Research Laboratory, Corvallis, OR. Pers. commun., 7 July 2005.

resource limitations. Three of these clusters correspond well to the mid-coast (Siletz, Alsea, and Yaquina complexes), mid-south coast (Coquille and Coos complexes), and the Umpqua River (Umpqua complex) monitoring areas. What stands out as different from the ODFW monitoring areas is the Lakes Complex, which was originally included in the ODFW mid-south coast monitoring area.

In defining our biogeographical strata, we considered that the four ODFW monitoring areas in the ESU, for the most part, reflected the geography, ecology, and genetics of the landscape. However, the lakes are very different from the other portions of the mid-south coast monitoring area ecologically and geographically, as well as genetically. In order to reflect this diversity and to reduce the risks to genetic and geographical diversity due to catastrophes, we partitioned the Ford et al. (2004) Lakes Complex into a fifth biogeographical stratum for use in defining areas of diversity important in conservation (Figure 30).

Because these units represent both biological diversity (genetic and ecological) and geographic variation, we consider that preserving all of them will accomplish two goals: preserving major genetic and life history variation in the ESU, and spreading risks due to catastrophes. These diversity strata and independent populations are very important to our analysis of persistence and sustainability found in the document describing biological recovery criteria (Wainwright et al. 2006).
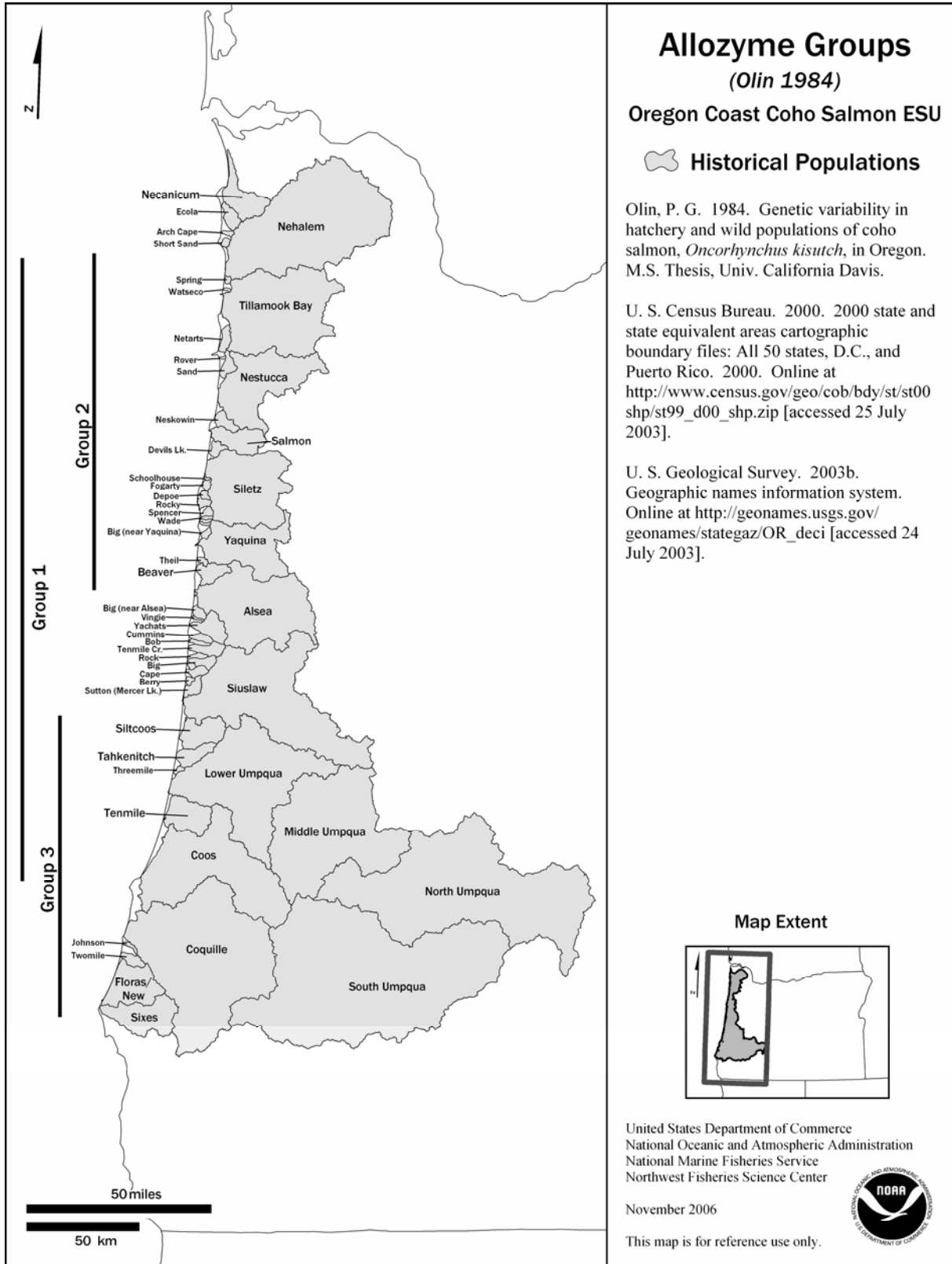
Figure 27. Allozyme clusters discerned in Olin's 1984 report on genetic variability in coho salmon of the Oregon Coast.

Gene Conservation Groups
(Kostow 1995)

Oregon Coast Coho Salmon ESU

- Mid-South Coast
- North/Mid-Coast
- Umpqua River
- Oregon Coast ESU (Weitkamp et al. 1995)

Kostow, K. 1995. Biennial report on the status of wild fish in Oregon. Oregon Department of Fish and Wildlife. (Available from ODFW 3406 Cherry Ave. NE, Salem, OR 97303).

USGS (U.S. Geological Survey). 2003b. Geographic names information system. Online at http://geonames.usgs.gov/ geonames/stategaz/OR_deci [accessed 24 July 2003].

USGS (U.S. Geological Survey). 2003d. Streams and Waterbodies of the United States. Online at http://edcftp.cr.usgs.gov/ pub/data/nationalatlas/hydrogm020.tar.gz [accessed 18 August 2003].

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure 28. Gene conservation groups for Oregon Coast coho salmon as defined in Kostow (1995).
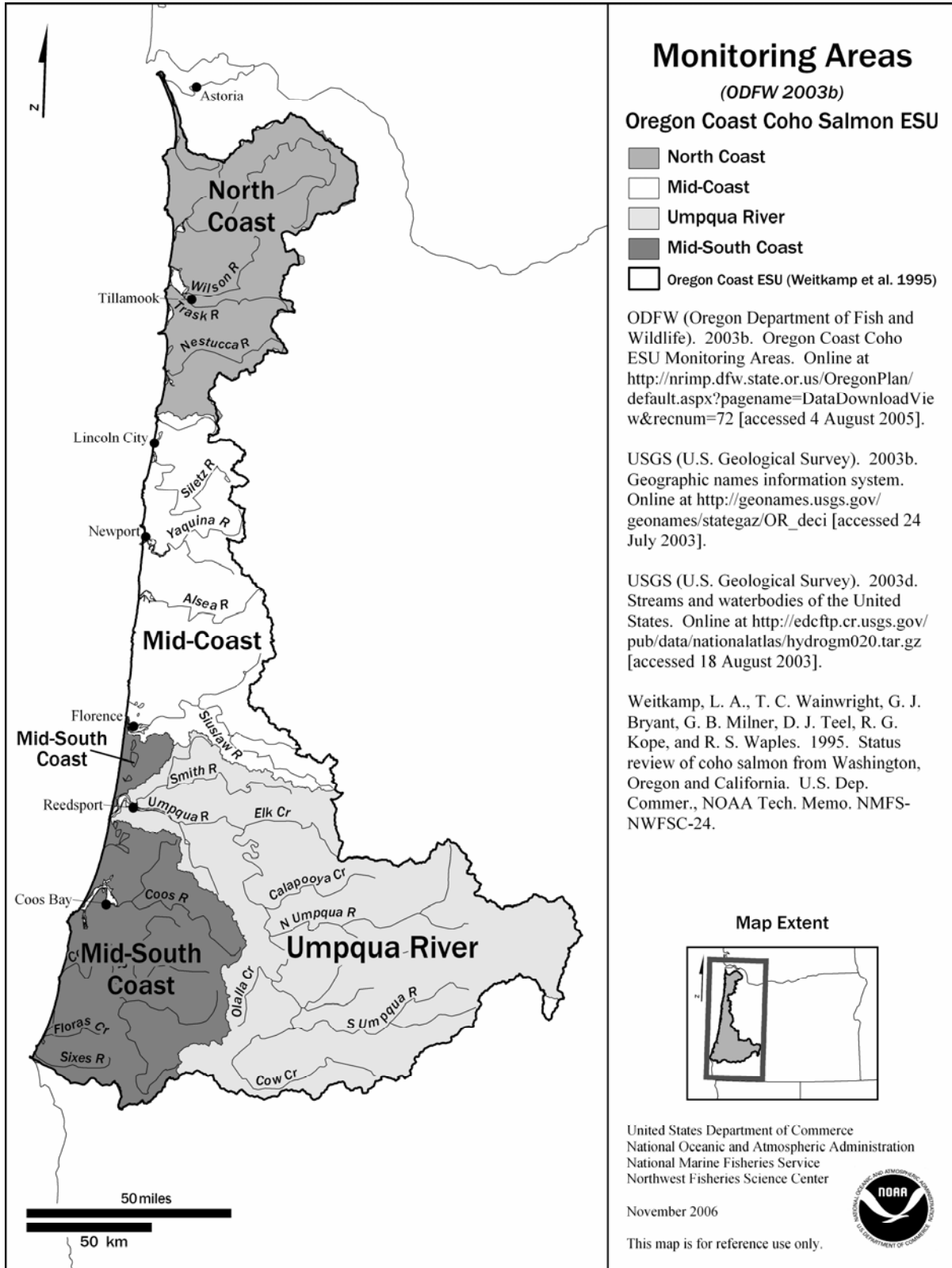
Figure 29. Oregon Coast coho salmon monitoring areas defined by ODFW in 2003.
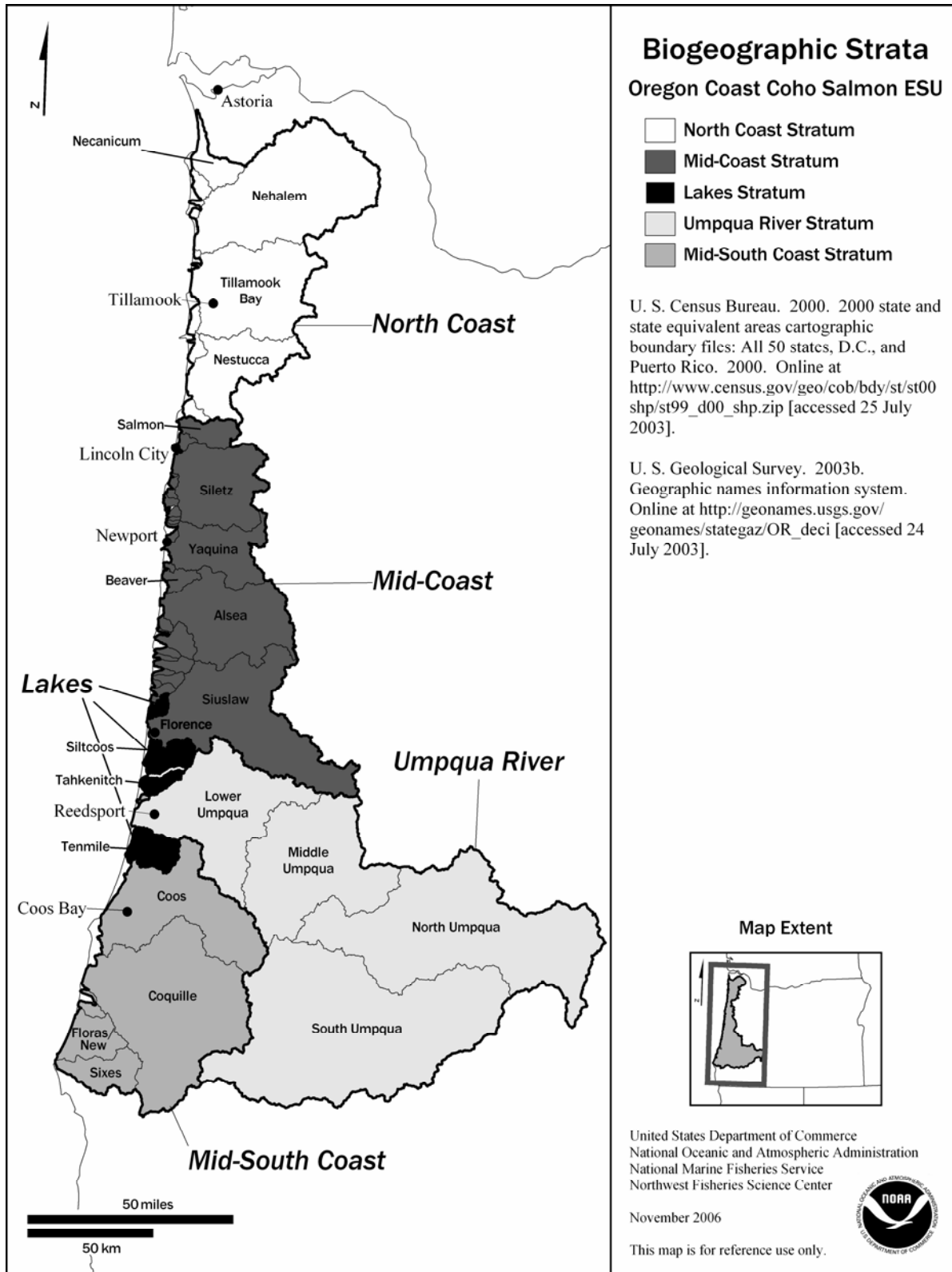
Figure 30. Biogeographic strata defined within the Oregon Coast Coho Salmon ESU. These strata reflect both biological clustering of genetic traits and geographical similarities.

Glossary

Abundance. The number of fish in a *population*.

Active channel width. The distance across a stream or channel as measured from bank to bank at bankful flow.

Allelle. Any one of a number of alternative forms of a gene that can occur at the same location (*locus*) on a chromosome. A *population* can have many alleles for a particular locus, but an individual can carry no more than two alleles at a *diploid* locus.

Allozymes. Alternative forms of an enzyme that have the same function, are produced by different *alleles*, and are often detected by *protein electrophoresis*.

Anthropogenic factor. A circumstance or influence caused or produced by human action.

Artificial propagation. *Hatchery* spawning and rearing of salmon, usually to the *smolt* stage.

AUC (Area Under the Curve). A statistical technique for estimating an annual total number of *spawners* from periodic spawner counts.

Barrier. A blockage such as a waterfall, culvert, or rapid that impedes the movement of fish in a stream system.

Biological Review Team (BRT). The team of scientists who evaluate scientific information for the National Marine Fisheries Service (NMFS) status reviews.

Carrying capacity. The number of individuals that the resources of a habitat can support.

Catastrophic events. Sudden events that disastrously alter large areas of landscape. These can include floods, landslides, forest fires, and volcanic eruptions.

Channel gradient. The slope of a stream reach.

CIMRS (Cooperative Institute for Marine Resources Studies). A cooperative project between Oregon State University and NOAA Fisheries Service.

CLAMS (Coastal Landscape Analysis and Modeling Study). A cooperative project between the Oregon State University Department of Forestry and the U.S. Forest Service Pacific Northwest Forest Science Laboratory.

Coded-wire tag (CWT). A small piece (0.25×0.5 or 1.0 mm) of stainless steel wire that is injected into the snouts of juvenile salmon and steelhead. Each tag is etched with a binary code that identifies its release group.

Comanagers. Federal, state, and tribal agencies that cooperatively manage salmon in the Pacific Northwest.

Delisting. Taking a species off of the endangered species list.

Demographic stochasticity. "Chance events in the survival and reproductive success of a finite number of individuals" (Shaffer 1981).

DEM (Digital Elevation Model). A digital data set representing a topographic map that can be used for computer analysis. We used DEMs to calculate the *intrinsic potential* of stream systems.

Density effects. Survival of juvenile salmon may be influenced by their density. Survival is usually higher when density is low.

Dependent populations. Populations that rely upon immigration from surrounding populations to persist. Without these inputs, dependent populations would have a lower likelihood of *persisting* over 100 years.

Depensation. The effect where a decrease in spawning stock leads to reduced survival or production of eggs through either 1) increased predation per egg given constant predator pressure, or 2) the "Allee effect" (the positive relationship between population density and the reproduction and survival of individuals) with reduced likelihood of finding a mate.

Diploid. Having two complete chromosome pairs in a nucleus.

Distinct population segment (DPS). A *population*, or group of populations of a vertebrate species that is "discrete" from other populations and *significant* to the biological species as a whole.

DNA (deoxyribonucleic acid). A complex molecule that carries an organism's heritable information. The two types of DNA commonly used to examine genetic variation are *mitochondrial DNA* (mtDNA), a circular molecule that is maternally inherited, and *nuclear DNA*, which is organized into a set of chromosomes (see also *allele* and *electrophoresis*).

Donor populations. These are *functionally independent* or *potentially independent populations* that are large enough to "donate" *migrant* adults to *dependent populations*.

Ecoregion. An integration of physical and biological factors such as geologic history, climate, and vegetation.

Effective migration rate. The proportion of successfully spawning adults that migrate to a new *population*. (Excludes *migrants* that do not successfully reproduce.) See also *Migration rate*.

Electrophoresis. The movement of charged particles in an electric field. This process has been developed as an analytical tool to detect genetic variation revealed by charge differences on proteins or molecular weight in DNA.

Endangered species. A species in danger of extinction throughout all or a significant portion of its range.

ESA. U.S. Endangered Species Act.

Escapement. Usually refers to adult fish that "escape" from both fisheries and natural *mortality* to reach the spawning grounds.

Estuarine habitat. Areas available for feeding, rearing, and smolting in tidally influenced lower reaches of rivers. These include marshes, sloughs and other backwater areas, tidal swamps, and tide channels.

Evaporation potential. The maximum depth of water that could evaporate in a year. Evaporation potential is principally determined by temperature and relative humidity. It is a measure of how much moisture "stress" plants are under due to dry conditions.

Evolutionarily Significant Unit (ESU). An ESU represents a *distinct population segment* of Pacific salmon under the *Endangered Species Act* that 1) is substantially reproductively isolated from conspecific populations and 2) represents an important component of the evolutionary legacy of the species. See also *Distinct population segment*.

Exploitation rate. The proportion of adult fish from a *population* that die as a result of fisheries.

Extinction. The loss of a species or ESU. May also be used for the extirpation of local populations.

Factors for decline. These are factors identified that caused a species to decrease in *abundance* and *distribution* and become threatened or endangered.

Fecundity. The number of offspring produced per female.

Fourth-field and fifth-field hydrologic units. In the United States Geological Survey (USGS), hydrologic units have been divided at different scales. The area of a fourth-field hydrologic unit is 440,000 acres and a fifth-field hydrologic unit is between 40,000 and 250,000 acres.

Freshwater habitat. Areas available for spawning, feeding, and rearing in freshwater.

Fry. Young salmon that have emerged from the gravel and no longer have an egg sack.

Functionally independent population. A high-*persistence population* whose dynamics or extinction risk over a 100-year time frame is not substantially altered by exchanges of individuals with other populations (*migration*). Functionally independent populations are net "donor" populations that may provide *migrants* for other types of populations. This category is analogous to the "independent populations" of McElhany et al. (2000).

Genetic distance. A quantitative measure of the genetic difference between a pair of samples, based on *allele* frequencies at multiple loci.

Genetic drift. Random changes in gene frequencies of *populations*.

Gradient. The slope of a stream system.

Habitat quality. The suitability of physical and biological features of an aquatic system to support salmon in the freshwater and estuarine system.

Hatchery. A facility where *artificial propagation* of fish takes place.

Historical abundance. The number of fish that were produced before the influence of European settlement.

Homing fidelity. The propensity of an adult salmon to return to its natal stream.

Hydrology. The distribution and flow of water in an aquatic system.

Independent Multidisciplinary Science Team (IMST). A scientific advisory body to the Oregon legislature and governor on watershed, forestry, agriculture, and fisheries science issues.

Inbreeding depression. Reduced survival rates of individuals in a *population* suffering from the effects of harmful recessive genes through matings between close relatives. Inbreeding depression may become a problem when populations get very small.

Independence. Reflects the interaction between *isolation* and *persistence*. A persistent population that is highly isolated is highly independent.

Intrinsic potential. A modeled attribute of streams that includes the *channel gradient*, *valley constraint*, and *mean annual discharge of water*. Intrinsic potential in this report refers to a measure of potential coho salmon habitat quality (Burnett et al. 2003).

Isolating mechanisms. Things that reduce the ability of *populations* to interbreed. These could include physical mechanisms such as distance and behavioral mechanisms such as *run timing*.

Isolation. The degree to which a *population* is unaffected by *migration* to and from other populations. As the influence of migration decreases, a population's isolation increases.

Jack. A male coho salmon that matures at age 2 and returns from the ocean to spawn a year earlier than normal.

Jacking rate. The proportion of adult coho salmon from a brood that return as *jacks*.

Juvenile. A fish that has not matured sexually.

Latitudinal cline (also known as a latitudinal diversity gradient.) A change in a biological trait that occurs across latitudes. For example, *jacking rate* generally increases from north to south.

Life history. The specific life cycle of a fish from egg to adult.

Limiting factors. Factors that limit survival or *abundance*. They are usually related to habitat quantity or quality at different stages of the life cycle. Harvest and predation may also be limiting factors.

Listed species. Species included on the "List of Endangered and Threatened Species" authorized under the *Endangered Species Act* and maintained by the *U.S. Fish and Wildlife Service* and *NOAA Fisheries Service*.

Littoral zone. In lakes, the area of lake bottom that receives enough light for rooted plants to grow. In the ocean, the marine ecological realm that experiences the effects of tidal and longshore currents and breaking waves to a depth of 5 to 10 m (16 to 33 feet) below the low-tide level, depending on the intensity of storm waves. (Encyclopædia Britannica 2004).

Locus. Location on a chromosome that holds a specific gene. Plural is loci.

Lowland habitat. Low-gradient stream habitat with slow currents, pools, and backwaters used by fish. This habitat is often converted to agricultural or urban use.

Marine survival rate. The proportion of smolts entering the ocean that return as adults.

Mean annual discharge of water. A single value or average that summarizes or represents the annual discharge amount, typically expressed in cubic meters per second.

Metric. A unit of measure.

Microsatellite. A class of repetitive DNA used for estimating genetic distances.

Migrant. A fish that is born in one *population* but returns to another population to spawn.

Migration. Movement of fish from one *population* to another.

Migration rate. The proportion of *spawners* that migrate from one *population* to another. See also *Effective migration rate*.

Mitochondrial DNA (mtDNA). The *DNA* genome contained within mitochondria and encoding a small subset of mitochondrial functions. Only female mtDNA is transmitted to the next generation.

NMFS. National Marine Fisheries Service, also known as NOAA Fisheries Service.

NOAA. National Oceanic and Atmospheric Administration.

NOAA Fisheries Service. NOAA's National Marine Fisheries Service, also known as NMFS.

Nuclear DNA (nDNA). The DNA contained in the chromosomes within the nucleus of eukaryotic cells. The nuclear genome in Pacific salmon is approximately 4.6 billion base pairs in size.

ODFW. Oregon Department of Fish and Wildlife.

ONCC TRT. Oregon and Northern California Coast Technical Recovery Team.

OWEB. Oregon Watershed Enhancement Board.

Parr. The life stage of salmonids that occurs after *fry* and is generally recognizable by dark vertical bars (parr marks) on the sides of the fish.

Persistence in isolation. A *population's* relative ability to sustain itself without input from neighboring populations.

Phylogenetic tree. The genetic distances and relationships among *populations*, frequently represented with a branching or tree-like diagram.

Population. A group of fish of the same species that spawns in a particular locality at a particular season and does not interbreed substantially with fish from any other group.

Population classification. The grouping of *populations* into *functionally independent*, *potentially independent*, and *dependent* classes.

Population dynamics. Changes in the number, age, and sex of individuals in a *population* over time, and the factors that influence those changes. Five components of populations that are the basis of population dynamics are birth, death, sex ratio, age structure, and dispersal.

Population identification. Delineating the boundaries of *historical populations*.

Population structure. This includes measures of age, density, and growth of fish populations.

Potentially independent populations. *High-persistence populations* whose *population dynamics* are substantially influenced by periodic immigration from other populations. In the event of the decline or disappearance of *migrants* from other populations, a potentially independent population could become a *functionally independent* population.

Production. The number of fish produced by a *population* in a year.

Productive capacity. Maximum possible *production* from a given area.

Productivity. The rate at which a *population* is able to produce fish.

Protein electrophoresis. An analytical laboratory technique that measures differences in the amino acid composition of proteins from different individuals. See also *Electrophoresis*.

Recovery. The reestablishment of a threatened or endangered species to a self-sustaining level in its natural ecosystem (in other words, to the point where the protective measures of the ESA are no longer necessary).

Recovery domain. The area and species that the TRT is responsible for.

Recovery plan. A document identifying actions needed to make *populations* of naturally produced fish comprising the Oregon Coast Coho Salmon *ESU* sufficiently *abundant*, *productive*, and diverse so that the ESU as a whole will be self-sustaining and will provide environmental, cultural, and economic benefits. A recovery plan will also include goals and criteria by which to measure the ESU's achievement of recovery, and an estimate of the time and cost required to carry out the actions needed to achieve the plan's goals.

Recovery scenarios. Various sequences of events expected to lead to *recovery* of Oregon Coast coho salmon.

Run timing. The time of year (usually identified by week) when spawning salmon return to the spawning beds.

Salmonids. Any of the species included in salmon, trout, and char.

Sclerophyllous. Describing trees and shrubs that have hard leaves or needles, and a short distance between leaves on the stem. This applies to tan oak, madrone, and chinquapin in mixed evergreen forest zones found in the interior Umpqua River Basin.

Significant. Biological significance refers to an effect that has a noteworthy impact on health or survival.

Smolt. A life stage of salmon that occurs just before the fish leaves freshwater. Smolting is the physiological process that allows salmon to make the transition from freshwater to salt water.

Smolt capacity. The maximum number of smolts a basin can produce. Smolt capacity is related to habitat quantity and quality.

Spawners. Adult fish on the spawning grounds.

Species. Biological definition: A small group of organisms formally recognized by the scientific community as distinct from other groups. Legal definition. Refers to joint policy of the USFWS and NMFS that considers a species as defined by the ESA to include biological species, subspecies, and *DPSs*.

Stock transfer. The practice of moving fish between basins or *populations*.

Stray rate. As used in this document, the stray rate refers to the number of spawning adults that return to a stream other than their natal stream within a basin. See also *Migration rate*.

Sustainability. An attribute of a population that persists over a long period of time and is able to maintain its genetic legacy and long-term adaptive potential for the foreseeable future.

Threatened species. A species not presently in danger of extinction but likely to become so in the foreseeable future.

TRT. Technical Recovery Team.

USFS. United States Forest Service.

USGS. United States Geologic Survey.

Valley constraint. The valley width available for a stream or river to move between valley slopes.

Viability. The likelihood that a *population* will sustain itself over a 100-year time frame.

Viability criteria. A prescription of a *population* conservation program that will lead to the *ESU* having a negligible risk of extinction over a 100-year time frame.

Warm-water fish. Spiny-rayed fish such as sculpins, minnows, darters, bass, walleye, crappie, and bluegill that generally tolerate or thrive in warm water.

References

Barbour, M. G., and J. Major (eds.). 1977. Terrestrial vegetation of California. Wiley, New York.

Bjorkstedt, E. P., B. C. Spence, J. C. Garza, D. G. Hankin, D. Fuller, W. E. Jones, J. J. Smith, and R. Macedo. 2005. An analysis of historical population structure for evolutionarily significant units of Chinook salmon, coho salmon, and steelhead in the North-Central California Coast recovery domain. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-SWFSC-382.

Brodeur, R. D., R. L. Emmett, J. P. Fisher, E. Casillas, D. J. Teel, and T. W. Miller. 2004. Juvenile salmonid distribution, growth, condition, origin, and environmental and species associations in the Northern California Current. Fish. Bull. 102:25–46.

Buckling, A., M. A. Wills, and N. Colgrave. 2003. Adaptation limits diversification of experimental bacteria populations. Science 302:2107–2109.

Buffington, J. M., T. E. Lisle, R. D. Woodsmith, and S. Hilton. 2002. Controls on the size and occurrence of pools in coarse-grained forest rivers. River Res. Appl. 18:507–531.

Burnett, K. M., G. H. Reeves, D. Miller, S. E. Clarke, K. C. Christiansen, and K. Vance-Borland. 2003. A first step toward broad scale identification of freshwater protected areas for Pacific salmon and trout. *In* J. Beumer, A. Grant, and D. C. Smith (eds.), Aquatic protected areas: What works best and how do we know?, Proceedings of the World Congress on Aquatic Protected Areas, Cairns, Australia, August 14–18, 2002, p. 144–154. Australian Society for Fish Biology, University of Queensland, Australia.

Cederholm, J. C., M. D. Kuntz, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial systems. Fisheries 24:6–13.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Am. Fish. Soc. 94(1):40–52.

Chapman, D. W. 1986. Salmon and steelhead abundance in the Columbia River in the nineteenth century. Trans. Am. Fish. Soc. 115:662–670.

Coulton, K., P. Williams, and P. Benner. 1996. An environmental history of the Tillamook Bay Estuary and Watershed. Project Tech. Rep. 09-96, USEPA #CE 99020292-1. Tillamook Bay National Estuary Project, Garibaldi, OR.

Currens, K. P., and D. Farnsworth. 1993. Mitochondrial DNA variation in Oregon coho salmon. Report to Oregon Department of Fish and Wildlife. (Available from Oregon Department of Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

Daly, C., W. Gibson, and G. Taylor. 2000a. 103-year high-resolution temperature climate data set for the conterminous United States. Online at http://www.ocs.orst.edu/prism/products/ matrix.phtml?vartype=tmax&view=data [accessed 30 September 2004].

Daly, C., W. Gibson, and G. Taylor. 2000b. United States monthly and annual mean number of days minimum temperature <= 32f. Online at http://www.climatesource.com [accessed 8 December 2004].

Daly, C., W. Gibson, and G. Taylor. 2002a. 103-year high-resolution precipitation climate data set for the conterminous United States. Online at ftp://ftp.ncdc.noaa.gov/pub/data/prism100 [accessed 8 October 2004].

Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002b. A knowledge-based approach to the statistical mapping of climate. Clim. Res. 22:99–113.

Dennis, B., P. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecol. Monogr. 61(2):115–143.

Drucker, B. 1972. Some life history characteristics of coho salmon of the Karluk River system, Kodiak Island, Alaska. Fish. Bull. 70:79–94.

Eames, M., T. Quinn, K. Reidinger, and D. Haring. 1981. Northern Puget Sound 1976 adult coho and chum tagging studies. Wash. Dept. Fish. Tech. Rep. 64.

Ehrlich, P., and J. Roughgarden. 1987. The Science of Ecology. Macmillan, New York.

ESRI (Environmental Systems Research Institute). 1998. World administrative boundaries. ESRI data and maps, CD #1. (Available from ESRI, 380 New York St., Redlands, CA 92373.)

ESRI (Environmental Systems Research Institute). 2002. ArcGIS. ESRI, Redlands, CA.

Flagg, T. A., F. W. Waknitz, D. J. Maynard, G. B. Milner, and C. V. Mahnken. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. *In* H. Schramm and B. Piper (eds.), Proceedings of the American Fisheries Society Symposium on the uses and effects of cultured fishes in aquatic ecosystems, March 12–17, 1994, Albuquerque, NM. Am. Fish. Soc. Symp. 15:366–375.

Flint, T., and G. Zillges. 1980. Little Bear Creek coho salmon stream life study. Wash. Dept. Fish. Prog. Rep. 124.

Forbes, S., K. Knudsen, and F. Allendorf. 1993. Genetic variation in DNA of coho salmon from the Lower Columbia River. Final Report to the U.S. Dept. Energy, Bonneville Power Administration, Division of Fish and Wildlife, Contract DE-BI79-92BP 30198. (Available from U.S. Department of Energy, Bonneville Power Administration, Public Information Office - ALP-22, PO Box 3621, Portland, OR 97208.)

Ford, M. J., D. Teel, D. M. van Doornik, D. Kuligowski, and P. W. Lawson. 2004. Genetic population structure of central Oregon Coast coho salmon (*Oncorhynchus kisutch*). Conserv. Genet. 5:797–812.

Franklin, J. F., and C. T. Dyrness. 1973. Natural vegetation of Oregon and Washington. USDA Forest Service General Tech. Rep. PNW-8. U.S. Gov. Printing Office, Washington, DC.

Gilbert, C. H. 1912. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus*. Fish Bull. 32:3–22.

Good, J. 2000. Summary and current status of Oregon's estuarine ecosystems. *In* State of the environment report. (Available from Oregon Progress Board, 155 Cottage St. NE, Salem, OR 97301.)

Hanski, I. A., and M. E. Gilpin (eds.). 1997. Metapopulation biology: Ecology, genetics, and evolution. Academic Press, San Diego.

Hartman, G. F., L. B. Holtby, and J. C. Scrivener. 1984. Some effects of natural and logging-related winter stream temperature changes on the early life history of coho salmon (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. *In* W. R. Meehan, T. R. Merrill, Jr., and T. A. Hanley (eds.), Proceedings of a symposium, fish and wildlife relationships in old-growth forests, 12–15 April 1982, Juneau, Alaska, p. 141–149.

Hartt, A. C. 1980. Juvenile salmonids in the oceanic ecosystem—the critical first summer. *In* W. J. McNeil and D. C. Himsworth (eds.), Salmonid ecosystems of the North Pacific, p. 25–57. Oregon State University Press and Oregon State Univ., Sea Grant College Program, Corvallis.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Int. North Pac. Fish. Comm. Bull. 46.

Hickman, J. C. 1993. The Jepson manual: Higher plants of California. University of California Press, Berkeley.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: Choice, dynamics & uncertainty. Chapman and Hall, New York.

Hjort, R. C., and C. B. Schreck. 1982. Phenotypic differences among stocks of hatchery and wild coho salmon, *Oncorhynchus kisutch*, in Oregon, Washington, and California. Fish. Bull. 80:105–11.

Holtby, L. B. 1987. The effects of logging on the coho salmon of Carnation Creek, British Columbia. *In* T. W. Chamberlin (ed.), Proceedings of the workshop: Applying 15 years of Carnation Creek results, January 13–15, 1987, Pacific Biological Station, Nanaimo, British Columbia, p. 159–174. Carnation Creek Steering Committee, British Columbia. (Available from J. C. Scrivener, Pacific Biological Station, Box 100, Nanaimo, BC, Canada V9R 5K6.)

HDP (Hydrosphere Data Products, Inc.). 1993. Hydrodata regional CD-ROMs: U.S. Geological Survey daily values, Vols. West 1, West 2. *In* L. A. Weitkamp, T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples (eds.), Status review of coho salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

IMST (Independent Multidisciplinary Science Team). 2002. Recovery of wild salmonids in Western Oregon lowlands. A report of the Independent Multidisciplinary Science Team, Oregon plan for salmon and watersheds. Tech. Rep. 2002-1 to the Oregon plan for salmon and watersheds, Governor's Natural Resources Office, Salem.

Iwamoto, R. N., B. A. Alexander, and W. K. Hershberger. 1984. Genotypic and environmental effects on the incidence of sexual precocity in coho salmon (*Oncorhynchus kisutch*). Aquaculture 43(1984):105–121.

Johnson, M. In press. Genetic structure, migration and patterns of allelic richness among coho salmon (*Oncorhynchus kisutch*) populations of the Oregon Coast. J. Mol. Biol.

Johnson, O. W., T. A. Flagg, D. J. Maynard, G. B. Milner, and F. W. Waknitz. 1991. Status review for lower Columbia River coho salmon. U.S. Dept. Commer., NOAA Tech. Memo. NMFS F/NWC-202.

Johnson, S. L. 1988. The effects of the 1983 El Niño on Oregon's coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon. Fish. Res. 6:105–123.

Johnson, S. L., M. F. Solazzi, and J. D. Rogers. 1993. Development and evaluation of techniques to rehabilitate Oregon's wild salmonids. Oregon Dept. Fish and Wildlife Research Proj. F-125-R-5, Annual Rep. (Available from Oregon Dept. Fish and Wildlife, PO Box 59, Portland, OR 97207.)

KCM (Kramer, Chin, and Mayo, Inc.). 1983. Devils Lake diagnostic and feasibility study. (Available from Lincoln City Planning Dept., 801 SW Hwy 101, Lincoln City, OR 97367.)

Knight, N. J. 1979. Factors affecting the smolt yield of coho salmon (*Oncorhynchus kisutch*) in three Oregon streams. Master's thesis. Oregon State Univ., Corvallis.

Kostow, K. 1995. Biennial report on the status of wild fish in Oregon. Oregon Department of Fish and Wildlife. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

Labelle, M. 1992. Straying patterns of coho salmon (*Oncorhynchus kisutch*) stocks from southeast Vancouver Island, British Columbia. Can. J. Fish. Aquat. Sci. 49:1843–1855.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. Am. Nat. 142(6):911–927.

Lande, R. 1998. Demographic stochasticity and Allee effect on a scale with isotropic noise. Oikos 83:353–358.

Lawson, P. W., E. A. Logerwell, N. J. Mantua, R. C. Francis, and V. N. Agostini. 2004. Environmental factors influencing freshwater survival and smolt production in two Pacific Northwest coho salmon (*Oncorhynchus kisutch*) populations. Can. J. Fish. Aquat. Sci. 61:360–373.

Lichatowich, J. A. 1989. Habitat alteration and changes in abundance of coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) in Oregon's coastal streams. *In* C. D. Levings, L. B. Holtby, and M. A. Henderson (eds.), Proceedings of the national workshop on effects of habitat alteration on salmonid stocks, p. 92–99. Can. Spec. Publ. Fish. Aquat. Sci. 105.

Loeffel, R. E., and H. O. Wendler. 1968. Review of the Pacific coast Chinook and coho salmon resources with special emphasis on the troll fishery. Prepared by the U.S. Working Group of the Informal Committee on Chinook and Coho. (Available from Oregon Dept. Fish and Wildlife, PO Box 59, Portland, OR 97207.)

Loeffel, R. E., and W. O. Forster. 1970. Determination of movement and identity of stocks of coho salmon in the ocean using the radionuclide Zinc-65. Res. Rep. Fish Comm. Oregon 2(1):1–13.

Mangel, M., and C. Tier. 1994. Four facts every conservation biologist should know about persistence. Ecology 75 (3):607–614.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42.

McGie, A. M. 1970. Research and management studies of Oregon coastal salmon. Annual report, July 1, 1969, to June 30, 1970. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McGie, A. M. 1971. Salmon research on coastal streams and reservoirs. Annual report July 1, 1970 to June 30, 1971. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McGie, A. M. 1972. Salmon research on coastal streams and reservoirs. Annual report, July 1, 1971 to June 30, 1972. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McGie, A. M. 1973. Salmon research on coastal streams and reservoirs. Annual report July 1, 1972 to June 30, 1973. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McGie, A. M. 1975. Research on anadromous fish in coastal watersheds of Oregon. Annual report, July 1, 1974 to June 30, 1975. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McGie, A. M. 1977. Anadromous fish research in Oregon's coastal watersheds. Oregon Fish Commission federal aid progress rep., Fisheries. Fish. Comm. Oregon, Div. Manage. Res., Coastal Rivers Invest. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

McNaughton, S. J., and L. L. Wolf. 1973. General ecology. Holt, Rinehart and Winston, New York.

Meffe, G. K., and R. C. Vrijenhoek. 1988. Conservation genetics in the management of desert fishes. Conserv. Biol. 2:157–169.

Miller, B., and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Trans. Am Fish. Soc. 132:546–559.

Miller, D. R., J. G. Williams, and C. W. Sims. 1983. Distribution, abundance and growth of juvenile salmonids off the coast of Oregon and Washington, summer 1980. Fish. Res. 2:1–17.

Milner, G. B. 1993. Isozyme variation of coho salmon (*Oncorhynchus kisutch*) and its potential to estimate stock compositions of mixed stock fisheries. *In* L. Berg and P. W. Delaney (eds.), Proceedings of the coho workshop, Nanaimo, B.C., May 26–28, 1992, p. 182–192. (Available from Dept. Fisheries and Oceans Canada, Habitat Management Sector, Policy and Information Unit, 327-555 W. Hastings St., Vancouver, BC V6B 5G3.)

Moilanen, A., and M. Nieminen. 2002. Simple connectivity measures in spatial ecology. Ecology 83:1131–1145.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geol. Soc. Am. Bull. 109:596–611.

Morgan, A. R., and K. A. Henry. 1959. The 1955–1956 silver salmon run into the Tenmile Lakes system. Fish Comm. Oregon Res. Briefs 7(1):57–77.

Moring, J. R., and R. L. Lantz. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I—Biological studies. Oregon Dept. Fish and Wildlife, Fish. Res. Rep. 9.

Moritz, C., S. Lavery, and R. Slade. 1995. Using allele frequency and physiology to define units for conservation and management. *In* J. L. Nielsen (ed.), Symposium on evolution and the aquatic ecosystem: Defining unique units in population conservation, Monterey, CA (USA), 23–25 May 1994. Am. Fish. Soc. Symp. 17:249–262.

Mullen, R. E. 1981a. Oregon's commercial harvest of coho salmon *Oncorhynchus kisutch* (Walbaum). Oregon Dept. Fish and Wildlife, Fish Div. Info. Rep. 81-3.

Mullen, R. E. 1981b. Estimates of historical abundance of coho salmon *Oncorhynchus kisutch* (Walbaum), in Oregon coastal streams and in the Oregon Production Index area. Oregon Dept. Fish and Wildlife, Fish Div. Info. Rep. 81-5.

Myers, J., C. Busack, D. Rawding, A. Marshall, D. Teel, D. M. Van Doornik, and M. T. Maher. 2006. Historical population structure of Pacific salmonids in the Willamette River and lower Columbia River basins. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-73.

Natural Resources Canada. 2003. Canadian geographical names—querying Canadian geographical names. Online at http://geonames.nrcan.gc.ca/search/search_e.php [accessed 5 November 2003].

Nicholas, J. W., L. Van Dyke, and R. C. Buckman. 1982. Straying by hatchery-reared coho salmon released in Yaquina Bay, Oregon. Info. Rep. 82-6. Oregon Dept. Fish and Wildlife.

Nickelson, T. E. 2001. Population assessment: Oregon Coast Coho Salmon ESU. Info. Rep. 2001-02. Oregon Dept. Fish and Wildlife.

Nickelson, T. E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Info. Rep. 98-4. Oregon Dept. Fish and Wildlife.

Nickelson, T. E., and P. W. Lawson. 1998. Population viability of coho salmon (*Oncorhynchus kisutch*) in Oregon coastal basins: Application of a habitat-based life history model. Can. J. Fish. Aquat. Sci. 55:2383–2392.

Nielsen, J. L. 1994. Invasive cohorts: Impacts of hatchery-reared coho salmon on the trophic, developmental, and genetic ecology of wild stocks. *In* D. J. Stouder, K. L. Fresh, R. J. Feller (eds.), Theory and application in fish feeding ecology, Vol. 18 of The Belle W. Baruch Library in Marine Science, p. 361–385. University of South Carolina Press, Columbia.

NMFS (National Marine Fisheries Service). 1991. Notice of Policy: Policy on applying the definition of species under the Endangered Species Act to Pacific salmon. Fed. Reg. 56:58612–58616.

NMFS (National Marine Fisheries Service), Quinault Treaty Area Indian Tribes, U.S. Fish and Wildlife Service (USFWS), and Washington State Department of Fisheries (WDF). 1983. Coho salmon spawning escapement goals for North Washington coastal rivers. Final report of a workshop held October 13–14, 1982, in Renton, WA.

NOAA (NOAA Fisheries Service). 1999. Vector digital data (no title given). Online at http://www.nwr.noaa.gov/1esumaps/cohoesu_e00.zip [accessed 2 July 2003].

NOAA (NOAA Fisheries Service). 2003. Transmittal letter from NWFSC to Regional Office.

NOAA (NOAA Fisheries Service). 2004. Oregon Coast coho run timing for 2001. ODFW data. Online at http://www.nwfsc.noaa.gov/trt/orcoast.htm#docs [accessed 30 January 2004].

ODFW (Oregon Department of Fish and Wildlife). 2002a. Natural Resources Information Management Program. Barriers to fish passage. Vector digital data. Online at ftp://rainbow.dfw.state.or.us/pub/gis/other/shape/bar_pts.zip [accessed 29 August 2003].

ODFW (Oregon Department of Fish and Wildlife). 2002b. Natural Resources Information Management Program (2002). ODFW dams coverage. Online at ftp://rainbow.dfw.state.or.us/pub/gis/other/shape/dam_pts.zip [accessed 30 January 2004].

ODFW (Oregon Department of Fish and Wildlife). 2003a. Distribution of Oregon anadromous salmon and steelhead habitat: Coho salmon. Eleventh edition. Online at ftp://rainbow.dfw.state.or.us/pub/gis/k100/shape/coho/coho_v11.zip [accessed 16 July 2003].

ODFW (Oregon Department of Fish and Wildlife). 2003b. Lake system tributary spawning run for 2001. Online at http://oregonstate.edu/dept/odfw/coastal_salmonid_inventories/coho_abundance/estimates_for_coho_lake_basins [accessed 15 September 2003].

ODFW (Oregon Department of Fish and Wildlife). 2003c. Oregon Coast Coho ESU monitoring areas. Online at http://nrimp.dfw.state.or.us/OregonPlan/default.aspx?pagename=DataDownloadView&recnum=72 [accessed 4 August 2005].

ODFW (Oregon Department of Fish and Wildlife). 2003d. Potential historical abundance. ODFW research Web site. Online at http://oregonstate.edu/dept/odfw/coastal_salmonid_inventories/coho_abundance/estimates_for_coho_lake_basins [accessed 10 September 2003].

Olin, P. G. 1984. Genetic variability in hatchery and wild populations of coho salmon, *Oncorhynchus kisutch*, in Oregon. Master's thesis. Univ. California, Davis.

ONHP (Oregon Natural Heritage Program). 2001. ORNHP/ODFW ecoregions of Oregon. Vector digital data. Oregon Geospatial Data Clearinghouse. Online at http://www.sscgis.state.or.us/data/shapefile/k250/ecoregion.zip [accessed 31 July 2003].

ONHP (Oregon Natural Heritage Program). 2003. Oregon natural heritage plan. (Available from Oregon Department of State Lands, 775 Summer St. NE, Suite 100, Salem, OR 97301.)

Oregon Climate Service. 2000a. United States Average Annual Precipitation, 1961–1990. NRCS (Natural Resources Conservation Service). Online at ftp://ftp.ftw.nrcs.usda.gov/pub/ams/ prism/data/states/or/or_shp.zip [accessed 1 August 2003].

Oregon Climate Service. 2000b. 103-year high-resolution precipitation climate data set for the conterminous United States. Online at ftp://ftp.ftw.nrcs.usda.gov/pub/ams/prism/data/ natl_atlas/prism_shp.zip [accessed 1 August 2003].

Orr, E. L., and W. N. Orr. 2000. Geology of Oregon. Kendall/Hunt, Dubuque, Iowa.

OWEB (Oregon Watershed Enhancement Board). 1999. Oregon watershed enhancement manual. Salem, OR. Online at http://www.oregon.gov/ OWEB/docs/pubs/ws_assess_manual.shtml [accessed 1 August 2003].

Pearcy, W. G. 1992. Ocean ecology of North Pacific salmonids. University of Washington Press, Seattle.

Pearcy, W. G., and J. P. Fisher. 1988. Migrations of coho salmon, *Oncorhynchus kisutch*, during their first summer in the ocean. Fish. Bull. 86(2):173–186.

Pritchard, A. L. 1940. Studies on the age of the coho salmon (*Oncorhynchus kisutch*) and the spring salmon (*Oncorhynchus tshawytscha*) in British Columbia. Trans. R. Soc. Can., Serve. 3, 34(V):99–120.

Proctor, C. M., J. C. Garcia, D. V. Galvin, G. C. Lewis, L. C. Lower, and A. M. Mass. 1980. An ecological characterization of the Pacific Northwest coastal region. FWS/OBS-79/11 through 79/15, 5 vol. U.S. Fish and Wildlife Service, Biological Services Program.

R Development Core Team. 2003. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reeves, G. H., L. E. Benda, K. M. Burnett, P. A. Bisson, and J. R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Am. Fish. Soc. Symp. 17:334–349.

Regional Ecosystem Office. 2002. Hydrologic Unit Boundaries for Oregon, Washington, and California: Version 1.3. Vector digital data. Regional Ecosystem Office. Online at http:// www.reo.gov/gis/ projects/watersheds/reohucv13.zip [accessed 11 July 2003].

Reimers, P. E. 1971. The movement of yearling coho salmon through Sixes River estuary. Fish Comm. Oregon, Coastal rivers investigation. Info. Rep. 71-2. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

Reimers, P., R. Bender, J. Muck, T. Rumreich, R. Smith, and M. Manion. 1993. Fish management review, Southwest region, Tenmile, Coos, Coquille District, February 9–10, 1993, p. 1–6. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

Ricker, W. E. 1972. Hereditary and environmental factors affecting certain salmonid populations. *In* R. C. Simon and P. A. Larkin (eds.), The Stock Concept in Pacific Salmon, p. 19–160. MacMillan Lectures on Fisheries. Univ. British Columbia, Vancouver, BC.

Rieman, B. E., and J. B. Dunham. 2000. Metapopulations and salmonids: A synthesis of life history patterns and empirical observations. Ecol. Freshw. Fish. 9(1-2):51–64.

Rodgers, J. D., R. D. Ewing, and J. D. Hall. 1987. Physiological changes during seaward migration of wild juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 44(2):452–457.

Rodgers, J. D., S. L. Johnson, T. E. Nickelson, and M. F. Solazzi. 1993. The seasonal use of natural and constructed habitat by juvenile coho salmon (*Oncorhynchus kisutch*) and preliminary results from two habitat improvement projects on smolt production in Oregon coastal streams. *In* L. Berg and P. W. Delaney (eds.), Proceedings of the Coho Workshop, Nanaimo, B. C., May 26–28, 1992, p. 344–351. (Available from Department of Fisheries and Oceans Canada, Habitat Management Sector, Policy and Information Unit, 327-555 W. Hastings St., Vancouver, BC V6B 5G3.)

Roper, B. 1994. U.S. Forest Service, Tiller Ranger District, letter to L. Weitkamp, NWFSC, 28 May 1994. Enclosed information reflects current understanding of juvenile coho salmon within the upper south Umpqua Basin, OR.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169–199.

Rosgen. D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO.

Ruckelshaus, M. H., K. P. Currens, W. H. Graeber, R. R. Fuerstenberg, K. Rawson, N. J. Sands, and J. B. Scott. 2006. Independent populations of Chinook salmon in Puget Sound. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-78.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In* C. Groot and L. Margolis (eds.), Pacific salmon life histories, p. 396–445. University of British Columbia Press, Vancouver.

Sedell, J. R., and W. S. Duvall. 1985. Influence of forest and rangeland management on anadromous fish habitat in Western North America. Water transportation and storage of logs. Gen. Tech. Rep. PNW-186. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Shaffer, M. L. 1981. Minimum population sizes for species conservation. Bioscience 31:131–134.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (S*almo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dept. Fish Game, Fish Bull. 98.

Signell, R. 2003. NGDC/WDC MGG, Boulder-Coastline Extractor. Vector digital data. National Oceanic and Atmospheric Administration. Online at http://rimmer.ngdc.noaa.gov/coast/ [accessed 24 November 2003].

Silverstein, J. T., and W. K. Hershberger. 1992. Precocious maturation in coho salmon (*Oncorhynchus kisutch*): Estimation of the additive genetic variance. J. Hered. 83:282–286.

Skeesick, D. G. 1970. The fall immigration of juvenile coho salmon into a small tributary. Fish Comm. Oregon Res. Rep. 2(1):1–6.

Solazzi, M. F. 1986. Electrophoretic stock characterization of coho salmon populations in Oregon and Washington, and coastal Chinook salmon populations in Oregon. Oregon Dept. Fish and Wildlife Info. Rep. 86-5.

Solazzi, M. F., S. L. Johnson, B. Miller, T. Dalton, K. A. Leader. 2003. Salmonid life-cycle monitoring project 2002. Monitoring program Rep. No. OPSW-ODFW-2003-2. Oregon Dept. Fish and Wildlife, Portland, OR.

Soulé, M. E. (ed.). 1987. Viable populations for conservation. Cambridge University Press, Cambridge.

Stevens, D. L., Jr., and A. R. Olsen. 2002. Variance estimation for spatially balanced samples of environmental resources. Environmetrics 14(5):593–610.

Steward, C. R., and T. C. Bjornn. 1990. Supplementation of salmon and steelhead stocks with hatchery fish: A synthesis of published literature. U.S. Dept. Energy, Bonneville Power Administration, Tech. Rep. 90-1. (Available from U.S. Dept. Energy, Bonneville Power Administration, Fish and Wildlife, PO Box 3621, Portland, OR 97208.)

Stillwater Sciences Inc. 1998. North Umpqua Cooperative watershed analysis: Synthesis report volume 2. PacifiCorp, 1998. Online at http://www.pacificorp.com/File/File986.pdf [accessed 9 January 2004].

Streamnet. 2003. PNW reach file. Online at ftp://ftp.streamnet.org/ pnwr/e00/zip/oreghyd.exe [accessed 7 July 2003].

Sumner, F. H. 1953. Migrations of salmonids in Sand Creek, Oregon. Trans. Am. Fish. Soc. 82:139–149.

Terrel, T. T. 1979. Physical regionalization of coastal ecosystems of the United States and its territories. FWS/OBS-78/80. U.S. Fish and Wildlife Service, Biological Services Program.

U.S. Census Bureau. 2000. 2000 state and state equivalent areas cartographic boundary files. Vector digital data. Online at http://www.census.gov/geo/cob/bdy/st/st00shp/st99_d00_shp.zip [accessed 25 July 2003].

USDI Bureau of Land Management. 1998. (10 meter) digital elevation model collection Oregon (merged into 1 degree buffered blocks). Online at http://www.or.blm.gov/gis/resources/dataset.asp?cid= 102 [accessed 8 October 2002].

USGS (U. S. Geological Survey). 1995. Major lithology. Online at http://www.icbemp.gov/spatial/min/ [accessed 5 October 2004].

USGS (U.S. Geological Survey). 2003a. Geographic names information system. Online at http:// geonames.usgs.gov/geonames/stategaz/CA_deci [accessed 5 November 2003].

USGS (U.S. Geological Survey). 2003b. Geographic names information system. Online at http:// geonames.usgs.gov/geonames/stategaz/OR_deci [accessed 24 July 2003].

USGS (U.S. Geological Survey). 2003c. Geographic names information system. Online at http:// geonames.usgs.gov/geonames/stategaz/WA_deci [accessed 5 November 2003].

USGS (U.S. Geological Survey). 2003d. Streams and waterbodies of the United States. Online at http://edcftp.cr.usgs.gov/pub/data/nationalatlas/hydrogm020.tar.gz [accessed 18 August 2003].

USGS (U. S. Geological Survey). 2004. Monthly streamflow statistics for Oregon. Online at http://nwis.waterdata.usgs.gov/or/nwis/monthly [accessed 7 December 2004].

Uremovich, B. 1977. Straying of fall Chinook salmon from Elk River Hatchery into Sixes River, 1970–1976. Oregon Dept. Fish and Wildlife, Research Section, Corvallis, OR.

Ursitti, V. L. 1989. Residualism of juvenile coho salmon in Eel Lake, Oregon. Info. Rep. 89-9. Oregon Dept. Fish and Wildlife.

Wainwright, T. C., M. W. Chilcote, P. W. Lawson, T. Nickelson, C. W. Huntington, J. S. Mills, K. M. S. Moore, G. H. Reeves, H. A. Stout, and L. A. Weitkamp. 2006. Biological recovery criteria for the Oregon Coast coho salmon evolutionarily significant unit. Draft Report, January 2006. (Available from T. C. Wainwright, NWFSC, Fish Ecology Division, Newport Research Station, Newport, OR.)

Waples, R. S. 1990. Conservation genetics of salmon. Vol. II. Effective population size and rate of loss of genetic diversity. J. Hered. 81:267–276.

Waples, R. S. 1991a. Definition of "species" under the Endangered Species Act: Application to Pacific salmon. U.S. Dept. Commer., NOAA Tech. Memo., NMFS-F/NWC-194.

Waples, R. S. 1991b. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. U.S. Natl. Mar. Fish. Serv. Mar. Fish. Rev. 53(3):11–22.

Waples, R. S. 1995. Evolutionarily Significant Units and the conservation of biological diversity under the Endangered Species Act. Am. Fish. Soc. Symp. 17:8–27.

Waples, R. S., and D. J. Teel. 1990. Conservation genetics of Pacific salmon. Vol. I. Temporal changes in allele frequency. Conserv. Biol. 4:144–156.

WDF (Washington Department of Fisheries), WDW (Washington Department of Wildlife), and WWTIT (Western Washington Treaty Indian Tribes). 1993. 1992 Washington State salmon and steelhead stock inventory (SASSI). Wash. Dept. Fish and Wildlife, Olympia: Appendix I–Hood Canal and Strait of Juan de Fuca (December 1994), North Puget Sound (June 1994), and South Puget Sound (September 1994) volumes; Appendix II–Coastal stocks (August 1994); and Appendix III–Columbia River stocks (June 1993). (Available from Washington Dept. Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501.)

WDNR (Washington Department of Natural Resources). 2003. Willapa Hills. Online at http://www.dnr.wa.gov/geology/willapa.htm [accessed on September 2004].

Weeks, H. 1994. Oregon Dept. Fish and Wildlife, Portland, letter to L. Weitkamp, NWFSC, 4 May 1994. Information on Oregon coho salmon life history characteristics.

Weidemann, A. M. 1984. The ecology of Pacific Northwest coastal sand dunes: A community profile. FWS/OBS-84/04. U.S. Fish and Wildlife Service.

Weitkamp, L. A. 2004. Ocean conditions, marine survival, and performance of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in southeast Alaska. Doctoral dissertation. Univ. Washington, Seattle.

Weitkamp, L., and K. Neely. 2002. Coho salmon (*Oncorhynchus kisutch*) ocean migration patterns: Insight from marine coded-wire tag recoveries. Can. J. Fish. Aquat. Sci. 59:1100–1115.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-24.

Welch, D. W., J. F. T. Morris, M. E. Thiess, M. Trudel, A. R. Ladoucer, M. C. Jacobs, T. B. Zubkowski, and H. R. MacLean. 2004. CCGS W.E. Ricker Gulf of Alaska salmon survey, October 8–27, 2003. Canadian Data Report of Fisheries and Aquatic Sciences 1145.

Williams, T. H., E. P. Bjorkstedt, W. Duffy, D. Hillemeier, G. Kautsky, T. Lisle, M. McCain, M. Rode, R. G. Szerlong, R. Schick, M. N. Goslin, and A. Agrawal. 2006. Historical population structure of coho salmon in the Southern Oregon/Northern California coasts evolutionarily significant unit. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-SWFSC-390.

Zhou, S. 2000. Stock assessment and optimal escapement of coho salmon in three Oregon coastal lakes. ODFW Fish Division. (Available from Oregon Dept. Fish and Wildlife, 3406 Cherry Ave. NE, Salem, OR 97303.)

Appendix A: Vegetation

Because of the specific requirements of different plant communities, dominant vegetation types are a valuable indicator of relative precipitation, temperature, soil type, solar radiation, and altitude. Therefore, changes of vegetation types can indicate changes in the physical environment, which may affect freshwater salmon habitat. The following discussion of vegetation was compiled from studies by Franklin and Dyrness (1973), Barbour and Major (1977), and Hickman (1993).

Sitka Spruce Zone—Coastal regions in Oregon are forested with a Sitka spruce-dominated plant community: Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), red alder (*Alnus rubra*), and Douglas fir (*Pseudotsuga menziesii*) are major species that occur there. This vegetation type is restricted to coastal regions and river valleys and only on the coastal plains does it extend farther than a few kilometers inland. The Sitka Spruce Zone reaches elevations above 150 m (490 feet) only in areas immediately adjacent to the ocean. However, where mountains are adjacent to the coast, the zone may extend to 600 m (1,970 feet). This vegetation type only occupies areas with a uniformly wet and mild climate. Sitka spruce forests could be considered a variant of western hemlock forests of higher elevations and inland areas, but they are distinguished by frequent summer fogs and proximity to the ocean (Franklin and Dyrness 1973).

Western Hemlock Zone—Along the Oregon Coast, the western hemlock-dominated plant community replaces Sitka spruce at elevations above 150 m (490 feet). This zone includes western hemlock, Douglas fir, red alder, and western red cedar as major tree species. South of the Columbia River, the Western Hemlock Zone extends southward along the Coast Range to the Klamath Mountains and southward along the Cascade Mountains to the Umpqua River.

Alpine and Subalpine zones—The headwaters of rivers draining higher mountains, such as the Cascade Mountains and Oregon Coast ranges, begin in alpine meadows and subalpine parklands, before they change to western hemlock-dominated forests below 700–1,000 m (2,300–3,280 feet). The higher alpine regions appear as a mosaic of meadows and tree patches with long-lasting and deep snow cover. The Subalpine Zone is dominated by mountain hemlock (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa* var. *lasiocarpa*) and is wetter and colder than areas at lower elevations, but has less extended snow cover than the higher alpine areas. With the exception of some of the higher peaks in the Coast Range, the majority of this zone is found in the drainage of the North Umpqua River.

Umpqua Valley—The interior Umpqua River Valley area is a complex of many different vegetation types. These include coniferous tree associations including Douglas fir, Ponderosa pine (*Pinus ponderosa*) and incense-cedar (*Calocedrus decurrens*), oak forest stands, woodlands and savannas with Oregon oak (*Quercus garryana)*, California black oak (*Quercus kelloggii*) and madrone (*Arbutus menziesii*), grasslands with Kentucky bluegrass (*Poa pratensis*), orchard grass (*Dactylis glomerata*), and Idaho bent (*Agrostis Idahoensis*), sclerophyllus hillside communities

dominated by Douglas fir, tan oak (*Lithocarpus densiflora*), canyon live oak (*Quercus chrysolepis*), madrone, chinquapin (*Chrysolepis chrysophylla*), and riparian communities with black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), many willow species (*Salix rigida*, *S. lasiandra*, *S. fluviatilis*, and *S. sessilifolia*), Oregon oak, and California laurel (*Umbellularia california*).

Mixed Conifer and Evergreen Forest zones—The Klamath Mountain Province (ONHP 2003) extends into the Umpqua River Basin in the region of the south Umpqua River and mainstem Umpqua River. This section of the province is the northern Siskiyou Mountains. In the western Siskiyou Mountains, the dominant vegetation is a mixed forest of evergreen-needle-leaved trees and broad-leaved evergreen sclerophyllous trees. Dominants in these mixed evergreen forests are Douglas fir, tan oak, madrone, and chinquapin. These species are more allied with forests found to the south than those in the more mesic coastal areas.

Appendix B: Ecoregions of the Oregon Coast Coho Salmon ESU from South of the Columbia River to Cape Blanco

Level 3 ecoregions are shown in Figure 16; level 4 ecoregions are shown in Figure 17. These descriptions are compiled from OWEB (1999) and ONHP (2003).

Level 3 Ecoregion Descriptions

Klamath Mountain Ecoregion—The Klamath Mountain Ecoregion within the Oregon Coast Coho Salmon ESU is found in the interior Umpqua River Basin, encompassing systems such as Cow Creek, south Umpqua River, and a portion of the north Umpqua River. This area is the most northerly of a system of mountains that extend into northwestern California (the Siskiyou Mountains). These are the oldest landscapes in Oregon, due to their origin as ocean crust or island archipelago environments that were carried eastward on a tectonic plate that collided with the continent of North America. These terranes (exotic pieces of landscapes) were then welded to the continent by granitic intrusives (Orr and Orr 2000). This area is a very diverse geological landscape, which includes serpentine, limestone, and gabbro, as well as granite and basalt. The Umpqua portion of the Klamath Mountains Ecoregion is less rugged than others found in the Rogue Basin just to the south. This portion of the ecoregion tends to receive less precipitation than the more coastal portions of the Klamath Mountains and summer high temperatures can average more than 32ºC (90ºF). Vegetation is diverse in this area and is described in the level 4 ecoregion descriptions for the Siskiyou foothills, Umpqua interior foothills, and coastal Siskiyous.

Oregon Coast Range Ecoregion—The entire coast of Oregon is included within the Oregon Coast Range Ecoregion, and extends eastward to include the northern and central Oregon Coast Range Mountains. Geology is a mix of sedimentary sandstones, siltstones, and mudstones, with areas of volcanic activity. Elevations range from sea level to 1,200 m (4,000 feet). The marine climate moderates temperatures, which average 10ºC (50ºF). Average annual rainfall may vary from 152 to 460 cm (60 to 180 inches) per year. The soils in this region are generally deep and mature and vegetation is dominated by giant Sitka spruce, Douglas fir, and western hemlock forests. In the southern end of the range, Coast redwood, Port Orford cedar, red alder, and tan oak also become codominants.

West Cascade Ecoregion—The West Cascades Ecoregion within the Oregon Coast Coho Salmon ESU is found in the Umpqua River Basin, specifically in the north Umpqua River and south Umpqua River drainages. Geology is closely related to volcanic activity of the Cascade Crest. The ecoregion is dominated by Douglas fir/western hemlock forests to about 1,000 m (3,300 feet). Above that, silver fir/mountain hemlock forests dominate. Very little of the area within the Oregon Coast Coho Salmon ESU is alpine area. This drier portion of the West

Cascades Ecoregion is subject to lightning-caused fire regimes similar to the Klamath Mountains. Snows are not as heavy as in the northern portion of the West Cascades Ecoregion in Oregon.

Level 4 Ecoregion Descriptions

Descriptions below refer to areas mapped in Figure 17.

Coastal Lowlands, elevations sea level to 90 m (300 feet)—Estuaries within the Oregon Coast Coho Salmon ESU are all drowned river mouths (Good 2000). They are mainly of three types: well-flushed drowned rivers, seasonally open to the ocean (such as Sixes River, Flores Creek/ New River); well-flushed drowned rivers, predominantly freshwater input (e.g., Coquille River, Umpqua River, Siuslaw River); and well-flushed drowned rivers with predominantly oceanic input (such as Coos River, Sand Creek, Yaquina River, Nestucca River). Many of these areas historically had relatively large areas of salt, brackish, and freshwater marshes; sloughs; and swamps. Most, however, have suffered losses of these areas of up to 80% of these tidally influenced systems through diking and channelization.

Sand dune sheets are part of the Pacific Northwest Coastal Region (Terrel 1979, Proctor et al. 1980) between the Strait of Juan de Fuca in Washington State and Cape Mendocino in California. Two hundred and twenty-five km of the Oregon Coast is covered by these dune systems. Some are found as isolated areas associated with bays and river mouths between headlands (such as Netarts Bay). Others are extensive dune sheets found on broad terraces (such as Coos Bay Dune Sheet and Sand Lake). These broad terraces may have extensive dune systems and may also harbor extensive freshwater lakes, bogs, fens, and blackwater streams (Wiedemann 1984, ONHP 2003).

Coastal Uplands, elevations to about 150 m (≈500 feet)—This ecoregion is characterized by uplifted marine consolidated and semiconsolidated sediments. These include sandstones and siltstones. Also included are some volcanics.

Volcanics—Volcanic geology is found at elevations from 300 to 1,200 m (1,000 to 4,000 feet). These volcanics are of various origins: the Columbia River basalts, the Siletz River, and the Yachats series of basalts. Some of the mountains found in this ecoregion may have been offshore seamounts buried by continental sediments (KCM 1983, ONHP 2003).

Willapa Hills—These low-lying hills are a continuation of a larger area north of the Columbia River (WDNR 2003). These are in the Western Hemlock Zone.

Mid-Coastal Sedimentary—The Mid-Coastal Sedimentary Ecoregion is underlain by siltstone and sandstone. The mountains are more rugged (dissected and higher) than the Willapa Hills. These sedimentary mountains are very prone to landslides if devegetated. Stream gradients and fluvial erosion rates can be high in these rugged areas, but are lower in the higher order streams that occupy the lowlands. Many of these areas have deep soils, and most are in the Western Hemlock Zone (ONHP 2003).

Southern Oregon Coastal Mountains—These are mountainous areas in the south portion of the Oregon Coast Coho Salmon ESU with ocean-modified climate. They are transitional between the Siskiyou and Coast ranges. These areas are underlain by Jurassic sandstone, metmorphosed sediments, granite, and serpentine (metamorphosed ocean sediments). Soils are dependent upon parent material. This is a complex much like the inland Siskiyous, but the ruggedness is less and elevations are lower. This is an area of very high plant diversity. The northern distribution limits of southern plant and animal species and southern limit of northern plant species are one reason for the diversity. Also the area's unusual geology and stable climate have lead to the evolution of local endemic plants. The Mixed Conifer and Evergreen zones are found in this subregion (Barbour and Major 1977, Orr and Orr 2000, ONHP 2003).

Inland Siskiyous—This area encompasses the Umpqua and Rogue River valleys and is very complex vegetationally. These vegetation types include Douglas fir forests, oak woodlands and savanna, mixed evergreen forest, mixed conifer forests, and Ponderosa pine woodlands. Grasslands and chaparral are found in the valley bottoms. Geology is complex with large areas of metamorphosed rocks such as serpentine and gabbro, sedimentary rocks such as limestone, as well as granite and basalt. Floristic elements of the Sierra Nevada Mountains, Sacramento Valley, Cascade Mountains, and Great Basin are all found in this ecoregion and contribute to the high plant diversity found here. Because of its unusual geology, and stable climate, it is also a major locality of vascular plant species evolution as well. Conifers are especially diverse in the Oregon section of the inland Siskiyou subregion with 18 species. This area has major climatic extremes ranging from 254 cm (100 inches) of precipitation per year to 50 cm (20 inches) (Barbour and Major 1977, Orr and Orr 2000, ONHP 2003).

Valley Foothills—This subregion is an extension of the Willamette Valley on the west side, and is transitional between the Cascade Mountains and the Coast Range. This area has lower rainfall than adjacent mountainous subregions due to a rainshadow effect. Oregon white oak and Douglas fir are potentially dominant in this area, but agricultural conversion has substantially reduced the native forests (ONHP 2003).

Umpqua Interior Foothills—This is an area of narrow interior valleys, terraces, and foothills with elevations from about 120 to 460 m (400 to 1,500 feet). Vegetation is a mix of Oregon white oak woodlands and coniferous forests with pastureland, vineyards, row crops, and orchards replacing the native vegetation. Other dominant tree species found are Douglas fir, Ponderosa pine, and madrone (ONHP 2003).

Umpqua Cascades—This portion of the Cascades is drier than the western Cascades. Grand fir, white fir, western hemlock, Pacific silver fir, Douglas fir, and Shasta red fir dominate. The diversity of vegetation is greater than the western Cascades subregions due to warmer summer temperatures and a longer growing season, as well as floristic elements from both northern and southern floristic provinces (ONHP 2003).

Appendix C: Potential Historical Abundance of Coho Salmon

Having estimates of potential historical abundance of coho salmon (*Oncorhynchus kisutch*) populations is useful for a number of reasons. Such estimates can be used to compare with current abundance, develop an understanding of limiting factors, and model the independence of individual populations. Here we use two independent approaches to estimate historical abundance of coho salmon in the Oregon Coast Coho Salmon ESU for the purpose of modeling the independence of individual populations.

Calculating Adult Abundance from Catch

Lichatowich (1989) estimated historical abundance of adult coho salmon based on in-river catch records. Mullen (1981a) compiled catch records for individual coastal basins within the Oregon Coast Coho Salmon ESU and converted pounds landed to estimated number of adult salmon. Both Mullen (1981b) and Lichatowich (1989) divided total number of fish landed coast-wide by an assumed exploitation rate of 40% to estimate total abundance. Mullen (1981b) estimated mean annual abundance for 5-year intervals from 1892 to 1940. Lichatowich (1989) estimated mean annual abundance for the 5 peak years between 1892 and 1920, which he considered a conservative measure of production because of the many problems associated with the accuracy of the early cannery records.

The methods of Mullen (1981b) and Lichatowich (1989) were adopted here with the exception that they were applied to the peak year of catch in each of 10 coastal basins during the period of 1882–1925 as estimated by Mullen (1981a). Because maximum catch of coho salmon in individual basins did not occur in a single year, this approach gives a better estimate of potential historical abundance. Peak catches in the 10 basins actually occurred in six different years. However, like the earlier estimates, these estimates of abundance only apply to streams where fisheries took place. The 10 basins included represent about 89% of the coho salmon distribution in the Oregon Coast Coho Salmon ESU.

Calculating Adult Abundance from GIS Data

An estimate of historical potential smolt abundance for each population in the Oregon Coast Coho Salmon ESU (Figure C-1) is from data converted from Coastal Landscape Analysis and Modeling Study (CLAMS) used to calculate intrinsic potential for coho salmon (Burnett et al. 2003) (Figures C-2 through C-5). The estimated smolt potential was then converted to adult potential by applying a marine survival rate.

Stream reaches were divided into two categories based on their gradient. Those reaches with a gradient less than or equal to 0.5% were assumed to be associated with wetlands and an expansive floodplain (Rosgen 1994, 1996, Montgomery and Buffington 1997, Buffington et al.

2002), which would provide winter habitat for coho salmon outside the active channel. For reaches with a gradient greater than 0.5%, the assumption was made that coho salmon smolts were produced primarily within the active channel.

For each population, potential smolt production was calculated as the sum of the potential of all reaches with intrinsic potential greater than 0. For each reach with a gradient less than or equal to 0.5%, potential smolt production was calculated from the equation

$$S = 0.0741 \, L \, (V{-}W) \, P \qquad\qquad (1)$$

where S is the potential number of smolts produced in the reach, L is the length of the reach (m), V is the valley width (m), W is the active channel width (m), P is the intrinsic potential of the reach (an index without units), and 0.0741 is the number of smolts per square meter (741/ha) based on data from NMFS et al. (1983).

Potential smolt production was calculated for each reach with a gradient greater than 0.5% from the equation

$$S = (0.3405) \, (0.5) \, L \, W \, P \qquad\qquad (2)$$

where 0.3405 is the number of smolts per square meter in main channel pools based on data from Nickelson (1998), and 0.5 is the proportion of the area in pools based on an assumed 50:50 pool:riffle ratio.

For lake populations, potential smolt production was estimated by multiplying the lake area by 741 smolts/ha. This is a deviation from the approach used in Washington (NMFS 1983), where only a 30-m-wide littoral zone is considered. However, Oregon coastal lakes are shallow, with littoral zones that cover most if not all of their area.

Potential historical adult abundance was estimated for each population by applying a 10% marine survival rate to the smolt estimates. These estimates were capped for two stream populations and several lake populations at 1,500 adults per mile of spawning habitat based on current estimates of the miles of stream in each basin that would be available for spawning. The value of 1,500 adults per mile is consistent with the maximum level observed in a lake system tributary in 2001, a high-survival year (ODFW 2003b, 2003d, Nickelson[7]), and the density of coho observed in Tenmile Lakes in the 1955 (Morgan and Henry 1959) before warm-water fish became a problem.

Results

The results of the two different approaches used to estimate potential historical abundance of coho salmon in the large basins of the Oregon Coast Coho Salmon ESU produced surprisingly similar results (Table C-1). Differences between the two estimates ranged from 1% for the Yaquina River to 73% for the Umpqua River. There is a strong correlation between the estimates derived by the two methods (Figure C-1).

---

[7] T. Nickelson, ODFW, Corvallis Research Laboratory, Corvallis, OR. Pers. commun., 2003.

The advantage of calculating adult abundance from computed intrinsic potential is that estimates can be made for basins where there are no historical fishery data. Table C-2 lists the estimated potential historical abundance of coho salmon for 56 putative populations of coho salmon in the Oregon Coast Coho Salmon ESU. Total adult abundance derived from smolt numbers and 10% marine survival was about 3.5 million adults if all populations peaked the same year.

Discussion

Historical abundance of coho salmon was estimated for the purpose of modeling the effects of relative abundance on population independence. For this exercise, marine survival was assumed to be 10% for all populations. This assumption results in an unrealistically high total abundance for the Oregon Coast Coho Salmon ESU when all populations are aggregated. This aggregate estimate of 3.3 million adult coho salmon is higher than the 978,000 for the peak five-year of Mullen (1981b) and the 1,385,000 (1,915,000 if you use the peak year) of Lichatowich (1989), both of which also included the Rogue River in the Southern Oregon Northern California ESU. The primary reasons for this result is that the populations are asynchronous; in other words, the peak abundance of the various populations did not occur in the same year as was assumed for this analysis. Thus it is an error to conclude that historical abundance was 3.3 million adult coho salmon. One example of an approach to use this information to come up with a more realistic ESU abundance estimate is to assume that only 60% of the coastal habitat was productive at any given time.[8] This would yield an estimate of 2.0 million fish, which may be on the low side because most fish are produced from the lowlands, which were likely more stable than the uplands where the Reeves analysis[9] applies. More work is needed to convert the smolt capacity estimates generated here into estimates of historical adult abundance.

It is interesting to note that the basins with the greatest discrepancy between peak adult abundance estimated from catch and that estimated from intrinsic potential are the basins with the greatest effects from splash damming at the turn of the twentieth century (Sedell and Duvall 1985). In each case, the abundance of adults estimated from intrinsic potential was at least 30% greater than that estimated from catch. Thus it could be that even as early as 1900, coho salmon populations had been significantly reduced by habitat destruction in some basins that would result in underestimates of abundance derived from harvest data.

---

[8] G. H. Reeves, U.S. Forest Service, Pacific Northwest Research Station, Corvallis, OR. Pers. commun., September 2004.
[9] See footnote 7.

Table C-1. Estimate of potential historical abundance of coho salmon in large basins of the Oregon Coast Coho Salmon ESU using methods based on peak historical catch and estimated habitat capacity (based on data from Chapman 1986, Lichatowich 1989, Burnett et al. 2003).

| | **Estimated potential historical abundance** | | | |
Basin	Based on catch (a)	Based on IP (b)	Difference	(b–a)/a
Nehalem River	240,000	333,000	93,000	39%
Tillamook	292,500	329,000	36,500	12%
Nestucca River	115,000	104,000	–11,000	–10%
Siletz River	125,000	122,000	–3,000	–2%
Yaquina River	120,000	122,000	2,000	2%
Alsea River	150,000	163,000	13,000	9%
Siuslaw River	292,500	267,000	–25,500	–9%
Umpqua River	585,000	820,000	235,000	40%
Coos River	150,000	206,000	56,000	37%
Coquille River	310,000	417,000	107,000	35%
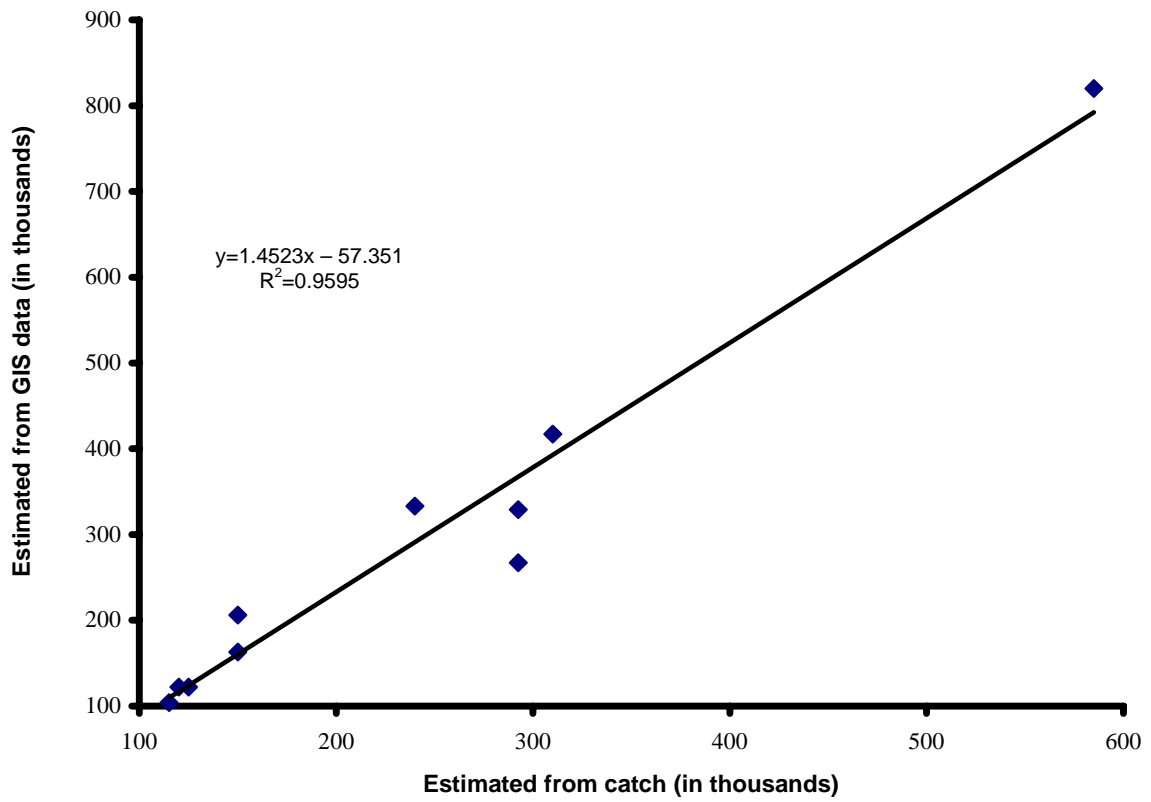
Figure C-1. The relationship between historical potential coho salmon adult abundance estimated by historical catch records and adult abundance calculated from GIS data (data from Table C-1).

Table C-2. Potential historical smolt and adult abundance for 56 putative populations of coho salmon in the Oregon Coast Coho Salmon ESU.

Population	Potential smolts	Adults at 10% marine survival	Population	Potential smolts	Adults at 10% marine survival
Necanicum	685,000	68,500	Alsea	1,628,000	163,000
Ecola	72,000	7,000	Big (near Alsea)	34,000	3,000
Arch Cape	3,000	300	Vingie	3,000	300
Short Sands	4,000	400	Yachats	110,000	11,000
Nehalem	3,330,000	333,000	Cummins	10,000	1,000
Spring	5,000	500	Bob	6,000	600
Watseco	5,000	500	Tenmile Creek	28,000	3,000
Tillamook Bay	3,288,000	329,000	Rock	6,000	600
Netarts	15,000	1,500	Big	18,000	2,000
Rover	2,000	200	China	5,000	500
Sand	123,000	12,000	Cape	15,000	2,000
Nestucca	1,037,000	104,000	Berry	54,000	5,000
Neskowin	49,000	5,000	Sutton (Mercer Lake)	84,000	8,000
Salmon	168,000	17,000	Siuslaw	2,674,000	267,000
Devils Lake	85,500	9,000	Siltcoos	771,000	77,000
Siletz	1,217,000	122,000	Tahkenitch	228,000	23,000
Schoolhouse	2,000	200	Threemile	22,000	2,000
Fogarty	18,000	2,000	Umpqua (Total)	8,199,000	820,000
Depoe Bay	7,000	700	Lower Umpqua	1,293,000	129,000
Rocky	10,000	1,000	Middle Umpqua	2,420,000	242,000
Spencer	11,000	1,000	North Umpqua	1,180,000	118,000
Wade	5,000	500	South Umpqua	3,310,000	331,000
Coal	4,000	400	Tenmile	525,000	53,000
Moolack	4,000	400	Coos	2,058,000	206,000
Big (near Yaquina)	26,000	3,000	Coquille	4,169,000	417,000
Yaquina	1,217,000	122,000	Johnson	8,000	800
Theil	20,000	2,000	Twomile	134,000	13,000
Beaver	265,000	27,000	Floras/New	396,000	34,000
			Sixes	372,000	37,000

Figure C-2. Intrinsic potential of rivers and streams on the north coast segment of the Oregon Coast Coho Salmon ESU.
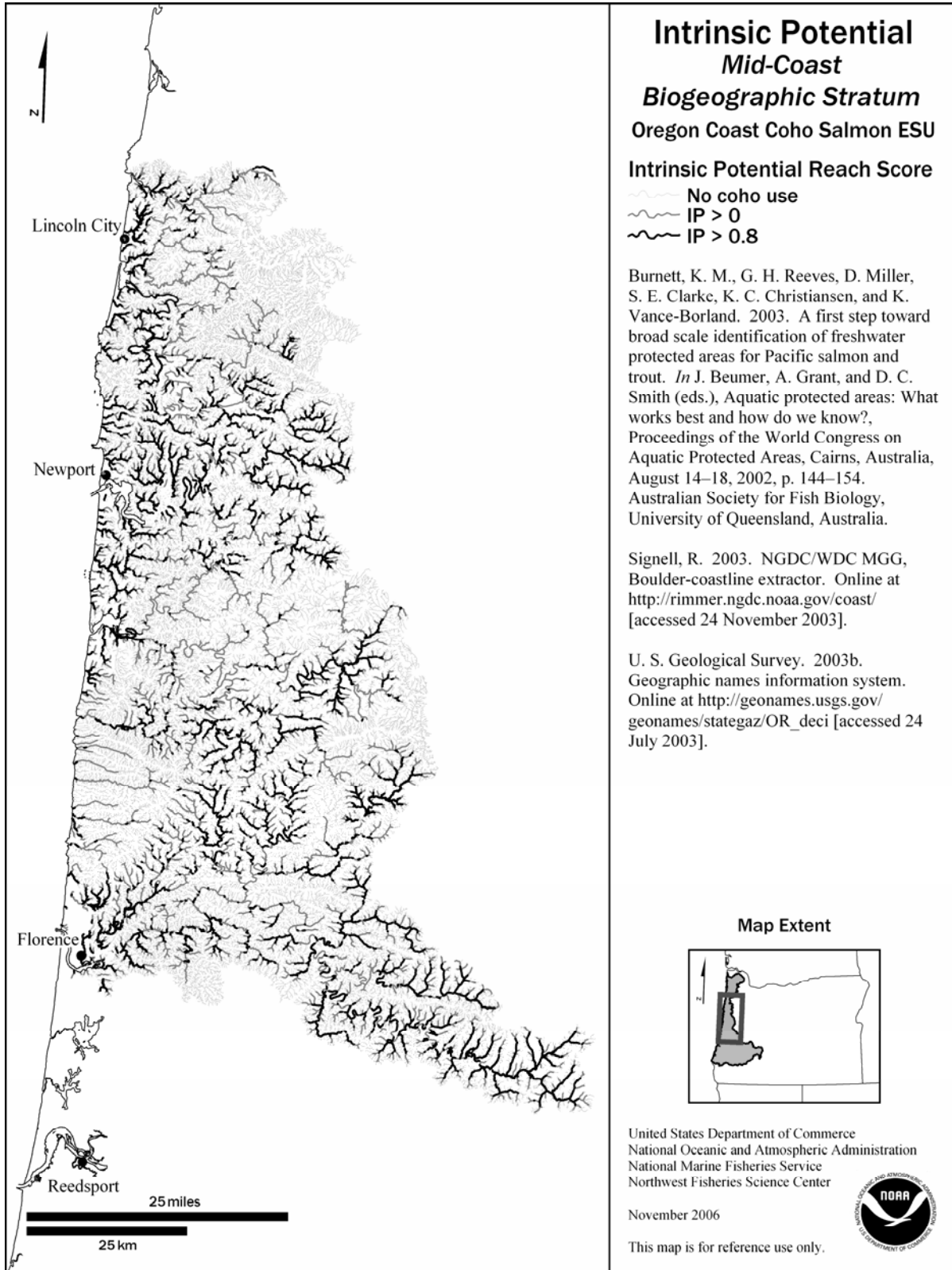
Figure C-3. Intrinsic potential of rivers and streams on the mid-coast segment of the Oregon Coast Coho Salmon ESU.

Intrinsic Potential
Umpqua River Basin
Biogeographic Stratum

Oregon Coast Coho Salmon ESU

Intrinsic Potential Reach Score
No coho use
IP > 0
IP > 0.8

Burnett, K. M., G. H. Reeves, D. Miller, S. E. Clarke, K. C. Christiansen, and K. Vance-Borland. 2003. A first step toward broad scale identification of freshwater protected areas for Pacific salmon and trout. *In* J. Beumer, A. Grant, and D. C. Smith (eds.), Aquatic protected areas: What works best and how do we know?, Proceedings of the World Congress on Aquatic Protected Areas, Cairns, Australia, August 14–18, 2002, p. 144–154. Australian Society for Fish Biology, University of Queensland, Australia.

Signell, R. 2003. NGDC/WDC MGG, Boulder-coastline extractor. Online at http://rimmer.ngdc.noaa.gov/coast/ [accessed 24 November 2003].

U. S. Geological Survey. 2003b. Geographic names information system. Online at http://geonames.usgs.gov/ geonames/stategaz/OR_deci [accessed 24 July 2003].

Map Extent

United States Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

November 2006

This map is for reference use only.

Figure C-4. Intrinsic potential of rivers and streams on the Umpqua River Basin segment of the Oregon Coast Coho Salmon ESU.

111
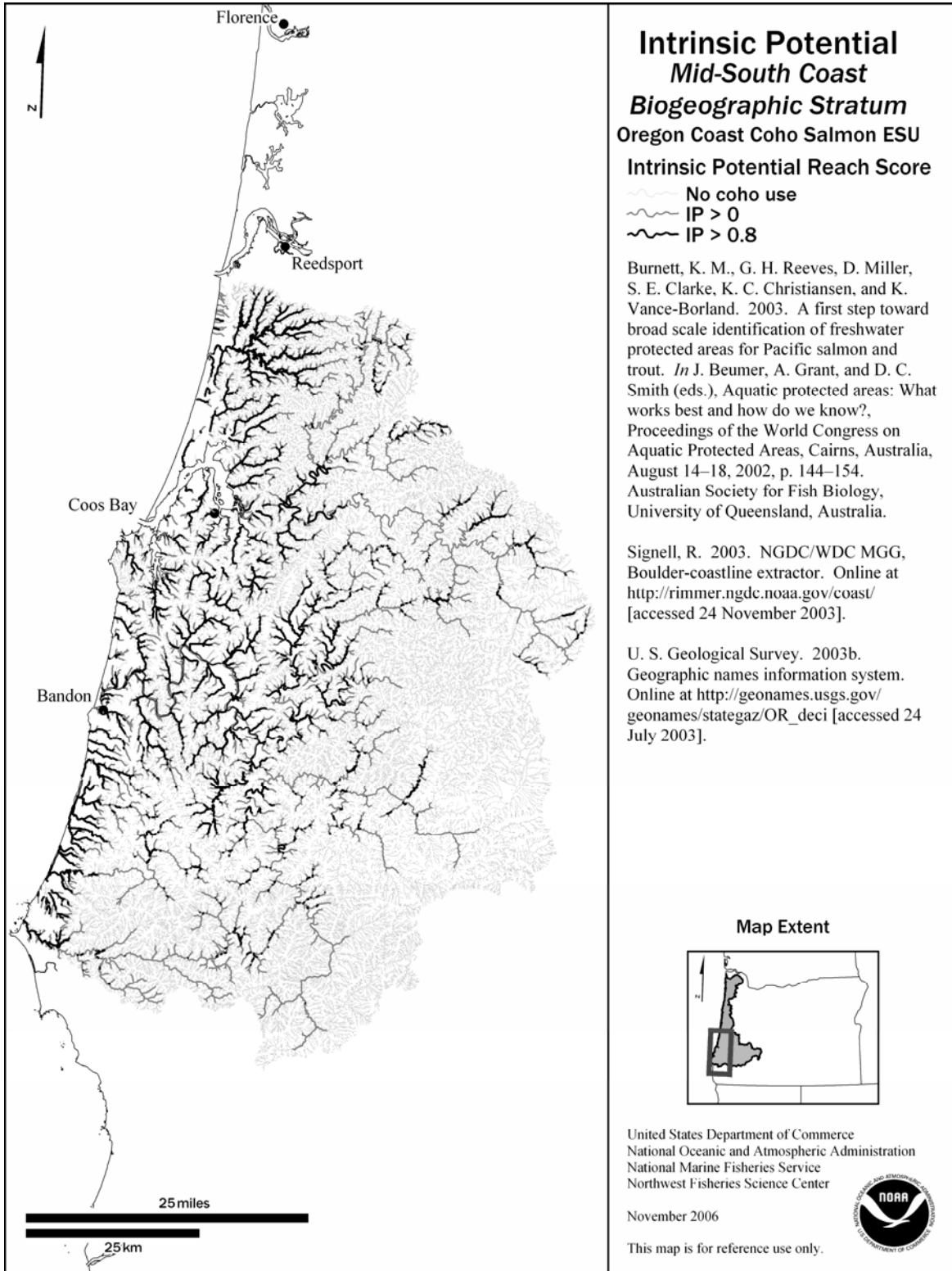
Figure C-5. Intrinsic potential of rivers and streams on the mid-south coast segment of the Oregon Coast Coho Salmon ESU.

Appendix D: Principal Components and Clustering Analysis

Introduction

The TRT identified historical coho salmon (*Oncorhynchus kisutch*) populations using river basins with unique ocean entry points as their fundamental units. Because these basins vary substantially in size and ecological conditions, these variations might mask potential subdivisions where local conditions produced multiple populations within a basin. In particular, the TRT and reviewers identified the large Umpqua River Basin as a candidate for subdivision, as the full river basin is more than four times the size of the next largest river basin, the Coquille River Basin (about 3 million acres vs. 0.7 million acres). Here, we describe our analysis of the Umpqua River Basin to determine whether it contains sufficiently diverse habitats as to represent multiple populations.

As an aid to describing potential populations within river basins, the Southern Oregon/Northern California Coast (SONCC) Coho Salmon Workgroup of the TRT developed a method for using principal component and clustering analyses of climate, physiographic, and biogeographic data to identify areas of similar environmental conditions (Williams et al. 2006). The SONCC Workgroup used this analysis as a guide to delineating historical coho populations in the SONCC coho salmon ESU, providing a geographic basis for describing probable population boundaries within the interior river systems.

The Oregon Coast Coho Salmon Workgroup (Workgroup) of the TRT used the SONCC Workgroup's analytical method to explore potential population structure within the large river basins. To do so, the Workgroup conducted principal components and cluster analysis using data from fifth-field watersheds throughout the ESU and on a subset of watersheds in the Umpqua River Basin.

Principal components analysis (PCA) is a statistical method for reducing the complexity of a data set while retaining most of the variability of the original data. In PCA, the data set is transformed into a set of new, uncorrelated variables that explain as much of the variability in the original data as possible. The analysis transforms the data to a new coordinate system for the data, making the first axis (or principal component) have the greatest variance, the second axis the second greatest, and so on. Because the first few principal components contain most of the variability of the original data, using principal components reduces the number of dimensions (variables) while retaining most of the information of the original set. This also serves to remove redundancy in correlated data so patterns within the data are apparent. PCA is frequently applied to complex data sets with internal correlation prior to cluster analysis, particularly in data mining and genetic analysis.

To identify areas of similarity, we used cluster analysis on the principal components across all the watersheds in the ESU and the subset of the watersheds in the Umpqua River Basin. Cluster analysis created groups of items within a data set by sequentially finding those items with minimal difference between them across all variables. In short, such analysis identifies which items (basins) are most similar given the input data and identifies major differences between groups of basins.

Methods

We analyzed environmental and ecological data according to the protocol described in Williams et al. (2006) for identifying potential population structure within river basins of the SONCC ESU, using all the data types in their analysis, and using the same source data where possible. We assembled data for this analysis in a geographical information system (GIS), including vegetation, weather, and lithology data. Table D-1 lists the data layers we used. As described in Williams et al. (2006), we reclassified the lithology into broad categories (Table D-2).

We then summarized data by fifth-field watershed, using the watershed boundaries provided by the Regional Ecosystem Office (2002). The summary method varied according to data type (indicated in Table D-1). For continuous polygon vector data, such as lithology or ecoregion, we calculated the proportion of total watershed area consisting of each type for each watershed, using ArcMap 8.3 (ESRI 2002). For continuous raster data, such as elevation or precipitation, we calculated the mean value across each watershed with the Spatial Analyst extension to ArcMap. The stream flow data, in discrete point vector format, required more complex analysis, as did two index values we calculated for each watershed: snow potential and precipitation to wet-days ratio, as follows.

Table D-1. Data sources for the principal components analysis. These data were stored in a GIS, which used various raster and vector formats for storage.

Data layer	Data type[a]	Data source
Fifth-field watershed boundaries	CPV	Regional Ecosystem Office 2002
Elevation (10-m digital elevation models)	CR	USDI Bureau of Land Management 1998
Annual precipitation (4-km PRISM[b] model)	CR	Oregon Climate Service 2000b
Annual temperature (4-km PRISM model)	CR	Daly et al. 2002a
Lithology	CPV	USGS 1995
Ecoregions (Level III)	CPV	ONHP 2001
Monthly freeze days (1-km PRISM model)	CR	Daly et al. 2000b
Annual and Monthly temperatures (1-km PRISM model)	CR	Daly et al. 2000a
Stream flow	DPV	USGS 2004

[a] CPV = continuous polygon vector, CR = continuous raster, DPV = discrete point vector.
[b] Parameter-elevation regressions on Independent Slopes Model (Daly et al. 2002b).

Table D-2. Reclassification scheme for geology data from USGS 1995. This table lists the original geology type provided and the reclassified type used in this analysis. Our goal for the reclassification was to closely match the number and breadth of categories used in Williams et al. 2006.

Lithology type in USGS (1995)	Reclassified type
Alkalic intrusive	Granitic
Alluvium	Alluvial
Calc-alkaline intrusive	Granitic
Calc-alkaline volcanoclastic	Volcanic
Conglomerate	Sedimentary
Dune sand	Alluvial
Felsic pyroclastic	Volcanic
Felsic volcanic flow	Volcanic
Glacial drift	Alluvial
Lake sediment and playa	Sedimentary
Mafic gneiss	Granitic
Mafic intrusive	Volcanic
Mafic pyroclastic	Volcanic
Mafic volcanic flow	Volcanic
Meta-sedimentary phyllite and schist	Sedimentary
Mixed eugeosynclinal	Sedimentary
Sandstone	Sedimentary
Shale and mudstone	Sedimentary
Siltstone	Sedimentary
Ultramafic	Made up <1% of the ESU area and was excluded from final analysis.

Many watersheds had no U.S. Geological Survey stream gage sites, so we were unable to directly use the gage data to determine the month of peak stream flow for each watershed. Instead, we estimated the month of peak flow for each watershed. We started by calculating the month of peak flow for each stream gage as the number of the month out of the 12-month long water year beginning October 1 (e.g., October was coded with a 1, June with an 8). Then, we used the spatial analyst's inverse distance weighted approximation to create a continuous grid of peak stream flow months for the entire ESU. This estimation analyzed data from 637 gage sites throughout Oregon, including 94 within the ESU. We then calculated the mean result for each watershed from the grid approximation and used it as the month of peak stream flow. As validation, we visually compared the result to gage and precipitation data to verify they were similar.

Williams et al. (2006) calculated a snow index to reflect the relative probability of snow in each watershed in the SONCC ESU from monthly precipitation and temperature data. Using their method for generating a snow index for each watershed, we calculated the mean precipitation for each month of the year, as well as the mean number of days with temperatures below freezing (freeze days). We then multiplied each month's precipitation by its freeze days and summed the result for the entire year. Each watershed's sum served as its snow index.

In addition, we calculated the precipitation to wet-days ratio for each watershed. This ratio, described in Williams et al. (2006), divides the mean annual inches of precipitation for

each watershed by the watershed's mean annual number of days with measurable precipitation. They calculated this ratio as a means to indicate whether precipitation is concentrated in large quantities over a short period during the year or if it is spread throughout the year.

We conducted the principal components analysis at two scales: once with all environmental data for the Oregon Coast Coho Salmon ESU (Tables D-3 and D-4), and again with the subset of data for the watersheds within the Umpqua River Basin. We used the *prcomp* function in the R statistical analysis package (R Development Core Team 2003) to perform the PCA after scaling the data to have a variance of one and a mean of zero.

To identify potential clusters across the entire ESU and within the Umpqua River Basin, we applied agglomerative hierarchical analysis to the first three principal components of each watershed. We performed the cluster analysis with the *agnes* function in R using the average distance method. For presentation and comparison to the proposed historic coho populations, we imported the clustering results into ArcMap and we used the resulting GIS data to create maps for review.

Results

Each principal component (PC) is an axis in the new coordinate system with an associated linear transformation described by its eigenvalues. Variables with greater absolute values of eigenvalues for a PC are more influential than other variables. For PCA of environmental data from the entire ESU, the first three PCs explained 74.9% of the variance in the data. Eigenvalues for the first six PCs and the cumulative variances are listed in Table D-5. Within the first PC, high negative or positive factors (>0.25) indicate that the proportion of sedimentary lithology is strongly differentiated from the proportion of volcanic lithology, as are the proportions of Coast Range and Cascades ecoregion areas. This PC is also strongly influenced by elevation, the month of peak stream flow, mean annual temperature, and mean annual low temperature. The second PC is most influenced by climate variables, with the precipitation to wet day ratio, annual precipitation, snow index, temperature range, and mean high temperature having strong influence. The proportion of Klamath Mountains ecoregion area was also influential.

Within the Umpqua River Basin data, the first three PCs accounted for 79.0% of the data's variance. Results for the first six PCs for the Umpqua River Basin data are presented in Table D-6. The first PC is mostly influenced by climate variables, with mean temperature, mean low and high temperature, snow index, and month of peak stream flow having the strongest influence along with elevation. The second PC is strongly driven by precipitation and the precipitation to wet day ratio, but also by a separation between proportion of area in the Klamath Mountains and Coast Range ecoregions.

Table D-3. Climate data for the Oregon Coast ESU used in the PCA for the Oregon Coast Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our analysis also included the data in Table D-4. The hydrologic unit code for each fifth-field watershed is listed in the HUC5 column.

Watershed	HUC5	Ppt[a]	Temperature (°C)				SNWI[b]	PWYR[c]	Peak[d]
			Mean	High	Low	Range			
Lower Nehalem R.	1710020203	111.16	9.48	14.50	4.45	10.06	149.1	1427.1	4.5
Necanicum R.	1710020101	111.89	10.44	15.06	5.82	9.24	96.9	1382.5	4.3
Middle Nehalem	1710020202	64.68	9.56	15.09	4.04	11.05	82.6	966.2	5.3
N. Fork Nehalem	1710020205	116.25	9.97	14.89	5.05	9.84	116.0	1446.1	4.2
Upper Nehalem R.	1710020201	74.40	9.25	14.68	3.82	10.86	112.7	1089.9	4.7
Lower Nehalem R.	1710020206	126.89	10.05	14.70	5.40	9.30	127.0	1533.1	4.1
Salmonberry R.	1710020204	139.86	8.80	13.26	4.33	8.94	205.6	1696.2	4.5
Kilchis R.	1710020306	132.71	10.29	15.08	5.50	9.59	143.2	1627.6	4.2
Miami R.	1710020307	123.98	10.50	15.27	5.74	9.52	118.0	1571.8	4.1
Wilson R.	1710020305	122.77	9.28	13.80	4.75	9.05	158.2	1517.6	4.5
Tillamook Bay	1710020308	87.36	10.38	15.10	5.66	9.44	76.1	1252.9	4.2
Spring Cr.	1710020309	93.54	10.68	15.36	5.99	9.37	67.2	1338.3	3.9
Trask R.	1710020304	109.41	9.64	14.36	4.91	9.45	137.7	1459.0	4.4
Tillamook R.	1710020303	97.08	10.47	15.28	5.66	9.62	92.9	1367.2	4.1
Nestucca R.	1710020302	109.13	10.38	15.33	5.43	9.90	114.1	1448.2	4.0
Little Nestucca R.	1710020301	105.27	10.83	16.08	5.58	10.50	88.5	1430.4	3.6
Salmon R.	1710020408	113.15	10.11	15.06	5.17	9.89	171.3	1739.7	3.8
Lower Siletz R.	1710020407	99.04	10.54	15.38	5.70	9.68	92.0	1400.9	4.1
Upper Siletz R.	1710020404	151.60	8.51	13.20	3.82	9.38	257.4	1968.0	4.1
Middle Siletz R.	1710020405	135.17	9.75	15.17	4.34	10.82	184.5	1711.6	4.1
Rock Cr.	1710020406	99.58	10.17	15.93	4.40	11.53	127.5	1335.0	4.3
Devils Lk./Moolack Cr.	1710020409	81.39	10.75	15.12	6.37	8.75	47.4	1203.2	4.2
Upper Yaquina R.	1710020401	72.41	10.74	16.11	5.37	10.74	78.0	1119.3	4.1
Lower Yaquina R.	1710020403	75.50	10.82	15.23	6.40	8.78	46.2	1206.7	4.3
Big Elk Cr.	1710020402	80.78	11.03	16.40	5.66	10.74	85.6	1287.6	4.3
Beaver Cr.	1710020505	82.47	10.87	15.40	6.33	9.13	49.4	1251.9	5.1
Drift Cr.	1710020503	108.92	11.12	16.37	5.87	10.50	87.2	1554.1	4.4
Upper Alsea R.	1710020501	90.75	11.11	16.40	5.82	10.58	106.7	1367.9	4.7
Lower Alsea R.	1710020504	94.79	11.27	16.51	6.03	10.44	79.6	1454.0	4.5
Big Cr./Vingie Cr.	1710020508	85.95	10.89	15.63	6.15	9.48	65.2	1398.0	4.4
Five Rivers/Lobster Cr.	1710020502	89.18	11.81	17.19	6.43	10.76	76.6	1409.6	4.4
Yachats R.	1710020506	89.10	11.33	16.63	6.04	10.59	65.1	1392.1	4.2
Lake Cr.	1710020604	83.59	11.60	17.15	6.05	11.10	79.0	1224.5	4.4
Cummins Cr./Tenmile Cr.	1710020507	91.12	11.10	16.10	6.10	9.99	65.0	1362.6	3.9
Deadwood Cr.	1710020605	88.23	11.69	17.00	6.38	10.62	72.2	1289.4	4.3
Indian Cr./Lake Cr.	1710020606	88.08	11.69	17.13	6.26	10.87	65.1	1341.0	4.2
N. Fork Siuslaw R.	1710020607	85.68	11.27	16.38	6.16	10.22	56.9	1272.6	3.9
Wildcat Cr.	1710020603	60.94	11.34	17.64	5.04	12.60	71.2	1039.4	4.4
Woahink L.	1710020701	74.17	11.13	16.04	6.22	9.82	42.9	1168.8	4.1
Lower Siuslaw R.	1710020608	77.23	11.40	16.69	6.11	10.59	56.7	1207.5	4.1

Table D-3 continued. Climate data for the Oregon Coast ESU used in the PCA for the Oregon Coast Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our analysis also included the data in Table D-4. The hydrologic unit code for each fifth-field watershed is listed in the HUC5 column.

Watershed	HUC5	Ppt[a]	Temperature (°C)				SNWI[b]	PWYR[c]	Peak[d]
			Mean	High	Low	Range			
Wolf Cr.	1710020602	56.60	11.40	17.63	5.16	12.47	63.5	977.5	4.4
Lower Smith R.	1710030307	70.62	11.20	16.51	5.88	10.64	52.4	1110.1	4.3
Upper Siuslaw R.	1710020601	52.94	11.34	17.50	5.18	12.32	55.7	942.2	4.4
Upper Smith R.	1710030306	52.59	11.14	17.16	5.11	12.05	50.9	958.3	4.5
Lower Umpqua R.	1710030308	71.23	11.21	16.40	6.02	10.37	51.6	1130.1	4.7
Middle Umpqua R.	1710030304	54.19	11.57	17.72	5.42	12.30	43.9	1015.6	5.0
Lakeside Frontal	1710030403	71.09	11.31	16.44	6.17	10.27	46.3	1131.1	4.4
Elk Cr.	1710030303	49.36	11.51	17.82	5.20	12.62	51.7	903.1	4.7
Upper Umpqua R.	1710030301	47.51	11.87	18.01	5.74	12.27	40.7	892.5	4.4
Millicoma R.	1710030402	74.41	11.38	17.09	5.66	11.43	60.4	1156.2	4.6
Calapooya Cr.	1710030302	50.53	11.74	17.84	5.63	12.20	55.0	922.4	4.4
Canton Cr.	1710030109	65.56	10.66	16.20	5.13	11.07	74.3	1060.9	4.6
Coos Bay	1710030404	66.92	11.45	16.54	6.37	10.18	40.5	1123.0	4.6
Lake Cr.	1710030305	63.63	11.55	17.42	5.68	11.75	55.3	1079.3	5.0
Steamboat Cr.	1710030108	63.75	9.76	15.48	4.04	11.43	81.9	1032.5	5.3
Rock Cr.	1710030110	67.24	11.30	16.89	5.71	11.18	77.6	1121.4	4.5
S. Fork Coos R.	1710030401	68.74	11.61	16.99	6.24	10.76	61.7	1117.2	4.4
Boulder Cr.	1710030106	55.97	8.90	14.88	2.92	11.96	113.1	985.1	5.9
Lemolo Lk.	1710030102	59.79	5.04	11.65	-1.58	13.23	213.7	1079.9	6.4
Upper N. Umpqua R.	1710030103	58.58	7.86	14.17	1.55	12.61	126.4	1033.7	6.6
Middle N. Umpqua R.	1710030107	56.03	10.26	16.29	4.23	12.03	86.2	985.9	5.2
Lower N. Umpqua R.	1710030112	42.73	11.98	18.35	5.61	12.75	46.7	819.6	4.6
Fish Cr.	1710030105	55.16	6.79	13.06	0.51	12.55	134.4	980.6	6.8
Clearwater Cr.	1710030104	55.07	6.58	13.05	0.10	12.95	138.4	989.0	6.7
Little R.	1710030111	58.31	11.10	17.09	5.11	12.01	68.5	1008.6	4.8
Lower Coquille R.	1710030506	65.31	11.38	16.82	5.93	10.89	47.5	1175.0	4.5
N. Fork Coquille R.	1710030505	69.09	11.56	17.44	5.69	11.75	56.8	1142.2	4.6
Upper S. Umpqua R.	1710030201	51.79	8.45	14.39	2.51	11.88	100.9	955.3	6.2
E. Fork Coquille R.	1710030504	72.32	11.42	16.63	6.21	10.50	62.5	1166.7	4.4
Middle S. Umpqua R.	1710030203	52.87	10.78	16.88	4.68	12.20	68.5	939.1	4.8
Lower S. Umpqua R.	1710030213	39.35	12.30	18.50	6.10	12.40	36.4	783.8	4.2
Ollala Cr.	1710030212	46.70	11.71	17.62	5.80	11.82	47.3	894.8	4.1
Diamond Lk.	1710030101	54.98	4.49	10.99	-2.01	13.00	179.1	1036.3	6.5
Myrtle Cr.	1710030211	46.10	11.81	17.87	5.75	12.13	44.1	865.7	4.6
Middle Main Coquille R.	1710030503	59.74	11.81	17.87	5.75	12.12	57.8	1153.0	4.3
Middle S. Umpqua R.	1710030210	40.59	11.99	18.11	5.87	12.24	35.9	815.9	4.3
Middle Fork Coquille R.	1710030502	64.57	11.52	17.19	5.84	11.32	67.7	1132.1	4.3
New R.	1710030604	76.94	11.54	16.56	6.52	9.96	50.2	1366.8	4.2
S. Umpqua R.	1710030205	46.08	11.41	17.37	5.45	11.92	49.8	895.7	4.6

Table D-3 continued. Climate data for the Oregon Coast ESU used in the PCA for the Oregon Coast
Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our
analysis also included the data in Table D-4. The hydrologic unit code for each fifth-field
watershed is listed in the HUC5 column.

Watershed	HUC5	Ppt[a]	Temperature (°C)				SNWI[b]	PWYR[c]	Peak[d]
			Mean	High	Low	Range			
Jackson Cr.	1710030202	48.39	8.41	14.27	2.54	11.73	100.8	944.1	5.6
Lower Cow Cr.	1710030209	50.67	11.29	16.56	6.02	10.54	48.8	945.3	4.3
Elk Cr.	1710030204	47.99	9.82	15.68	3.96	11.72	79.4	928.6	4.6
Sixes R.	1710030603	91.76	11.68	16.96	6.41	10.54	70.2	1549.3	4.2
W. Fork Cow Cr.	1710030208	66.37	10.88	15.70	6.05	9.65	74.6	1181.1	4.3
S. Fork Coquille R.	1710030501	94.71	11.44	17.15	5.73	11.42	114.4	1459.0	4.4
Upper Cow Cr.	1710030206	54.04	10.47	15.85	5.09	10.78	83.7	994.4	4.6
Middle Cow Cr.	1710030207	46.99	10.81	15.88	5.73	10.14	58.8	918.0	4.6

[a] The mean annual inches of precipitation of the watershed.
[b] The result of the snow index calculation.
[c] The precipitation to wet-day ratio.
[d] The numerical month of peak flow during the water year.

Table D-4. Physiographic and biogeographic data used for PCA for the Oregon Coast Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our analysis also included the data in Table D-3. The hydrologic unit code for each fifth-field watershed is listed in the HUC5 column. The lithology and ecoregion columns list the proportion of each watershed in the respective type.

| Watershed | HUC5 | Elev[a] | Lithology | | | | Ecoregion | | | |
			All[b]	Sed[c]	Gra[d]	Vol[e]	Coast[f]	Wval[g]	Casc[h]	Klm[i]
Lower Nehalem R.	1710020203	319.6	0.05	0.72	0.00	0.23	1.00	0.00	0.00	0.00
Necanicum R.	1710020101	206.5	0.14	0.48	0.00	0.33	1.00	0.00	0.00	0.00
Middle Nehalem	1710020202	286.0	0.04	0.81	0.00	0.15	1.00	0.00	0.00	0.00
N. Fork Nehalem	1710020205	235.4	0.06	0.72	0.00	0.22	1.00	0.00	0.00	0.00
Upper Nehalem R.	1710020201	379.0	0.03	0.74	0.00	0.23	1.00	0.00	0.00	0.00
Lower Nehalem R.	1710020206	275.2	0.07	0.20	0.00	0.70	1.00	0.00	0.00	0.00
Salmonberry R.	1710020204	581.4	0.00	0.01	0.00	0.99	1.00	0.00	0.00	0.00
Kilchis R.	1710020306	369.5	0.02	0.01	0.00	0.97	1.00	0.00	0.00	0.00
Miami R.	1710020307	286.5	0.07	0.18	0.00	0.74	1.00	0.00	0.00	0.00
Wilson R.	1710020305	470.4	0.02	0.20	0.00	0.78	1.00	0.00	0.00	0.00
Tillamook Bay	1710020308	52.2	0.19	0.19	0.00	0.22	1.00	0.00	0.00	0.00
Spring Cr.	1710020309	147.0	0.15	0.48	0.00	0.31	1.00	0.00	0.00	0.00
Trask R.	1710020304	440.2	0.09	0.20	0.00	0.71	1.00	0.00	0.00	0.00
Tillamook R.	1710020303	170.9	0.23	0.47	0.00	0.29	1.00	0.00	0.00	0.00
Nestucca R.	1710020302	360.6	0.02	0.52	0.00	0.43	1.00	0.00	0.00	0.00
Little Nestucca R.	1710020301	220.5	0.04	0.80	0.00	0.16	1.00	0.00	0.00	0.00
Salmon R.	1710020408	320.9	0.04	0.51	0.00	0.45	1.00	0.00	0.00	0.00
Lower Siletz R.	1710020407	193.3	0.08	0.55	0.00	0.36	1.00	0.00	0.00	0.00
Upper Siletz R.	1710020404	619.6	0.06	0.39	0.00	0.54	1.00	0.00	0.00	0.00
Middle Siletz R.	1710020405	338.7	0.04	0.50	0.00	0.46	1.00	0.00	0.00	0.00
Rock Cr.	1710020406	279.7	0.00	0.91	0.00	0.06	1.00	0.00	0.00	0.00
Devils Lk./Moolack Cr.	1710020409	92.1	0.10	0.76	0.00	0.13	1.00	0.00	0.00	0.00
Upper Yaquina R.	1710020401	175.5	0.00	0.99	0.00	0.00	1.00	0.00	0.00	0.00
Lower Yaquina R.	1710020403	80.0	0.03	0.90	0.00	0.00	1.00	0.00	0.00	0.00
Big Elk Cr.	1710020402	226.7	0.00	0.99	0.00	0.00	1.00	0.00	0.00	0.00
Beaver Cr.	1710020505	107.7	0.18	0.82	0.00	0.00	1.00	0.00	0.00	0.00
Drift Cr.	1710020503	311.6	0.00	0.98	0.02	0.00	1.00	0.00	0.00	0.00
Upper Alsea R.	1710020501	402.0	0.03	0.56	0.00	0.41	1.00	0.00	0.00	0.00
Lower Alsea R.	1710020504	243.7	0.04	0.85	0.00	0.08	1.00	0.00	0.00	0.00
Big Cr./Vingie Cr.	1710020508	138.9	0.32	0.31	0.00	0.37	1.00	0.00	0.00	0.00
Five Rivers/Lobster Cr.	1710020502	255.0	0.00	0.98	0.00	0.02	1.00	0.00	0.00	0.00
Yachats R.	1710020506	213.6	0.00	0.76	0.00	0.23	1.00	0.00	0.00	0.00
Lake Cr.	1710020604	352.7	0.06	0.89	0.00	0.05	1.00	0.00	0.00	0.00
Cummins Cr./Tenmile Cr.	1710020507	251.4	0.01	0.22	0.00	0.76	1.00	0.00	0.00	0.00
Deadwood Cr.	1710020605	279.9	0.00	0.99	0.00	0.00	1.00	0.00	0.00	0.00
Indian Cr./Lake Cr.	1710020606	237.3	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
N. Fork Siuslaw R.	1710020607	160.4	0.01	0.97	0.00	0.00	1.00	0.00	0.00	0.00
Wildcat Cr.	1710020603	280.5	0.00	0.96	0.00	0.03	0.98	0.02	0.00	0.00

Table D-4 continued. Physiographic and biogeographic data used for PCA for the Oregon Coast Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our analysis also included the data in Table D-3. The hydrologic unit code for each fifth-field watershed is listed in the HUC5 column. The Elev column lists the mean elevation of the watershed in feet. The lithology and ecoregion columns list the proportion of each watershed in the respective type.

Watershed	HUC5	Elev[a]	Lithology				Ecoregion			
			All[b]	Sed[c]	Gra[d]	Vol[e]	Coast[f]	Wval[g]	Casc[h]	Klm[i]
Waohink R.	1710020701	89.8	0.11	0.82	0.00	0.00	1.00	0.00	0.00	0.00
Lower Siuslaw R.	1710020608	192.6	0.05	0.90	0.00	0.02	1.00	0.00	0.00	0.00
Wolf Cr.	1710020602	298.6	0.00	0.99	0.00	0.01	0.98	0.02	0.00	0.00
Lower Smith R.	1710030307	231.6	0.00	0.97	0.00	0.02	1.00	0.00	0.00	0.00
Upper Siuslaw R.	1710020601	284.0	0.05	0.94	0.00	0.00	0.57	0.43	0.00	0.00
Upper Smith R.	1710030306	294.4	0.01	0.98	0.00	0.00	0.92	0.08	0.00	0.00
Lower Umpqua R.	1710030308	133.9	0.07	0.83	0.00	0.00	1.00	0.00	0.00	0.00
Middle Umpqua R.	1710030304	198.3	0.03	0.92	0.00	0.00	1.00	0.00	0.00	0.00
Lakeside Frontal	1710030403	112.4	0.17	0.78	0.00	0.00	1.00	0.00	0.00	0.00
Elk Cr.	1710030303	267.0	0.03	0.83	0.00	0.13	0.27	0.31	0.12	0.30
Upper Umpqua R.	1710030301	288.9	0.06	0.90	0.00	0.00	0.80	0.00	0.00	0.20
Millicoma R.	1710030402	348.1	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
Calapooya Cr.	1710030302	385.4	0.07	0.79	0.00	0.12	0.00	0.00	0.37	0.63
Canton Cr.	1710030109	883.5	0.00	0.00	0.00	0.98	0.00	0.00	1.00	0.00
Coos Bay	1710030404	91.8	0.19	0.72	0.00	0.03	1.00	0.00	0.00	0.00
Lake Cr.	1710030305	331.1	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
Steamboat Cr.	1710030108	966.4	0.00	0.00	0.00	0.93	0.00	0.00	1.00	0.00
Rock Cr.	1710030110	787.9	0.00	0.46	0.00	0.44	0.00	0.00	1.00	0.00
S. Fork Coos R.	1710030401	495.0	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
Boulder Cr.	1710030106	1202.1	0.00	0.00	0.00	0.99	0.00	0.00	1.00	0.00
Lemolo Lk.	1710030102	1671.4	0.27	0.00	0.00	0.72	0.00	0.00	1.00	0.00
Upper N. Umpqua R.	1710030103	1270.0	0.11	0.00	0.00	0.86	0.00	0.00	1.00	0.00
Middle N. Umpqua R.	1710030107	868.7	0.00	0.03	0.00	0.92	0.00	0.00	1.00	0.00
Lower N. Umpqua R.	1710030112	300.2	0.06	0.50	0.00	0.44	0.00	0.00	0.07	0.93
Fish Cr.	1710030105	1375.5	0.05	0.00	0.00	0.92	0.00	0.00	1.00	0.00
Clearwater Cr.	1710030104	1458.9	0.16	0.00	0.00	0.84	0.00	0.00	1.00	0.00
Little R.	1710030111	801.7	0.00	0.18	0.07	0.66	0.00	0.00	0.90	0.10
Lower Coquille R.	1710030506	84.5	0.28	0.67	0.00	0.03	1.00	0.00	0.00	0.00
N. Fork Coquille R.	1710030505	226.3	0.07	0.88	0.00	0.06	1.00	0.00	0.00	0.00
Upper S. Umpqua R.	1710030201	1098.4	0.00	0.00	0.00	0.96	0.00	0.00	1.00	0.00
E. Fork Coquille R.	1710030504	439.5	0.00	0.98	0.00	0.00	1.00	0.00	0.00	0.00
Middle S. Umpqua R.	1710030203	820.7	0.00	0.13	0.01	0.81	0.00	0.00	1.00	0.00
Lower S. Umpqua R.	1710030213	297.1	0.13	0.42	0.02	0.40	0.01	0.00	0.02	0.98
Ollala Cr.	1710030212	409.4	0.06	0.88	0.00	0.04	0.02	0.00	0.00	0.98
Diamond Lk.	1710030101	1814.2	0.19	0.00	0.00	0.74	0.00	0.00	1.00	0.00
Myrtle Cr.	1710030211	496.3	0.00	0.27	0.43	0.29	0.00	0.00	0.18	0.82
Middle Main Coquille R.	1710030503	188.5	0.09	0.91	0.00	0.00	1.00	0.00	0.00	0.00
Middle S. Umpqua R.	1710030210	372.9	0.05	0.78	0.00	0.02	0.00	0.00	0.00	1.00

Table D-4 continued. Physiographic and biogeographic data used for PCA for the Oregon Coast Coho Salmon ESU. We used a subset of this data in the PCA for the Umpqua River Basin. Our analysis also included the data in Table D-3. The hydrologic unit code for each fifth-field watershed is listed in the HUC5 column. The Elev column lists the mean elevation of the watershed in feet. The lithology and ecoregion columns list the proportion of each watershed in the respective type.

Watershed	HUC5	Elev[a]	Lithology				Ecoregion			
			All[b]	Sed[c]	Gra[d]	Vol[e]	Coast[f]	Wval[g]	Casc[h]	Klm[i]
Middle Fork Coquille R.	1710030502	455.7	0.00	0.99	0.00	0.01	0.80	0.00	0.00	0.20
New R.	1710030604	200.6	0.30	0.68	0.00	0.00	1.00	0.00	0.00	0.00
S. Umpqua R.	1710030205	549.4	0.04	0.46	0.21	0.28	0.00	0.00	0.12	0.88
Jackson Cr.	1710030202	1026.5	0.00	0.00	0.00	0.97	0.00	0.00	1.00	0.00
Lower Cow Cr.	1710030209	563.2	0.03	0.78	0.00	0.10	0.01	0.00	0.00	0.99
Elk Cr.	1710030204	833.3	0.00	0.15	0.17	0.57	0.00	0.00	0.81	0.19
Sixes R.	1710030603	311.7	0.08	0.90	0.02	0.00	1.00	0.00	0.00	0.00
W. Fork Cow Cr.	1710030208	735.0	0.00	0.85	0.03	0.10	0.67	0.00	0.00	0.33
S. Fork Coquille R.	1710030501	656.5	0.02	0.91	0.00	0.00	0.99	0.00	0.00	0.01
Upper Cow Cr.	1710030206	900.0	0.00	0.13	0.66	0.09	0.00	0.00	0.03	0.97
Middle Cow Cr.	1710030207	697.0	0.10	0.47	0.02	0.37	0.00	0.00	0.00	1.00

[a] Mean watershed elevation (feet above sea level)
[b] Alluvial lithology
[c] Sedimentary lithology
[d] Granitic lithology
[e] Volcanic lithology
[f] Coast Range Ecoregion
[g] Willamette Valley Ecoregion
[h] Cascades Ecoregion
[i] Klamath Mountains Ecoregion

Table D-5. Principal component eigenvectors and variance for the Oregon Coast Coho Salmon ESU.

Factor	PC1	PC2	PC3	PC4	PC5	PC6
Elevation	0.360	–0.058	–0.030	0.089	0.006	–0.139
% Cascades Ecoregion	0.333	–0.096	0.060	0.113	0.279	0.184
Month of peak stream flow	0.328	–0.080	0.234	–0.088	0.043	–0.170
% Volcanic geology	0.303	0.124	–0.200	0.148	0.174	0.437
Snow index	0.208	0.337	–0.072	0.175	–0.234	–0.171
Mean range of temp	0.171	–0.332	0.247	0.176	–0.052	–0.179
% Granitic geology	0.031	–0.157	–0.545	–0.018	–0.370	–0.316
% Alluvial geology	0.030	0.085	0.152	–0.851	–0.146	0.205
% Klamath Mtn Ecoregion	–0.012	–0.302	–0.455	–0.171	–0.210	–0.038
% Willamette Valley Ecoregion	–0.029	–0.115	0.310	0.250	–0.746	0.480
Precipitation	–0.089	0.441	–0.135	0.148	–0.071	0.040
Precipitation to wet-day ratio	–0.099	0.434	–0.104	0.108	–0.054	–0.004
Mean high temp	–0.258	–0.309	0.004	0.157	0.129	0.112
% Coast Range Ecoregion	–0.263	0.292	0.211	–0.012	0.002	–0.187
% Sedimentary geology	–0.306	–0.086	0.314	0.076	–0.048	–0.396
Mean temp	–0.333	–0.183	–0.096	0.090	0.153	0.187
Mean low temp	–0.356	–0.043	–0.173	0.017	0.153	0.228
Variance	6.81	4.37	1.55	1.14	0.93	0.82
Cumulative % of total variance	40.0	65.8	74.9	81.6	91.9	95.1

Table D-6. Principal component eigenvectors and variance for the Umpqua River Basin.

Factor	PC1	PC2	PC3	PC4	PC5	PC6
Mean temp	0.327	–0.012	–0.127	–0.151	0.067	0.019
Mean low temp	0.325	0.044	–0.186	–0.084	0.067	–0.074
Mean high temp	0.316	–0.078	–0.053	–0.224	0.065	0.128
% Sedimentary geology	0.279	0.159	0.336	0.071	0.062	–0.047
% Klamath Mtn Ecoregion	0.189	–0.369	–0.065	0.371	0.052	–0.304
% Coast Range Ecoregion	0.151	0.397	0.309	0.035	–0.023	0.404
% Willamette Valley Ecoregion	0.063	–0.026	0.306	–0.362	–0.739	–0.450
% Granitic geology	0.054	–0.153	–0.341	0.429	–0.594	0.432
Precipitation	–0.078	0.522	–0.113	0.040	–0.045	–0.082
Precipitation to wet-day ratio	–0.106	0.514	–0.074	0.157	–0.071	–0.101
Mean range of temp	–0.147	–0.288	0.369	–0.275	–0.034	0.477
% Alluvial geology	–0.160	–0.141	0.461	0.351	0.207	–0.188
% Volcanic geology	–0.281	–0.079	–0.268	–0.306	0.120	–0.066
% Cascades Ecoregion	–0.294	0.010	–0.226	–0.312	0.059	–0.004
Month of peak stream flow	–0.315	0.009	0.124	–0.020	–0.051	0.180
Snow index	–0.326	0.029	0.100	0.171	–0.081	–0.056
Elevation	–0.329	–0.040	–0.094	0.125	–0.050	–0.104
Variance	6.81	4.37	1.55	1.14	0.93	0.82
Cumulative % of total variance	50.2	68.3	79.0	87.0	92.3	95.8

Cluster analysis based on the first three PCs at the ESU scale generally identified bands of watersheds running north to south (Figures D-1 and D-2). The first cluster split eight watersheds in the upper Umpqua River Basin off from the rest of the ESU (Figure D-1). The next identified cluster consisted of the Salmonberry River in the Nehalem River basin and the Upper Siletz River, both systems with predominantly volcanic lithology. The Upper Siuslaw River and Elk Creek watersheds, each having a high proportion of area in the Willamette Valley ecoregion, formed a third cluster. The next cluster was a group of seventeen watersheds in the interior Umpqua River Basin. The remaining watersheds in the ESU along the Pacific Coast made up a fifth cluster.

Cluster analysis at the Umpqua River Basin scale resulted in clusters spanning the fourth-field watersheds in generally north-to-south and low-to-high elevation patterns (Figures D-3 and D-4). The three fifth-field watersheds in the portion of the basin closest to the ocean clustered together with the west fork of Cow Creek watershed. The next four watersheds to the east form another cluster. The next band east runs north to south across the middle of the north Umpqua River Basin and the eastern portion of the south Umpqua River Basin, and includes 10 watersheds mostly within the Klamath Mountains Ecoregion. Those in the extreme eastern portion of the basin, toward the headwaters of the north Umpqua River, also clustered together within the Cascades Ecoregion and all reflecting the strong influences identified in the first PCs.

Discussion

Our analysis indicates that the most influential factors for the ESU overall tended to be physiographic, both ecoregion distribution and lithology, while the most influential factors for the Umpqua River Basin tended to be climate variables. Throughout the ESU, the watersheds tended to be clustered by ecoregion. This is unsurprising given the nature of the ecoregion data as a consolidated biogeographic measure that incorporates the effects of climate and geology.

The first PC for the ESU-level analysis strongly separated the cluster of watersheds in the extreme eastern portion of the Umpqua River basin from the rest of the ESU. The first PC for the Umpqua River Basin analysis made a similar separation. These watersheds are generally in the Cascades ecoregion, tend to have higher elevation, lower mean temperatures, and substantially later peak stream flows than the rest of the ESU. These differences are clearly identified in the cluster analysis for both the ESU and the Umpqua River Basin, where these watersheds (with some variation on the western edge of the group) clustered together before any others. This indicates unique environmental conditions in this area.

The first PC in the ESU-level analysis also identified the influence of two watersheds with predominantly volcanic lithology (the Salmonberry River and Upper Siletz River watersheds). The Upper Siletz River is not used by coho salmon (ODFW 2003c). Burnett et al. (2003) found no areas of high intrinsic potential in either watershed, indicating poor potential for supporting coho salmon.

The clusters identified in the Umpqua Basin clearly identified similarities between the watersheds within the North Umpqua River fourth-field basin, as well as within those in the South Umpqua River Basin. Again, these watershed clusters strongly reflected ecoregion structure, as well as precipitation patterns. When considering the Umpqua River Basin PCA, the cluster including the upper Smith River, middle Umpqua River, upper Umpqua River, and Elk Creek watersheds includes mostly area in the Coast Range ecoregion but some area in the Willamette Valley ecoregion, and is clustered together in part because of their substantially lower annual precipitation than the watersheds closer to the Pacific Ocean.

The strong and consistent cluster patterns in the Umpqua River Basin indicate the presence of areas with related environmental conditions, likely influencing habitat attributes in ways important to coho salmon. The major ecological differences identified between areas within the ESU and particularly the Umpqua River Basin are potentially evidence for isolation of populations within the basin and may result in genetic structure over time.
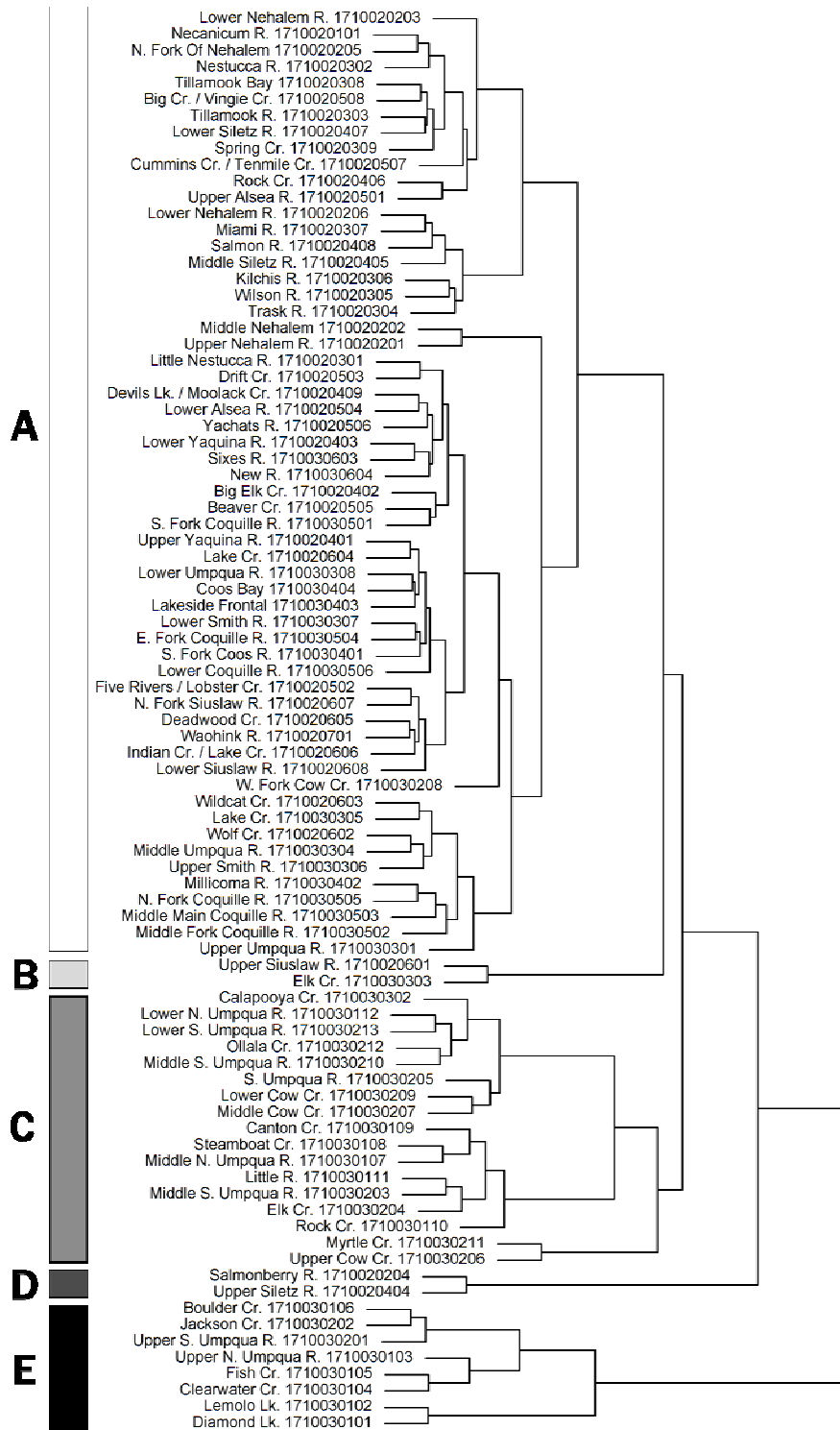
Figure D-1. Dendrogram showing clustering of the first three principal components for environmental data in the Oregon Coast Coho Salmon ESU, using the average distance method of agglomerative hierarchical clustering. Each watershed is identified by name and fifth-field watershed hydrologic unit code. The shaded boxes on the left identify the shaded clusters in Figure D-2.
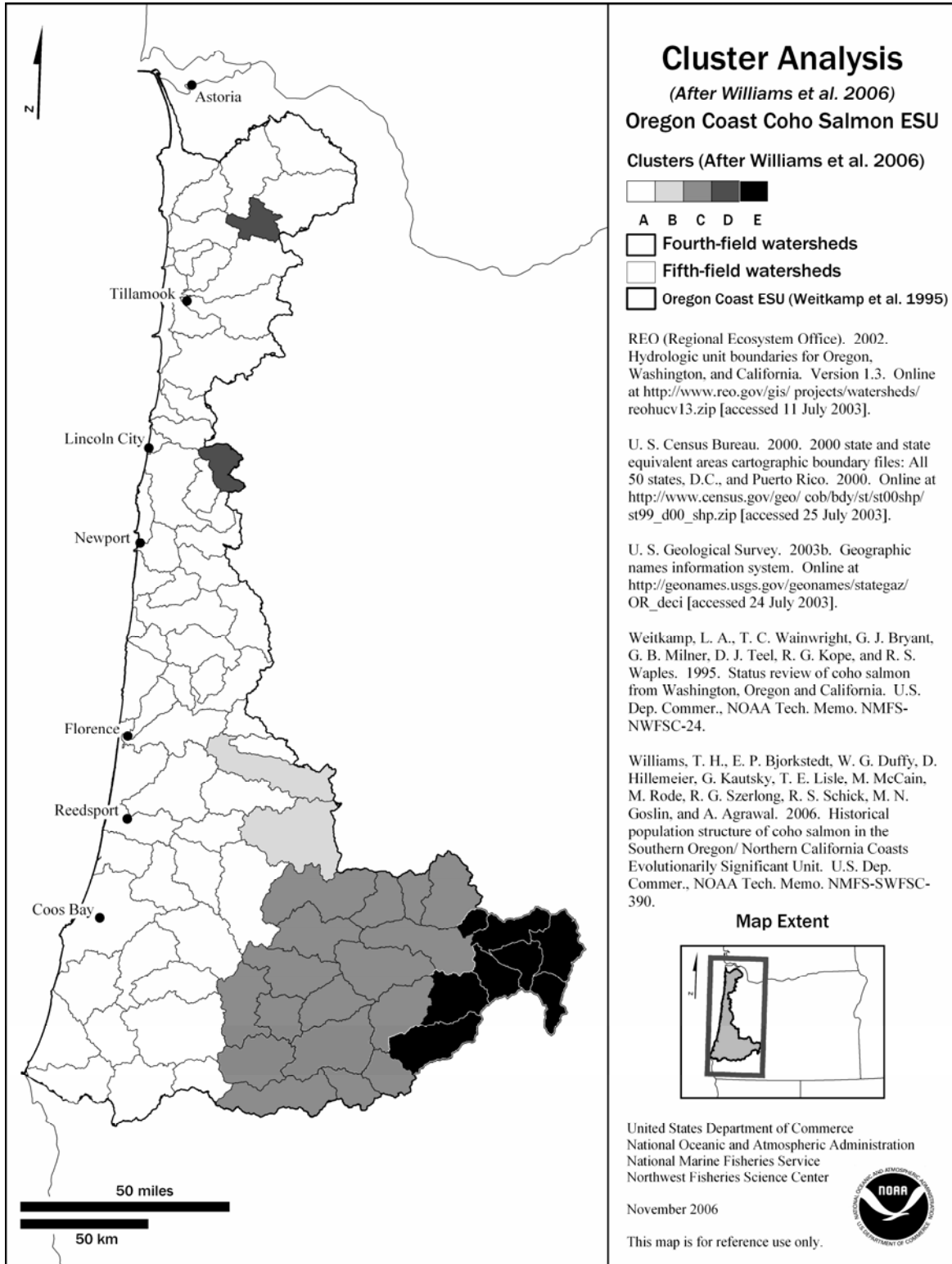
Figure D-2. The first five clusters from cluster analysis of the first three principal components for environmental data from the Oregon Coast Coho Salmon ESU. Each cluster is identified by shading corresponding to the shading used to identify groups in Figure D-1. These clusters resulted from average distance method analysis.
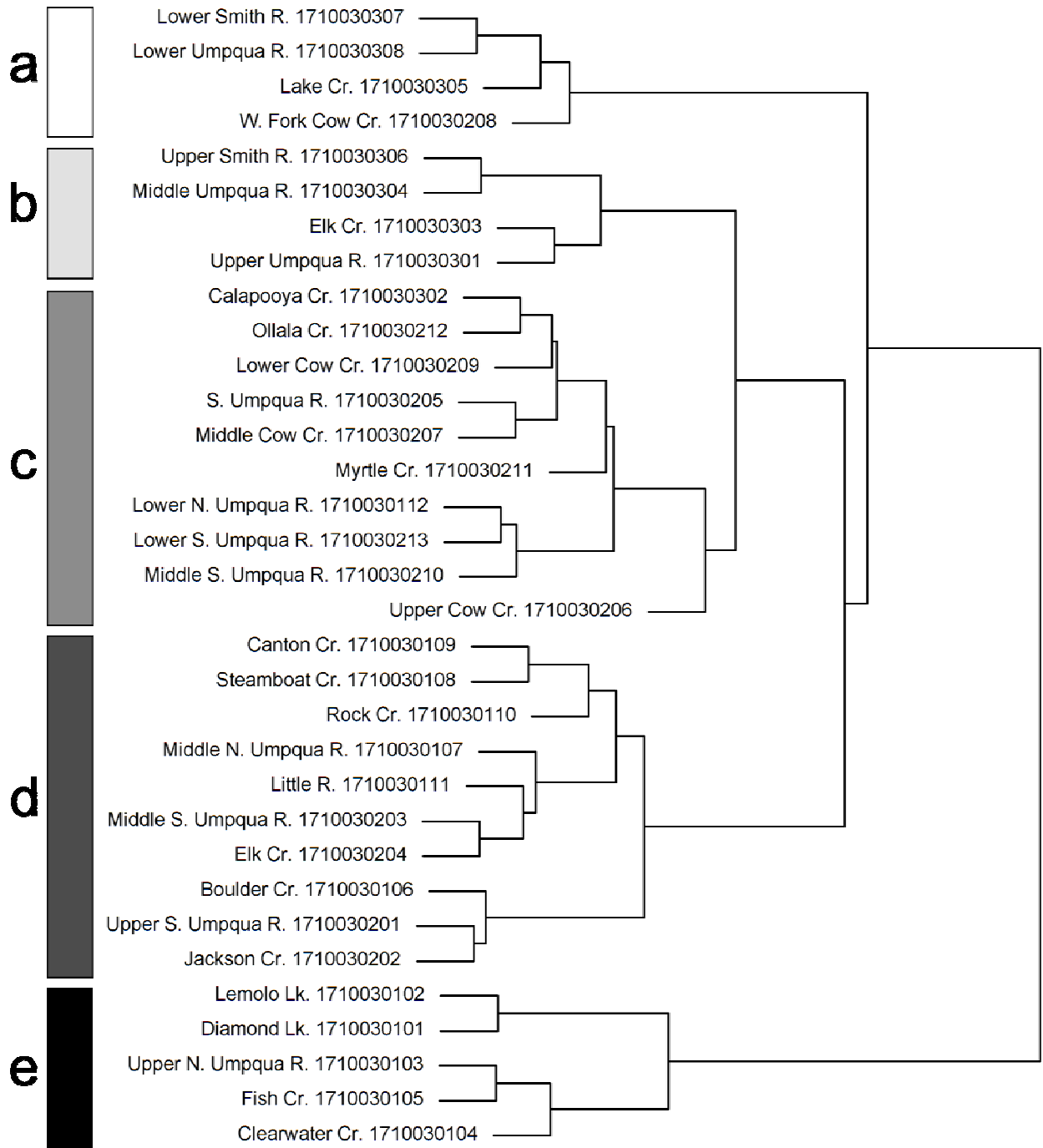
Figure D-3. Dendrogram of heirarchical clustering of the first three principal components for environmental data for watersheds within the Umpqua River Basin. The shaded boxes on the left identify the shaded clusters in Figure D-4. This dendrogram shows clusters resulting from the average distance method.
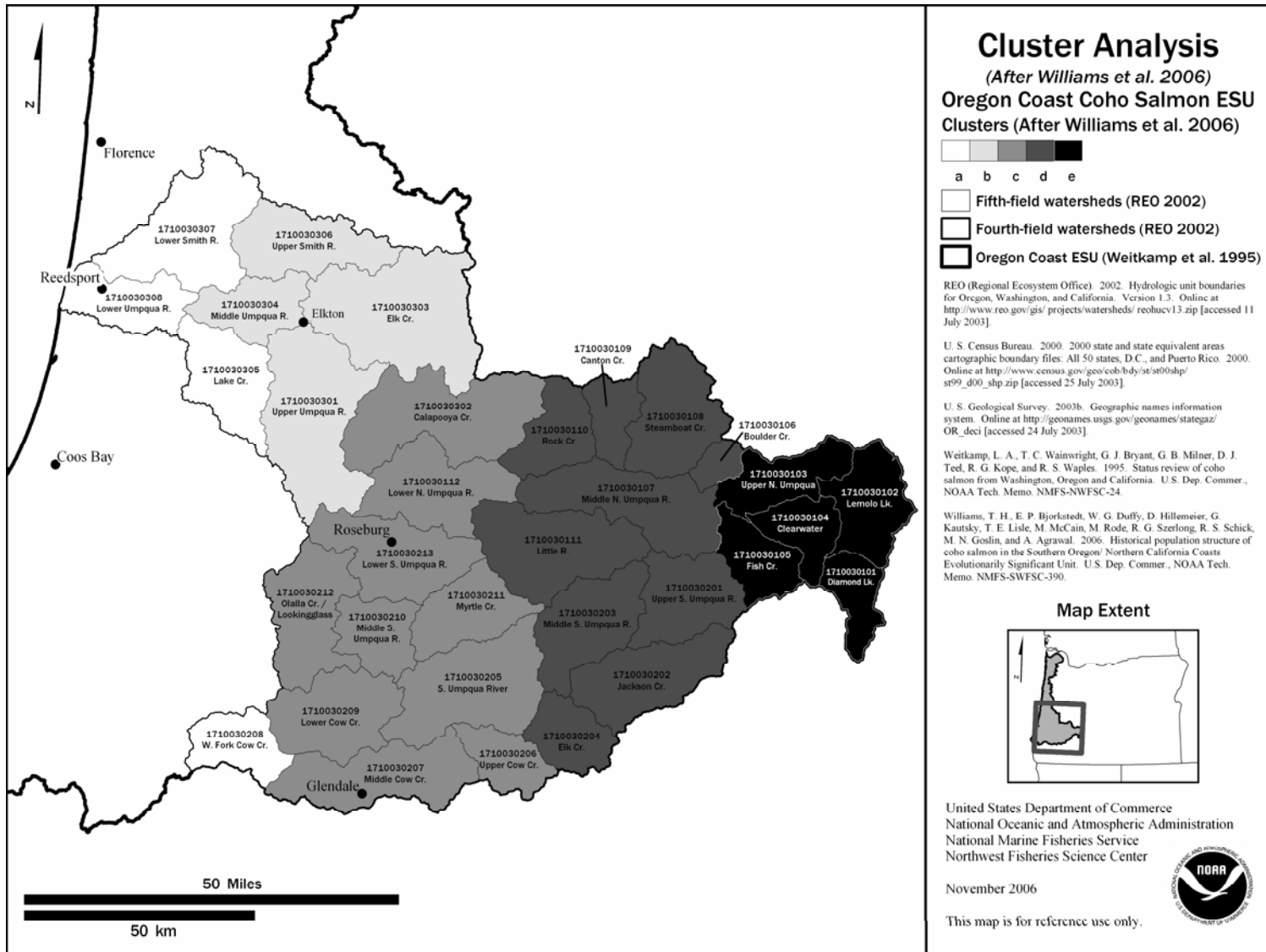
Figure D-4. Clusters of fifth-field watersheds in the Umpuqa River Basin identified by shading corresponding to groups shown in Figure D-3. These are the first five clusters identified in the average distance analysis.

129

Recent NOAA Technical Memorandums
published by the
Northwest Fisheries Science Center

NOAA Technical Memorandum NMFS-NWFSC-

78 **Ruckelshaus, M.H., K.P. Currens, W.H. Graeber, R.R. Fuerstenberg, K. Rawson, N.J. Sands, and J.B. Scott. 2006.** Independent populations of Chinook salmon in Puget Sound. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-78, 125 p. NTIS number PB2007-104920.

77 **Sloan, C.A., D.W. Brown, G.M. Ylitalo, J. Buzitis, D.P. Herman, D.G. Burrows, G. Yanagida, R.W. Pearce, J.L. Bolton, R.H. Boyer, and M.M. Krahn. 2006.** Quality assurance plan for analyses of environmental samples for polycyclic aromatic compounds, persistent organic pollutants, fatty acids, stable isotope ratios, lipid classes, and metabolites of polycyclic aromatic compounds. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-77, 30 p. NTIS number PB2007-104919.

76 **Gustafson R.G., J. Drake, M.J. Ford, J.M. Myers, E.E. Holmes, and R.S. Waples. 2006.** Status review of Cherry Point Pacific herring *(Clupea pallasii)* and updated status review of the Georgia Basin Pacific herring distinct population segment under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-76, 182 p. NTIS number PB2007-104918.

75 **Keller, A.A., B.H. Horness, V.J. Tuttle, J.R. Wallace, V.H. Simon, E.L. Fruh, K.L. Bosley, and D.J. Kamikawa. 2006.** The 2002 U.S. West Coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-75, 189 p. NTIS PB2006-111432.

74 **Pool, S.S., and R.D. Brodeur. 2006.** Neustonic mesozooplankton abundance and distribution in the northern California Current, 2000 and 2002. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-74, 76 p. NTIS PB2006-109275.

73 **Myers, J., C. Busack, D. Rawding, A. Marshall, D. Teel, D.M. Van Doornik, and M.T. Maher. 2006.** Historical population structure of Pacific salmonids in the Willamette River and lower Columbia River basins. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-73, 311 p. NTIS PB2006-109278.

72 **Keller, A.A., E.L. Fruh, K.L. Bosley, D.J. Kamikawa, J.R. Wallace, B.H. Horness, V.H. Simon, and V.J. Tuttle. 2006.** The 2001 U.S. West Coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-72, 175 p. NTIS PB2006-109277

71 **Nash, C.E., P.R. Burbridge, and J.K. Volkman (editors). 2005.** Guidelines for ecological risk assessment of marine fish aquaculture. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-71, 90 p. NTIS PB2006-109287.

70 **Keller A.A., T.L. Wick, E.L. Fruh, K.L. Bosley, D.J. Kamikawa, J.R. Wallace, and B.H. Horness. 2005.** The 2000 U.S. West Coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-70, 163 p. NTIS PB2006-109276.

Most NOAA Technical Memorandums NMFS-NWFSC are available online at the Northwest Fisheries Science Center web site (http://www.nwfsc.noaa.gov).