Review of the Status of Chinook Salmon (*Oncorhynchus tshawytscha*) from Washington, Oregon, California, and Idaho under the U.S. Endangered Species Act

Prepared by the
West Coast Chinook Salmon Biological Review Team

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EXECUTIVE SUMMARY

In 1994, the National Marine Fisheries Service (NMFS) received a petition (PRO-salmon 1994) requesting the listing of four populations of chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound as threatened or endangered species under the federal Endangered Species Act (ESA). In response to this petition and the more general concerns for the status of Pacific salmon throughout the region, NMFS announced that it would initiate ESA status reviews for all species and populations of anadromous salmonids in the states of Washington, Idaho, Oregon, and California. Subsequently, NMFS received a petition (ONRC and Nawa 1995) to list all chinook salmon south of British Columbia under the ESA.

The ESA allows the listing of “distinct population segments” of vertebrates as well as named species and subspecies. The policy of the NMFS on this issue for anadromous Pacific salmonids is that a population will be considered “distinct” for purposes of the ESA if it represents an evolutionarily significant unit (ESU) of the species as a whole. To be considered an ESU, a population or group of populations must 1) be substantially reproductively isolated from other populations, and 2) contribute substantially to the ecological or genetic diversity of the biological species. Once an ESU is identified, a variety of factors related to population abundance are considered in determining whether a listing is warranted.

West Coast Chinook Salmon ESUs

Previous status reviews conducted by the NMFS have identified three ESUs of chinook salmon in the Columbia River: Snake River fall-run (Waples et al. 1991), Snake River spring- and summer-run (Matthews and Waples 1991), and mid-Columbia River summer- and fall-run chinook salmon (Waknitz et al. 1995). In addition, prior to development of the ESU policy, the NMFS recognized Sacramento River winter chinook salmon as a "distinct population segment" under the ESA (NMFS 1987). In reviewing the biological and ecological information concerning west coast chinook salmon, the Biological Review Team (BRT) identified 11 additional ESUs for chinook salmon from Washington, Oregon, and California. Genetic data (from protein electrophoresis and DNA analysis) and tagging information were key factors considered for the reproductive isolation criterion, supplemented by inferences about barriers to migration created by natural features. Life-history differences were another important consideration in the designation of ESUs. The BRT utilized the classification system developed by Healey (1983, 1991) to describe the two races of chinook salmon: 1) ocean-type populations which typically migrate to seawater in their first year of life and spend most of their oceanic life in coastal waters, and 2) stream-type populations which migrate to sea as yearlings and often make extensive oceanic migrations. Genetic differences, as measured by variation in allozymes, indicate that the ocean- and stream-type races represent two major (and presumably monophyletic) evolutionary lineages. A number of additional factors were considered to be important in evaluations of ecological/genetic diversity, with data on life-history characteristics (especially ocean distribution, time of freshwater entry, age at smoltification and at maturation) and geographic, hydrological, and environmental characteristics being particularly informative.

Chinook Salmon ESUs

1) Sacramento River Winter-Run ESU

This ESU includes the Upper Sacramento River below Keswick Dam. Historically, winter-run populations existed in the Upper Sacramento, Pit, McCloud, and Calaveras Rivers. Winter-run chinook salmon were distinguished from other chinook salmon populations in the Sacramento River Basin based on their unique run-timing and genetic characteristics. Adult winter-run chinook salmon enter the Sacramento River from November to June and spawn from late-April to mid-August, with a peak from May to June. No other chinook salmon population has a similar life-history pattern. In general, winter-run chinook salmon exhibit an ocean-type life-history strategy, and remain near the coasts of California and Oregon during their marine residence. Winter-run chinook salmon also mature at a relatively young age (2-3 years old). DNA analysis indicates substantial genetic differences between winter-run and other chinook salmon temporal runs in the Sacramento River.

2) Central Valley Spring-Run ESU

This ESU contains the Sacramento River Basin and includes chinook salmon entering the Sacramento River from March to July and spawning from late August through early October, with a peak in September. Spring-run fish in the Sacramento River exhibit an ocean-type life history, emigrating as fry, subyearlings, and yearlings. Marine coded-wire-tag (CWT) recoveries are primarily from fisheries off the California and Oregon coast. Differences in adult size, fecundity, and smolt size were also observed between spring- and fall-run chinook salmon in the Sacramento River. DNA analyses indicates moderate differences between the spring, fall, and late-fall runs in the Sacramento River.

3) Central Valley Fall-Run ESU

This ESU contains the Sacramento and San Joaquin River Basins and includes fall and late-fall run chinook salmon. These populations enter the Sacramento and San Joaquin Rivers from July through March and spawn from October through March. Fish in this ESU are ocean-type chinook salmon, emigrating predominantly as fry and subyearlings, remaining off the California coast during their ocean migration. Fall-run chinook salmon in the Sacramento and San Joaquin River Basins are physically and genetically distinguishable from coastal forms.

4) Southern Oregon and California Coastal ESU

This ESU includes native spring and fall runs of chinook salmon south of Cape Blanco, Oregon. Historically, the range may have extended to the Ventura River in California, but currently does not extend south of San Francisco Bay, California. Also included in this ESU are populations in the Klamath River Basin from the mouth upriver to the confluence of the Trinity and Klamath Rivers. Chinook salmon in this ESU exhibit an ocean-type life history, with marine distribution predominantly off the California and Oregon coasts. In contrast, populations north of Cape Blanco (ESU 5) migrate in a northerly direction, travelling as far north as British Columbia and Alaska. The Cape Blanco region is a major biogeographic boundary for numerous species. Fall-run populations predominate in this ESU, with the exception of the Rogue River Basin where there is a substantial spring run. The status of naturally-spawning chinook salmon in San Francisco Bay was not determined by the BRT due to a lack of information. Furthermore, the BRT was unable to document the existence of extant naturally-spawning chinook salmon populations south of San Francisco Bay. Ecologically, the majority of the river systems in this ESU are relatively small and heavily influenced by a maritime climate.

5) Upper Klamath and Trinity Rivers ESU

This ESU includes fall- and spring-run chinook salmon in the Klamath and Trinity River Basin upstream of the confluence of the Klamath and Trinity Rivers. Historically, spring-run chinook salmon were probably the predominant run. This ESU still retains several distinct spring-run populations, albeit at much reduced abundance levels. As with all chinook salmon populations south of the Columbia River, fish from this ESU exhibit an ocean-type life history; however, genetically and physically, these fish are quite distinct from coastal (ESU 4 and 6) and Central Valley chinook salmon (ESU 1, 2, and 3). Marine recoveries of CWTs indicate that both the fall and spring runs have a coastal distribution off the California and Oregon coasts.

6) Oregon Coast ESU

This ESU contains coastal basins north of, and including, the Elk River, Oregon, to the mouth of the Columbia River. This ESU includes fall, summer, and spring runs of chinook salmon, with fall-run fish predominating in this ESU. With the exception of the Umpqua River Basin, the majority of streams in the ESU are relatively short. The marine distribution, age structure, and genetic characteristics of fish from this ESU are very different from neighboring ESUs (ESU 4 and 9), although somewhat similar to that of fish from the Washington Coast (ESU 7).

7) Washington Coast ESU

This ESU contains coastal basins north of the mouth of the Columbia River to, but not including, the Elwha River. This ESU includes fall, summer, and spring runs of chinook. These fish exhibit an ocean-type life history (as do all coastal stocks in Washington, Oregon, and California), but their marine distribution and age structure differs considerably from fish in the Puget Sound (ESU 8) and Lower Columbia River (ESU 9) ESUs. Fish in this ESU generally mature at 3-, 4-, and 5-years-old and migrate in a northerly direction to British Columbian and Alaskan coastal waters.

8) Puget Sound ESU

This ESU contains coastal basins of the eastern part of the Strait of Juan de Fuca, Hood Canal, and Puget Sound. This includes the Elwha River and extends to the Nooksack River Basin and the U.S. Canadian Border. Spring-, summer-, and fall-run chinook salmon are included in this ESU. Puget Sound chinook salmon tend to mature at ages 3 and 4, and are not recovered in Alaskan waters to the same extent as fish from the Washington coast (ESU 7). The genetic and life-history characteristics of Puget Sound chinook salmon are very distinct from the adjacent Washington Coast ESU (ESU 7); however, the Elwha River chinook salmon were somewhat intermediate between the two ESUs.

9) Lower Columbia River ESU

This ESU contains tributaries to the Columbia River from the mouth of the Columbia River to, but not including, the Klickitat River. This includes natural fall- and spring-run chinook salmon, with the exception of spring-run chinook salmon in the Willamette River Basin above Willamette Falls (see ESU 10). Chinook salmon in this ESU were genetically distinct from their neighboring ESUs, and exhibited distinctive life-history traits (age at maturation) and ocean-migration distribution.

10) Upper Willamette River ESU

This ESU contains the Willamette River Basin above the Willamette Falls. The ESU includes natural spring-run chinook salmon, but excludes fall-run chinook salmon that were introduced above the Willamette Falls. These fish exhibit an ocean-type life history, and are very distinct from adjacent ESUs genetically, in their age structure, and in marine distribution. Furthermore, the geography and ecology of the Willamette Valley is considerably different from surrounding areas. Historically, migratory access above Willamette Falls was only possible during a narrow temporal window, which provided a powerful isolating mechanism for upper Willamette River spring-run stocks.

11) Mid-Columbia River Spring-Run ESU

This ESU includes tributaries to the Columbia River from the Klickitat River Basin upstream to include the Yakima River Basin, excluding the Snake River Basin. This ESU includes natural spring-run chinook salmon that exhibit a stream-type life history. Genetically and morphologically, this ESU is very distinct from ocean-type spring-run chinook salmon which exist in the Lower Columbia River ESU, and fall-run (ocean-type) fish which cohabit the same rivers as fish belonging to this ESU. Streams in this region drain desert areas east of the Cascades (Columbia Basin Ecoregion) and are ecologically differentiated from the colder, less productive, glacial streams of the upper-Columbia River Spring-Run ESU and from the generally higher elevation streams of the Snake River.

12) Upper-Columbia River Summer- and Fall-Run ESU

This ESU contains tributaries to the Columbia River upstream of the confluence of the Snake and Columbia Rivers to the Chief Joseph Dam. It includes fall- and summer-run (ocean-type) chinook salmon, with the exception of chinook salmon which spawn in the Marion Drain, an irrigation collection canal to the Yakima River (see Status Review). Summer-run fish in this ESU were heavily influenced by the Grand Coulee Fish Maintenance Project (1939-43), whereby fish returning to spawn in the upper Columbia River were trapped at the Rock Island Dam, downstream of the Wenatchee River. Some of these fish were released into enclosed sections of the Wenatchee and Entiat Rivers to spawn naturally, while others were spawned in hatcheries. The result of this project was the mixing of multiple populations into one relatively homogenous group.

13) Upper Columbia River Spring-Run ESU

This ESU includes tributaries to the Columbia River upstream from the Yakima River to the Chief Joseph Dam. It includes spring-run chinook salmon in the Wenatchee, Entiat, and Methow River Basins. These fish all exhibit a stream-type life history. Although slight genetic differences exist between this ESU and the other ESUs containing stream-type fish (see ESU 11 and 15), ecological differences in spawning and rearing habitats between these stream-type ESUs were important in establishing the ESU boundaries. Fish in this ESU were also influenced by the Grand Coulee Fish Maintenance Project (1939-43). The result of this project was the mixing of multiple populations into one relatively homogenous group.

14) Snake River Fall-Run ESU

This ESU contains tributaries to the Columbia River from the Dalles Dam to the confluence of the Snake and Columbia Rivers, including the Snake River Basin. It includes all native populations of fall-run chinook salmon in the mainstem Snake River and the following subbasins: Deschutes, John Day, Tucannon, Grand Ronde, Imnaha, Salmon, and Clearwater Rivers. Previously, this ESU had only included fall-run chinook salmon from the Snake River Basin, but based on new information presented in this review the ESU was expanded to include the Columbia River populations listed above. Fish from this ESU exhibit an ocean-type life history. Genetic- and ocean-migration differences contrast fish from this ESU with those from ESU 12. The BRT also noted ecological differences between the Snake River Basin and the upper-Columbia River (above the confluence of the Snake River).

15) Snake River Spring- and Summer-Run ESU

This ESU includes tributaries to the Snake River upstream of the Snake and Columbia Rivers' confluence. It includes all natural populations of spring- and summer-run chinook salmon in the mainstem Snake River and the following subbasins: Tucannon River, Grand Ronde River, Imnaha River, and Salmon River. Although genetic differences between this and other stream-type ESUs (ESU 11 and 13) are moderate, ecological differences in spawning and rearing habitat were substantial enough to warrant the establishment of distinct ESUs. Genetically and behaviorally, these fish are very different from the ocean-type fall-run fish that exist in the Snake River Basin.

Assessment of Extinction Risk

The ESA (section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the ESA, the determination as to whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place.

For the purposes of this review, the BRT did not evaluate likely or possible effects of conservation measures and therefore did not make recommendations as to whether identified ESUs should be listed as threatened or endangered species. The BRT did, however, draw scientific conclusions about the risk of extinction faced by ESUs under the assumption that present conditions will continue.

With respect to the 11 newly-identified ESUs, the BRT concluded that two (Sacramento River Spring Run and Upper Columbia River Spring Run) are at risk of extinction, primarily due to seriously depressed abundance. Five ESUs (Central Valley Fall Run, Southern Oregon and California Coast, Puget Sound, Lower Columbia River, and Upper Willamette River) are at risk of becoming endangered, due to a variety of factors. Only four ESUs (Upper Klamath and Trinity

Rivers, Oregon Coast, Washington Coast, and Middle Columbia River Spring Run) are not at risk of extinction or endangerment.

Chinook Salmon ESUs

1) Sacramento River Winter-Run ESU

Historically, the winter run was abundant and comprised populations in the McCloud, Pit, Little Sacramento, and Calaveras Rivers. Presently, the ESU has been reduced to a single spawning population confined to the mainstem Sacramento River below Keswick Dam. Since counting began in 1967, the population has been declining at an average rate of 18% per year, or roughly 50% per generation. This ESU is currently listed as endangered under the California Endangered Species Act and was listed as threatened in 1989 and reclassified as endangered in 1994 under the U.S. Endangered Species Act.

2) Central Valley Spring-Run ESU

Spring-run chinook salmon were once the predominant run in the Central Valley. Dam construction and habitat degradation has eliminated spring-run populations from the entire San Joaquin River Basin and from many tributaries to the Sacramento River Basin. Abundance has declined dramatically from historical levels, and much of the present day production is from artificial propagation. There are only a few naturally-spawning populations remaining and these all have relatively low abundances (<1000). Furthermore, there is concern that the hatchery propagated spring-run fish have been inadvertently hybridized with fall-run fish. Hatchery release practices result in high levels of straying and an increased potential for hatchery strays spawning with native fish. The majority of the BRT concluded that this ESU was at risk of extinction in the foreseeable future.

3) Central Valley Fall-Run ESU

Total abundance in this ESU is relatively high, perhaps near historical levels. However, the status of populations in the San Joaquin River Basin are extremely depressed. Spawning and rearing habitat quality throughout the ESU are severely impacted by agricultural and municipal water use activities. Returns to the hatcheries account for 20% of the spawning escapement, and hatchery strays spawning in the wild may account for an further 30% of the spawning escapement. The exchange of stocks between Central Valley hatcheries may have resulted in considerable loss of among-population genetic diversity. Furthermore, naturally-spawning populations that are least influenced by hatchery strays are experiencing generally negative trends in abundance. Finally, relatively high ocean and freshwater harvest rates may threaten the sustainability of naturally spawning populations. The majority of the BRT felt that this ESU is likely to become at risk of extinction in the foreseeable future.

4) Southern Oregon and California Coastal ESU

Populations in this ESU have generally experienced declines in abundance from historical levels, with the exception of populations in the Rogue River. Spring-run populations outside of the Rogue River have undergone severe declines. There is an almost complete lack of data for coastal rivers south of the Klamath River, and many rivers which historically sustained large populations of fall-run chinook salmon contain severely reduced populations or their populations have been extirpated. The BRT unanimously concluded that this ESU was likely to become at risk of extinction in the foreseeable future.

5) Upper Klamath and Trinity Rivers ESU

Fall-run populations in this ESU are at relatively high abundances, near historical levels, and trends are generally stable. Hatchery production contributes significantly to total escapement. In contrast, spring-run abundance is at only 10% of historical levels, and much of the present production is hatchery-derived. Dam construction eliminated much of the historical spring-run spawning and rearing habitat and was responsible, in part, for the extirpation of at least seven spring-run populations. Due to the disparity in risk status between spring and fall runs, the BRT had considerable difficulty in evaluating the status of this ESU. The majority of the BRT concluded that this ESU, as a whole, was not presently at significant risk of extinction, but there was substantial concern for the status of spring-run populations.

6) Oregon Coast ESU

Total abundance in this ESU is relatively high. Long-term trends for populations are generally upward, although a number of populations are experiencing severe short-term trends in abundance. Spring-run populations are generally in better condition in this ESU than in other coastal ESUs. Hatchery production appears to be a relatively minor component of total escapement. The BRT unanimously concluded that chinook salmon in this ESU are not in danger of extinction nor are they likely to become so in the foreseeable future.

7) Washington Coast ESU

Long-term trends for most populations in this ESU have been upward; however, several smaller populations are experiencing sharply downward trends. Fall-run populations are predominant and tended to be at a lower risk than spring or summer runs. Hatchery production is significant in the southern portion of this ESU, whereas the majority of the populations in the northern portion of the ESU have minimal hatchery influence. The BRT unanimously concluded that chinook salmon in this ESU are not in danger of extinction nor are they likely to become so in the foreseeable future.

8) Puget Sound ESU

Total abundance in the ESU is relatively high; however, much of this production is hatchery-derived. Both long- and short-term trends in abundance are predominantly downward, and several populations are exhibiting severe short-term declines. Spring-run chinook salmon populations throughout this ESU are all depressed. The BRT was concerned that the high level of hatchery production is masking more severe underlying trends in abundance. In many areas, spawning and rearing habitats were severely degraded and migratory access restricted or eliminated. A majority of the BRT concluded that this ESU is likely to become endangered in the foreseeable future.

9) Lower Columbia River ESU

Abundance in this ESU is relatively high; however, the majority of the fish appear to be hatchery-produced. The chinook salmon fall run in the Lewis River appears to be the only healthy naturally-produced population in this ESU. Long- and short-term trends in abundance are mostly negative, some severely so. The numbers of naturally-spawning spring runs are very low, in fact, the BRT was unable to identify any healthy native spring-run populations. The pervasive influence of hatchery fish in almost every river in this ESU and the degradation of freshwater habitat suggested that many naturally-spawning populations are not able to replace themselves. The majority of the BRT concluded that this ESU is likely to become endangered in the foreseeable future.

10) Upper Willamette River ESU

Total abundance in this ESU is relatively high (20,000-30,000 adults) and stable; however, approximately 10% of escapement spawns naturally, and of the natural spawners more than half are first-generation hatchery strays. The introduction of non-native fall-run chinook salmon above Willamette Falls is viewed as a potential risk to the genetic integrity of this ESU. Furthermore, exchanges of fish between hatcheries in this ESU has most likely lead to the homogenization of populations within the ESU, although this ESU is still quite distinct from adjacent ESUs. The majority of the historical spawning habitat is now inaccessible, and the remaining habitat is quite limited and degraded. The majority of the BRT concluded that this ESU is likely to become endangered in the foreseeable future.

11) Mid-Columbia River Spring-Run ESU

Total abundance in the ESU has declined considerably from historical levels, but appears to be relatively stable during recent years. Natural production accounts for most of the escapement in the Yakima and Deschutes River Basins. Habitat degradation, especially due to agricultural practices, affects most of the rivers in this ESU. The majority of the BRT concluded that chinook salmon in this ESU are not in danger of extinction nor are they likely to become so in the foreseeable future.

12) Upper-Columbia River Summer- and Fall-Run ESU

Total abundance in this ESU is quite high, although naturally spawning chinook salmon in the Hanford Reach are responsible for the vast majority of the production. The BRT was concerned about the recent decline in summer-run populations in this ESU, and the apparent increase in the contribution of hatchery return to total escapement. It was unclear if, under current conditions, the naturally spawning summer-run chinook salmon populations are self-sustaining. In an earlier review, this ESU was determined to be neither at risk of extinction nor likely to become so, and its status was not reviewed in detail here.

13) Upper Columbia River Spring-Run ESU

Recent total abundance in this ESU is quite low, and escapements from 1994-96 were the lowest in 60 years. At least 6 populations of spring-run chinook salmon in the ESU have been extirpated, and almost all remaining naturally-spawning populations have fewer than 100 spawners. Hydrosystem development has blocked access to much historical habitat and directly impeded adult and smolt migrations. The majority of the BRT concluded that this ESU is currently at risk of extinction.

14) Snake River Fall-Run ESU

Historically the Snake River component of this ESU was the predominant source of production. Currently the five-year average for Snake River fall-run chinook salmon is about 500 adults (compared with 72,000 in the 1930s and 1940s). The abundance of naturally-spawning fish in the Deschutes River has averaged about 6,000 fish (1990-96). There is some uncertainty as to the origins of fish spawning in the lower Deschutes River, and their relationship to fish in the upper Deschutes River (above Sherars Falls). Extirpated populations in the John Day, Umatilla, and Walla Walla Rivers are believed to have belonged to this ESU. Hydrosystem development blocks access to most of the historical spawning habitat in the Snake River portion of this ESU, as well as affecting migration corridors. Snake River fall-run chinook salmon are currently listed as a threatened species under the U.S. ESA. The BRT concluded that the newly defined ESU (which includes the Deschutes River population) is likely to become in danger of extinction in the foreseeable future.

15) Snake River Spring- and Summer-Run ESU

Recent abundance of the naturally-spawning population for this ESU has averaged about 2,500 fish, compared to historical levels of approximately 1.5 million. Both long- and short-term trends are negative for all populations. A number of populations have been extirpated in this ESU, primarily due to dam construction. This ESU is presently listed as a threatened species under the U.S. ESA and was not reviewed further in this document.

ACKNOWLEDGMENTS

The status review for west coast chinook salmon was conducted by a team of scientists from the National Marine Fisheries Service (NMFS) and the U.S. Geological Survey (USGS). The members of the biological review team (BRT) contributed a substantial amount of time and effort to this process. The BRT included: Peggy Busby, Dr. Stewart Grant, Dr. Robert Iwamoto, Dr. Robert Kope, Dr. Conrad Mahnken, Gene Matthews, Dr. James Myers, Philip Roni, Dr. Michael Schiewe, David Teel, Dr. Thomas Wainwright, F. William Waknitz, Dr. Robin Waples, and Dr. John Williams of NMFS Northwest Fisheries Science Center; Gregory Bryant and Craig Wingert of NMFS Southwest Region; Dr. Peter Adams and Dr. Steve Lindley from NMFS Southwest F.S.C. (Tiburon Laboratory); Alex Wertheimer of NMFS Alaska Fisheries Science Center (Auke Bay Laboratory); and Dr. Reg Reisenbichler from the USGS Biological Resource Division. Their review was dependent on information submitted directly to NMFS, which was presented at one of the Biological and Technical Committee meetings, provided in response to queries by NMFS or previously published in reports or the scientific literature. A number of state, federal, and tribal agencies actively provided information and critical review during the status review process. The authors wish to acknowledge in particular the efforts of Lisa Seeb and Penny Crane of the Alaska Department of Fish and Game; Alan Baracco, Colleen Harvey, Bill Loudermilk, Debra McKee, Mike Wallace, Dave McLeod, Larry Preston, and Wade Sinnen from the California Department of Fish and Game; Kathryn Kostow and Jay Nicholas of the Oregon Department of Fish and Wildlife; Susan Bishop, formerly of the Northwest Indian Fisheries Commission; Duane Anderson and Gary Christofferson of StreamNet; Jim Craig and Doug Olsen from U.S. Fish and Wildlife Service; Jerry Boberg and Al Olsen of the U.S. Forest Service; and Anne Marshall, Carol Smith, Bill Tweit, and Bob Woodard of the Washington Department of Fish and Wildlife.

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INTRODUCTION

On 14 March 1994, the National Marine Fisheries Service (NMFS) was petitioned by the Professional Resources Organization-Salmon (PRO-Salmon) to list spring-run populations of chinook salmon (*Oncorhynchus tshawytscha*) in the North Fork and South Fork Nooksack River, the Dungeness River[1], and the White River (Fig. 1) as threatened or endangered species under the Endangered Species Act (ESA) either singly, or in some combination (PRO-Salmon 1994). At about the same time, NMFS also received petitions to list additional populations of other Pacific salmon species in the Puget Sound area. In response to these petitions and the more general concerns for the status of Pacific salmon throughout the region, NMFS announced on 12 September 1994 that it would initiate ESA status reviews for all species of anadromous salmonids in Washington, Oregon, California, and Idaho (NMFS 1994d). This proactive approach was intended to facilitate more timely, consistent, and comprehensive evaluations of the ESA status of Pacific salmonids than would be possible through a long series of reviews of individual populations. Subsequent to this announcement, NMFS was petitioned on 1 February 1995 by the Oregon Natural Resources Council (ONRC) and Siskiyou Project Staff Ecologist Dr. Richard K. Nawa to list 197 stocks of chinook salmon either separately or in some combination.

This document reports results of the comprehensive ESA status review of chinook salmon from Washington, Oregon, California, and Idaho. To provide a context for evaluating these populations of chinook salmon, biological and ecological information for chinook salmon in British Columbia, Alaska, and Asia were also considered. This review thus encompasses, but is not restricted to, the populations identified in the PRO-Salmon and ONRC-Nawa petitions.

Because the ESA stipulates that listing determinations should be made on the basis of the best scientific information available, NMFS formed a team of scientists with diverse backgrounds in salmon biology to conduct this review. This Biological Review Team (BRT) for chinook salmon included: Peggy Busby, Dr. Stewart Grant, Dr. Robert Iwamoto, Dr. Robert Kope, Dr. Conrad Mahnken, Gene Matthews, Dr. James Myers, Philip Roni, Dr. Michael Schiewe, David Teel, Dr. Thomas Wainwright, F. William Waknitz, Dr. Robin Waples, and Dr. John Williams of NMFS Northwest Fisheries Science Center; Gregory Bryant and Craig Wingert of NMFS Southwest Region; Dr. Steve Lindley and Dr. Peter Adams from NMFS Southwest Region (Tiburon Laboratory); Alex Wertheimer of NMFS Alaska Fisheries Science Center (Auke Bay Laboratory); and Dr. Reg Reisenbichler from the USGS Biological Resource Division. NMFS received scientific and technical information from Pacific Salmon Biological and Technical Committees (PSBTCs) convened in Washington, Oregon, and California. Meetings of the PSBTC were not held in Idaho because all chinook salmon populations in Idaho

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[1] The use of the term "spring-run" to describe the chinook salmon returning to the Dungeness River has been discontinued by state, tribal, and federal agencies. It has been replaced with the term "native," but in this report the term "spring-run" has been retained for the purpose of maintaining consistency with older references to the stock.

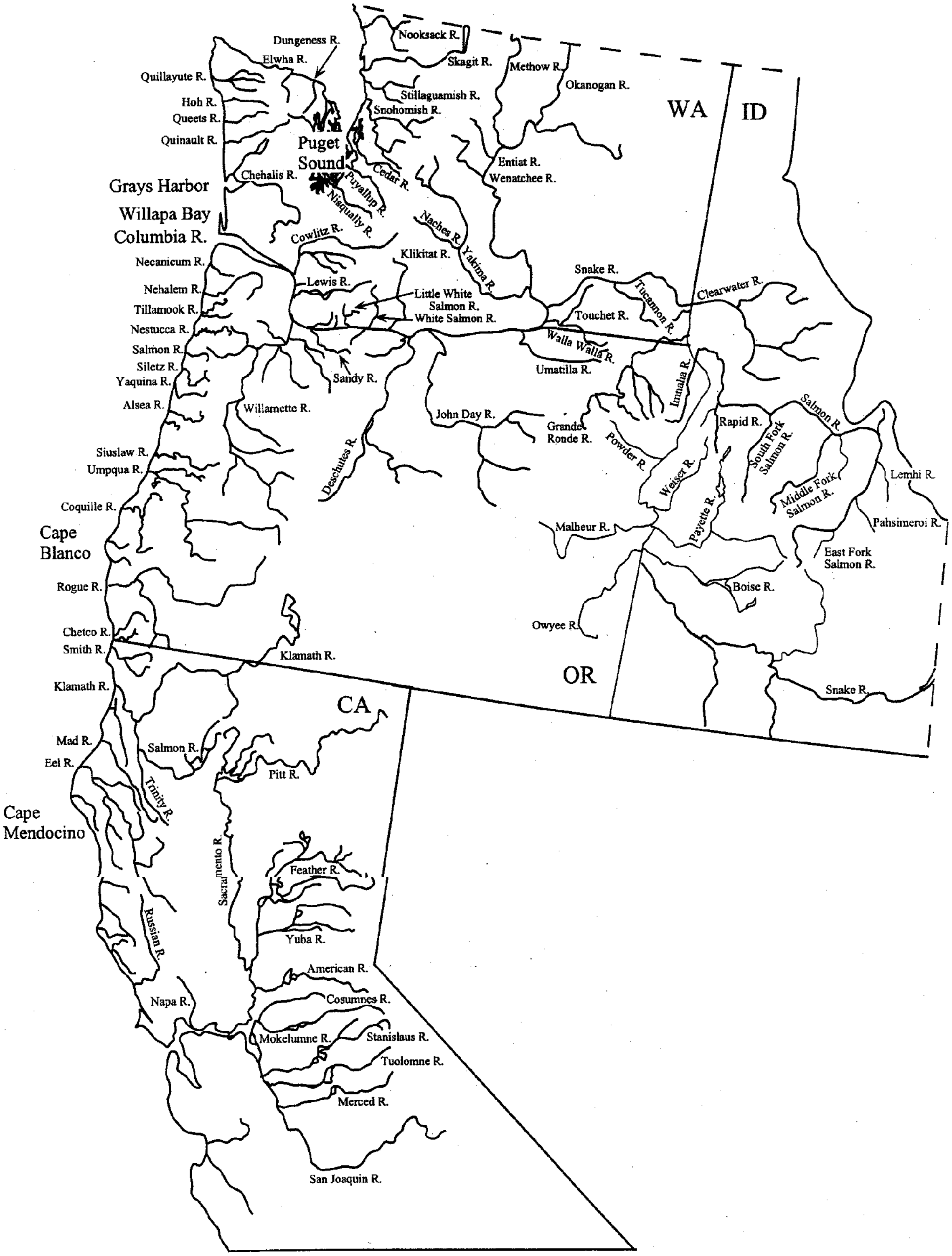

Figure 1. Map showing major rivers and other key geographic features discussed.

are already listed under the ESA. The BRT discussed and evaluated scientific information gathered at the PSBTC meetings, and also reviewed information submitted to the ESA administrative record for chinook salmon, including specific comments by co-managing agencies on a draft version of this document (CDFG 1997b, HVTC 1997, IDFG 1997, LIBC 1997, NWIFC 1997a, ODFW 1997a, and WDFW 1997a, YTFP 1997a).

In determining whether a listing under the ESA is warranted, two key questions must be addressed:

1) Is the entity in question a "species" as defined by the ESA?
2) If so, is the "species" threatened or endangered?

These two questions are addressed in separate sections of this report. If it is determined that a listing(s) is warranted, then NMFS is required by law (1973 ESA Sec. 4(a)(1)) to identify one or more of the following factors responsible for the species' threatened or endangered status: 1) destruction or modification of habitat, 2) overutilization by humans, 3) disease or predation, 4) inadequacy of existing regulatory mechanisms, or 5) other natural or human factors. This status review does not formally address factors for decline; except insofar as they provide information about the degree of risk faced by the species in the future if current conditions continue. A separate document identifies factors for decline of chinook salmon from Washington, Oregon, California, and Idaho, and is presented subsequent to any proposed listing recommendation.

The "Species" Question

As amended in 1978, the ESA allows listing of "distinct population segments" of vertebrates as well as named species and subspecies. However, the ESA provides no specific guidance for determining what constitutes a distinct population, and the resulting ambiguity has led to the use of a variety of criteria in listing decisions over the past decade. To clarify the issue for Pacific salmon, NMFS published a policy document describing how the agency will apply the definition of "species" in the ESA to anadromous salmonid species, including sea-run cutthroat trout and steelhead (NMFS 1991). A more detailed discussion of this topic appeared in the NMFS "Definition of Species" paper (Waples 1991b). The NMFS policy stipulates that a salmon population (or group of populations) will be considered "distinct" for purposes of the ESA if it represents an evolutionarily significant unit (ESU) of the biological species. An ESU is defined as a population that 1) is substantially reproductively isolated from conspecific populations and 2) represents an important component of the evolutionary legacy of the species.

The term "evolutionary legacy" is used in the sense of "inheritance," that is, something received from the past and carried forward into the future. Specifically, the evolutionary legacy of a species is the genetic variability that is a product of past evolutionary events and that represents the reservoir upon which future evolutionary potential depends. Conservation of these genetic resources should help to ensure that the dynamic process of evolution will not be unduly constrained in the future.

The NMFS policy identifies a number of types of evidence that should be considered in the species determination. For each of the criteria, the NMFS policy advocates a holistic approach that considers all types of available information as well as their strengths and limitations. Isolation does not have to be absolute, but it must be strong enough to permit evolutionarily important differences to accrue in different population units. Important types of information to consider include natural rates of straying and recolonization, evaluations of the efficacy of natural barriers, and measurements of genetic differences between populations. Data from protein electrophoresis or deoxyribonucleic acid (DNA) analyses can be particularly useful for this criterion because they reflect levels of gene flow that have occurred over evolutionary time scales.

The key question with respect to the second ESU criterion is, if the population became extinct, would this represent a significant loss to the ecological/genetic diversity of the species? Again, a variety of types of information should be considered. Phenotypic and life-history traits such as size, fecundity, migration patterns, and age and time of spawning may reflect local adaptations of evolutionary importance, but interpretation of these traits is complicated by their sensitivity to environmental conditions. Data from protein electrophoresis or DNA analyses provide valuable insight into the process of genetic differentiation among populations but little direct information regarding the extent of adaptive genetic differences. Habitat differences suggest the possibility for local adaptations but do not prove that such adaptations exist.

Background of Chinook Salmon under the ESA

On 7 November 1985, NMFS received a petition from the American Fisheries Society (AFS) to list the winter-run chinook salmon in the Sacramento River as a threatened species under the federal ESA. NMFS initially announced its decision not to list this population as threatened or endangered on 27 February 1987 (NMFS 1987). Subsequently, the winter-run chinook salmon population experienced a further decline, and an emergency listing to list the population as threatened was made on 4 August 1989 (NMFS 1989); the listing was extended on 2 April 1990 (NMFS 1990a). A final rule to list the Sacramento River winter-run chinook salmon as threatened was made on 5 November 1990 (NMFS 1990b). The winter run continued to decline and was subsequently listed as endangered 4 January 1994 (NMFS 1994b).

On 7 June 1990, NMFS received a petition from Oregon Trout and five co-petitioners to list Snake River spring-run chinook salmon, Snake River summer-run chinook salmon, and Snake River fall-run chinook salmon under the ESA. A final rule was announced on 22 April 1992 (NMFS 1992), which determined that Snake River chinook salmon should be listed as threatened under the ESA. Furthermore, it was determined that the spring- and summer-run populations collectively constituted a separate ESU from the fall-run chinook salmon under the ESA. As a result of record low adult returns in 1994 and projected returns for 1995, an emergency interim rule was announced 18 August 1994 to reclassify the Snake River spring/summer run and Snake River fall run as endangered (NMFS 1994c); however, both Snake River chinook salmon ESUs were subsequently classified (17 April 1995) in a final ruling as being threatened (NMFS 1995a).

A petition for the listing of summer-run chinook salmon in the mid-Columbia River[2] was submitted to NMFS on 3 June 1993, by the American Rivers and ten co-petitioners. On 23 September 1994, NMFS determined that the mid-Columbia River summer-run chinook salmon stocks petitioned did not constitute an ESU, but belonged to a larger fall- and summer-run chinook salmon ESU located along the mainstem Columbia River between the Chief Joseph and McNary Dams (NMFS 1994a). NMFS concluded that this ESU did not warrant a listing of endangered or threatened.

Summary of Information Presented by the Petitioners

This section briefly summarizes information presented by the petitioners (Professional Resources Organization (PRO)-Salmon 1994, Oregon National Resources Council (ONRC) and Nawa 1995) to support their arguments that specific chinook salmon stocks in Washington, Oregon, Idaho, and California qualify as threatened or endangered species under the ESA. Previous ESA petitions for chinook salmon under the ESA have been evaluated and summarized in elsewhere (NMFS 1987, Matthews and Waples 1991, Waples et al. 1991b, Waknitz et al. 1995).

Distinct Population Segments

The PRO-Salmon (1994) petition requested that NMFS evaluate four stocks of chinook salmon in Washington state for listing as threatened or endangered under the ESA: the North Fork Nooksack River spring run, South Fork Nooksack River spring run, Dungeness River spring run, and White River spring run. The petitioners presented several alternative groupings of these stocks into one or more ESUs, which might also include stocks not specifically mentioned in their petition. The ONRC and Nawa (1995) petition listed 197 “stocks” in Washington, Oregon, California, and Idaho to be considered for listing as threatened or endangered, either separately or in one or more ESUs. The authors specifically included non-native stocks, such as Clearwater River spring-run chinook salmon, which contains components of other spring-run stocks from the

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[2] Mid-Columbia was used by the petitioners to refer to the Columbia River Basin between Priest Rapids and Chief Joseph Dams.

Snake River spring- and summer-run ESU. They argued that if an ESU that contains the original components of a mixed stock is identified and listed as threatened or endangered, then the mixed stock should be included in the ESU.

ONRC and Nawa suggested several alternative scenarios for chinook salmon, specifically, to list:

- chinook salmon and their critical habitat as an ESU in Washington, Oregon, California, and Idaho; or

- spring, summer, fall, and winter chinook salmon and their critical habitat as four distinct ESUs; or

- ESUs which comprise one or more of the 197 stocks of chinook salmon (listed in the petition), the four stocks previously petitioned by PRO-Salmon in addition to stocks which belong to the four existing chinook salmon ESUs identified by NMFS, and their critical habitat; or

- each of the 197 stocks of chinook salmon (listed in the petition) and the 4 stocks previously petitioned by PRO-Salmon as separate ESUs, in addition to the 4 existing chinook salmon ESUs identified by NMFS; or

- regional ESUs: (a) spring- and summer-run chinook salmon in Washington, Oregon, California, and Idaho; (b) coastal fall chinook salmon that spawn in rivers and creeks south of Cape Blanco, Oregon (excluding Rogue River fall chinook salmon); (c) Columbia River fall chinook salmon, which spawn in tributaries below McNary Dam; (d) Puget Sound fall and summer/fall chinook salmon (including Sooes River fall chinook salmon on the Washington Coast); and (e) fall chinook salmon from the Central Valley of California (including "wild" fall chinook salmon that spawn in small tributaries to San Francisco Bay) and their critical habitat.

Population Abundance

Both the PRO-Salmon (1994) and ONRC and Nawa (1995) petitions cited extensive information to document the decline of specific chinook salmon stocks. PRO-Salmon (1994) cited the work of Nehlsen et al. (1991), who considered the four stocks of chinook salmon in the petition to be at a high or moderate risk of extinction, and WDF et al. (1993), who identified the status of the four stocks as "critical," based on "chronically low" escapement or redd counts. The spring run on the White River had declined from 5,432 in 1942 to a low of 66 in 1977, and return numbers have averaged less than 200 fish from 1978-91 (PRO-Salmon 1994). Escapement estimates for the North Fork Nooksack River spring run are less accurate because of unfavorable river conditions for sampling. Spawner/redd surveys nevertheless indicate a considerable decrease in stock size.

ONRC and Nawa (1995) surveyed and categorized 417 stocks of chinook salmon, of which they considered 67 (16.1%) to be extinct, 21 (5.0%) nearly extinct, 95 (22.8%) declining, 75 (18.0%) composite production [in which the hatchery contribution exceeds natural production], and a further 37 (8.9%) of unknown status. Using information from a number of sources, the petitioners presented overall and regional estimates of the decline of chinook salmon stocks. Nehlsen et al. (1991) listed 64 stocks of chinook salmon that they determined to be at a high or moderate risk of extinction or of special concern. WDF et al. (1993) determined the status of 40 of the 108 (37.0%) chinook salmon stocks in Washington State to be “critical” or “depressed.” The Wilderness Society (1993) reported that 63% of spring- and summer-run chinook salmon stocks in Washington, Oregon, California, and Idaho were considered to be extinct, with a further 24% being endangered or threatened. Similarly, among fall chinook salmon stocks, 19% were extinct, and 25% endangered or threatened.

On a regional basis, the Central Valley of California had the highest percentage of extinct stocks (40%), with only one wild stock classified as not declining according to ONRC and Nawa (1995). Stocks within the coastal basins south of Cape Blanco, Oregon had also experienced a similar decrease in abundance, with 67% of the stocks classified as extinct, nearly extinct, or declining. Within the Columbia River Basin, chinook salmon stocks below McNary Dam (River Kilometer [RKm] 470) have been heavily influenced by artificial propagation, and only six wild stocks were identified that were not declining. According to ONRC and Nawa, the Columbia River chinook salmon stocks above McNary Dam have experienced the second highest level of extinction (28%), with 44% of the stocks being classified as declining. In the Snake River, the petitioners identified 13 stocks (28%) as being extinct and 22 stocks (47%) to be in decline. No wild stocks were found that were not declining. Among chinook salmon stocks in Puget Sound, 50% of the spring-run stocks were extinct. Only coastal stocks north of Cape Blanco, Oregon were not found to be seriously declining. ONRC and Nawa (1995) presented individual stock historical abundance information for many of the 417 stocks surveyed. This information further documented many of the regional declines noted above.

Causes of Decline for Chinook Salmon

The petitioners identified several factors which they believe have either singly or in combination resulted in the chinook salmon stock declines in abundance described above. Because the petitions cover such a wide geographic area, encompassing several terrestrial and marine ecological regions, and because the populations surveyed have been impacted by varying anthropogenic factors, only a very generalized review of this topic will be given.

PRO-Salmon (1994) and ONRC and Nawa (1995) both cited references indicating that habitat degradation is the major cause for the decline in the petitioned chinook salmon stocks. The influence of dams[3] was most commonly implicated by ONRC and Nawa (1995) as being responsible for the decline or extinction of chinook salmon stocks. Of the stock extinctions surveyed in the coastwide region, 76% were dam related. This was most noticeable in the Central Valley, California where 100% of the extinctions surveyed were dam related (Campbell and Moyle 1990). Furthermore, 48 of the spring- and summer-run stocks found to be in decline were affected by dams. Two of the four chinook salmon stocks petitioned by PRO-Salmon (1994) were impacted to some extent by dam operation, but logging[4] and agricultural land use/water diversion (including diking) also figured as major factors in all four stocks. The Nooksack Technical Group (1987) indicated that sedimentation from logging activities had seriously impacted the quality of the spawning habitats in both the North and South Forks of the Nooksack River. PRO-Salmon (1994) considered water diversion for agricultural use to be a major contributor to the decline of the Dungeness River spring run. Overall, ONRC and Nawa (1995) estimated that logging was responsible, in part, for 60% of the declines and 6% of the extinctions among the stocks surveyed. Similarly, agriculture, water withdrawal, mining and urbanization factors were implicated in 58% of the declines and 9% of the extinctions among the 417 stocks surveyed. Both petitioners also presented evidence that the exploitation rates on the stocks were sufficiently high to have seriously depleted stocks or been partially responsible for the extinction of stocks (Dosewallips, Duckabush, and Mokelumne Rivers spring-run chinook salmon (ONRC and Nawa 1995)).

The other major concern of the petitioners was the impact of introduced and/or artificially propagated fish on indigenous stocks. Potentially deleterious impacts of artificial propagation presented by ONRC and Nawa (1995) include: interbreeding of fall and spring runs in California due to habitat alterations (Campbell and Moyle 1990), interspecies hybridization between chinook and coho salmon (*Oncorhynchus kisutch* Walbaum) (Bartley et al. 1990), competition between hatchery and native stocks, interbreeding between hatchery and native chinook salmon stocks, disease introductions by artificially propagated fish, and the unsustainability of hatchery stocks in general. Finally, ONRC and Nawa (1995) suggested the “inadequacy of existing regulatory mechanisms” was a general reason for the overall decline in abundance of chinook salmon.

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[3] The term *dams* includes the physical presence of mainstem dams, the operation of the hydropower system, reservoir storage, and water withdrawal associated with dams.

[4] Logging activities include tree-cutting, road building, and splash-damming (historically).

INFORMATION RELATING TO THE SPECIES QUESTION

In this section, we summarize biological and environmental information and consider the relevancy of each in determining the nature and extent of West Coast chinook salmon ESUs. ESU boundaries were determined by the BRT on the basis of the team's professional opinion of the degree to which environmental and biological attributes exhibited significant changes with respect to the reproductive isolation and ecological/genetic diversity of West Coast chinook salmon.

General Biology of Chinook Salmon

Chinook salmon, also commonly referred to as king, spring, quinnat, Sacramento, California, or tyee salmon, is the largest of the Pacific salmon (Netboy 1958). The species distribution historically ranged from the Ventura River in California to Point Hope, Alaska in North America, and in northeastern Asia from Hokkaido, Japan to the Anadyr River in Russia (Healey 1991). Additionally, chinook salmon have been reported in the Mackenzie River area of northern Canada (McPhail and Lindsey 1970). Of the Pacific salmon, chinook salmon exhibit arguably the most diverse and complex life history strategies Healey (1986) described 16 age categories for chinook salmon, 7 total ages with 3 possible freshwater ages. This level of complexity is roughly comparable to sockeye salmon (*O. nerka*), although sockeye salmon have a more extended freshwater residence period and utilize different freshwater habitats (Miller and Brannon 1982, Burgner 1991). Two generalized freshwater life-history types were initially described by Gilbert (1912): “stream-type” chinook salmon reside in freshwater for a year or more following emergence, whereas “ocean-type” chinook salmon migrate to the ocean within their first year. Healey (1983, 1991) has promoted the use of broader definitions for “ocean-type” and “stream-type” to describe two distinct races of chinook salmon. This racial approach incorporates life history traits, geographic distribution, and genetic differentiation and provides a valuable frame of reference for comparisons of chinook salmon populations. For this reason, the BRT has adopted the broader “racial” definitions of ocean- and stream-type for this review.

The generalized life history of Pacific salmon involves incubation, hatching, and emergence in freshwater, migration to the ocean, and subsequent initiation of maturation and return to freshwater for completion of maturation and spawning (Fig. 2). Juvenile rearing in freshwater can be minimal or extended. Additionally, some male chinook salmon mature in freshwater, thereby foregoing emigration to the ocean. The timing and duration of each of these stages is related to genetic and environmental determinants and their interactions to varying degrees. Salmon exhibit a high degree of variability in life-history traits; however, there is considerable debate as to what degree this variability is the result of local adaptation or the general plasticity of the salmonid genome (Ricker 1972, Healey 1991, Taylor 1991).

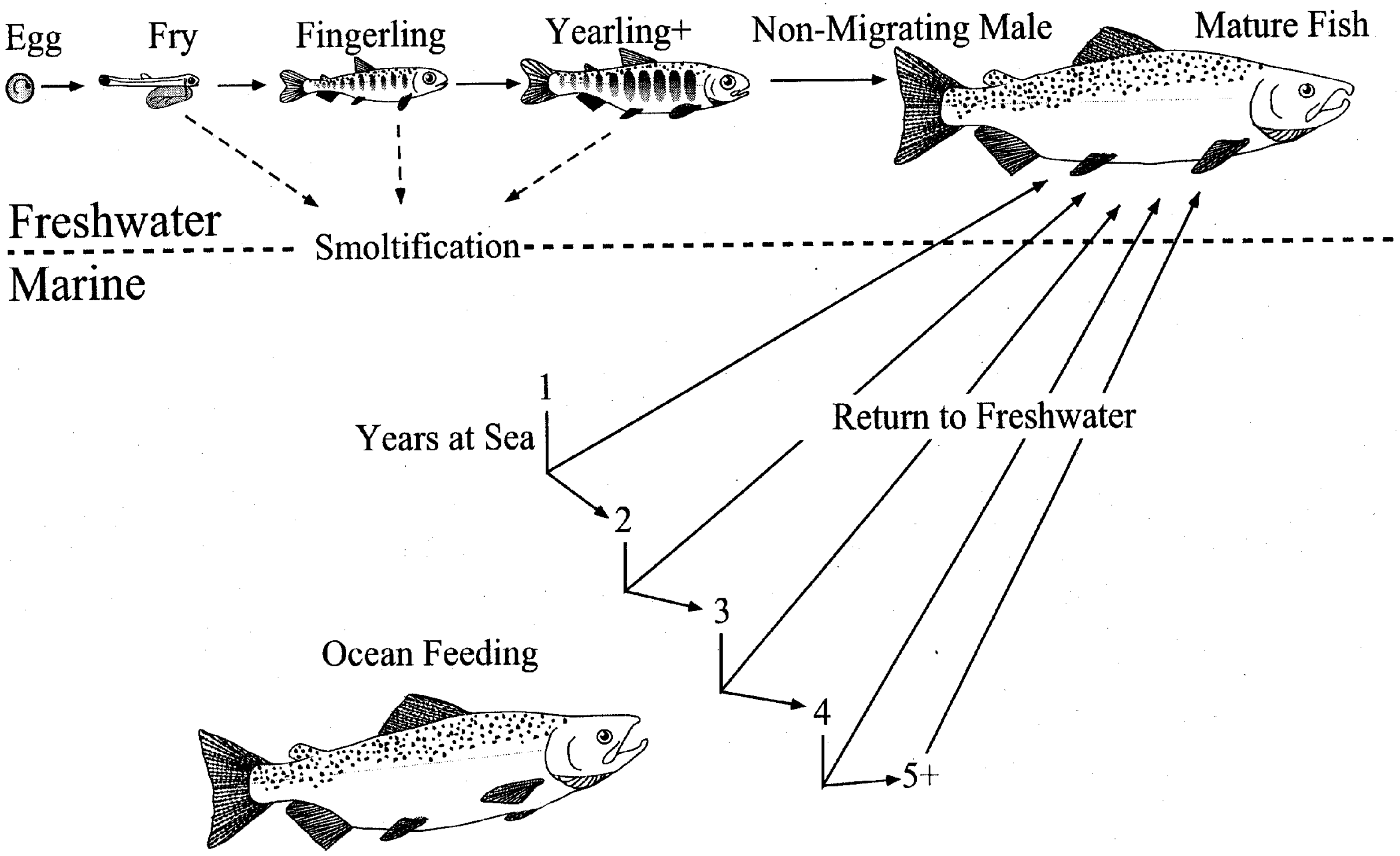

Figure 2. Diagramatic representation of potential smolting and maturation strategies utilized by chinook salmon.

Several types of biological evidence were considered in evaluating the contribution of West Coast chinook salmon to ecological/genetic diversity of the biological species under the ESA. Life-history traits examined for naturally spawning chinook salmon populations included smolt size and outmigration timing, age and size at spawning, river-entry timing, spawn timing, fecundity, and ocean migration. These traits are believed to have both a genetic and environmental basis, and similarities among populations could indicate either a shared genetic heritage or similar responses to shared environmental conditions.

The analysis of life-history trait information is complicated by several factors. Data collected from different locations during different years are confounded by spatial and temporal environmental variability. This variability creates considerable “noise,” which may be as large as differences between geographically distant populations, and may mask subtle regional patterns. High interannual variability also complicates the comparison of results from studies conducted during different time periods. For chinook salmon, for which a single broodyear may return from the ocean over a 5- or 6-year period, variations in ocean productivity due to events such as the 1983 El Niño (Johnson 1988b) may bias estimates of age distribution, age-size relationships, and/or age and size-related fecundity estimates. Furthermore, it may be difficult to distinguish between fish from different runs emigrating from, or returning to, the same river system. Direct comparisons of chinook salmon life-history traits between stocks under controlled conditions are limited in number, and the extent to which inference can be made to wild populations is uncertain.

A third confounding complication is that the expression of life-history traits may be altered by anthropogenic activities such as land-use practices (Hartman et al. 1984, Holtby 1987), harvest (Ricker 1981), or artificial propagation (Steward and Bjornn 1990, Flagg et al. 1995b). To help limit any bias introduced by artificial propagation, life-history trait comparisons in this status review have focused on naturally spawning populations. However, because of the widespread practice of off-station plants of hatchery-reared fry and smolts, many studies of naturally spawning populations may have inadvertently included first-generation hatchery fish or fish whose ancestors have been hatchery reared. Life-history trait information from hatchery populations was used only when insufficient information from naturally spawning populations was available, as in the case of ocean migration patterns. As with environmental variability, the effects of anthropogenic activities may confound the expression of life-history traits and are difficult to factor out.

Because of these potential sources of variability, we felt that statistical analyses of life-history trait variability would not be particularly informative. Instead, data were collected from as many sources as possible from each system to give some indication of the mean and range in character traits. Older data sets were especially sought to provide insight into chinook salmon population characteristics prior to the proliferation of hatchery programs, which have produced fish with relatively high juvenile survival and growth rates and modified saltwater entry dates.

Ecological Features

Geological Events

The geologic events of the last 20,000 years have provided mechanisms for genetic isolation, colonization, and population interbreeding. In determining ESU boundaries it is useful to understand the factors that may have shaped present day chinook salmon population distributions. Much of the present distribution of aquatic and terrestrial species in western North America is a legacy of the volcanic, tectonic, and glacial forces that have shaped this region. Events such as headwater transfer or stream capture have altered the flow of major rivers and the aquatic species that inhabit them. The Cordilleran ice sheet was the last major glacial event to affect the distribution of chinook salmon. At its height some 10,000-15,000 years ago, vast areas of Southeast Alaska, British Columbia, Washington, and Idaho were covered with ice (McPhail and Lindsey 1970). This created a discontinuous distribution of chinook salmon stocks. Two major ice-free refugia existed: Beringia, composed of the Bering land bridge connecting Eastern Siberia and Western Alaska; and Cascadia, composed of the lands south of the mid-Columbia River drainage (McPhail and Lindsey 1970). An additional ice-free refuge existed on the coast of the Olympic Peninsula in the area of the Chehalis River. The drop in sea level during the glacial periods may have created minor refugia along the coast of Vancouver Island or the present-day Queen Charlotte Islands (McPhail and Lindsey 1986). As the ice sheet receded, the colonization of newly exposed freshwater habitat began from the two refugia.

Chinook salmon colonization during the postglacial period (approximately beginning 10,000 years ago) occurred through a number of possible pathways. Straying adults could invade coastal river systems, as could salmon that moved farther upriver to headwaters exposed by the receding glaciers. Ice dams and land expansion after the retreat of glacial ice sheets caused rivers to alter course and change watersheds. Watershed capture has resulted in the exchange of aquatic organisms between several major river systems. Parts of the present day Fraser River drainage flowed into the Columbia River via the Okanogan River and Shuswap Creek during the last deglaciation (McPhail and Lindsey 1986). Species that moved into the Upper Fraser River from the Columbia River also gained access to southeastern Alaskan coastal rivers. The Stikine, Skeena, and Nass Rivers at various times drained east into the Fraser River Basin relative to their current westerly flow to the Gulf of Alaska (McPhail and Lindsey 1986). Similarly, the Alsek River in Alaska, which also flows to the Gulf of Alaska, drained what is now part of the Yukon River headwaters (Lindsey and McPhail 1986). Presently, the headwaters of the Taku, Stikine, and Yukon Rivers lie within 50 miles of one another. Chinook salmon populations from Beringia also had access to the Mackenzie River in Canada during the deglaciation, which may explain recurring reports of chinook salmon in that river system (McPhail and Lindsey 1970).

Ecoregions

The fidelity with which chinook salmon return to their natal stream implies a close association between a specific stock and its freshwater environment. The selective pressures of different freshwater environments may be responsible for differences in life-history strategies among stocks. Miller and Brannon (1982) hypothesized that local temperature regimes are the major factor influencing life-history traits. If the boundaries of distinct freshwater habitats coincide with differences in life histories it would suggest a certain degree of local adaptation. Therefore, identifying distinct freshwater, terrestrial, and climatic regions may be useful in identifying chinook salmon ESUs. The Environmental Protection Agency (EPA) has established a system of ecoregion designations based on soil content, topography, climate, potential vegetation, and land use (Omernik 1987). These ecoregions are similar to the physiographic provinces determined by the Pacific Northwest River Basins Commission (PNRBC 1969) for the Pacific Northwest. Historically, the distribution of chinook salmon in Washington, Oregon, California, and Idaho would have included 13 of the present day EPA ecoregions (Fig. 3). Similarly, there is a strong relationship between ecoregions and freshwater fish assemblages (Hughes et al. 1987). We have retained the ecoregion names and numbers used by Omernik (1987) and included physiographic information presented by PNRBC (1969), present day water use information (USGS 1993), river flow information (Hydrosphere Products, Inc. 1993), and climate data from the U.S. Department of Commerce (1968) into the appropriate ecoregion description (Omernik and Gallant 1986, Omernik 1987). Additional information for British Columbia (Environment Canada 1977, 1991) and Alaska (Hydrosphere Products, Inc. 1993) is included for comparative purposes. The following ecoregions are wholly or partially contained within the historical natural range of chinook salmon in Washington, Oregon, California, and Idaho.

Coastal Range (#1)

Extending from the Olympic Peninsula through the Coast Range proper and down to the Klamath Mountains and the San Francisco Bay area, this region is influenced by medium to high rainfall levels due to the interaction between marine weather systems and the mountainous nature of the region. Topographically, the region averages about 500 m in elevation, with mountain tops under 1,200 m. These mountains are generally rugged with steep canyons. Between the ocean and the mountains lies a narrow coastal plain composed of sand, silt, and gravel. Tributary streams are short and have a steep gradient; therefore, surface runoff is rapid and water storage is relatively short term during periods of no recharge. These rivers are especially prone to low flows during times of drought. Regional rainfall averages 200-240 cm per year (Fig. 4), with generally lower levels along the southern Oregon coast. Average annual river flows for most rivers in this region are among the highest found on the West Coast when adjusted for watershed area (Fig. 5). River flows peak during winter rain storms common in December and January (Fig. 6). Snow melt adds to the surface runoff in the spring, providing a second flow peak, and

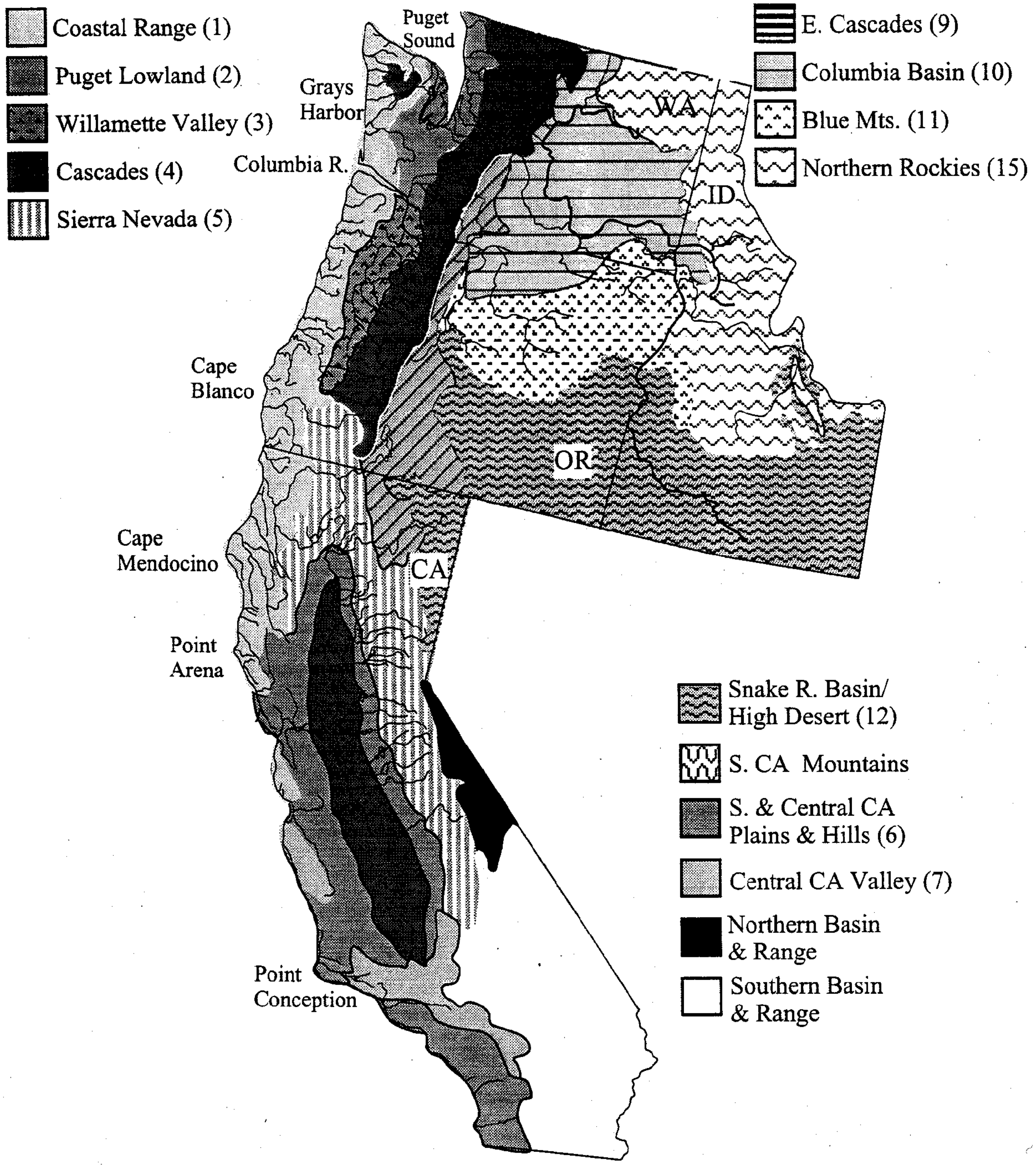

Figure 3. U.S. Environmental Protection Agency ecoregions for California, Idaho, Oregon, and Washington (Omernik and Gallant 198, Omernik 1987). Regions are based on land use, climate, topography, potential natural vegetation, and soils. Ecoregions with number designations are described in the text.

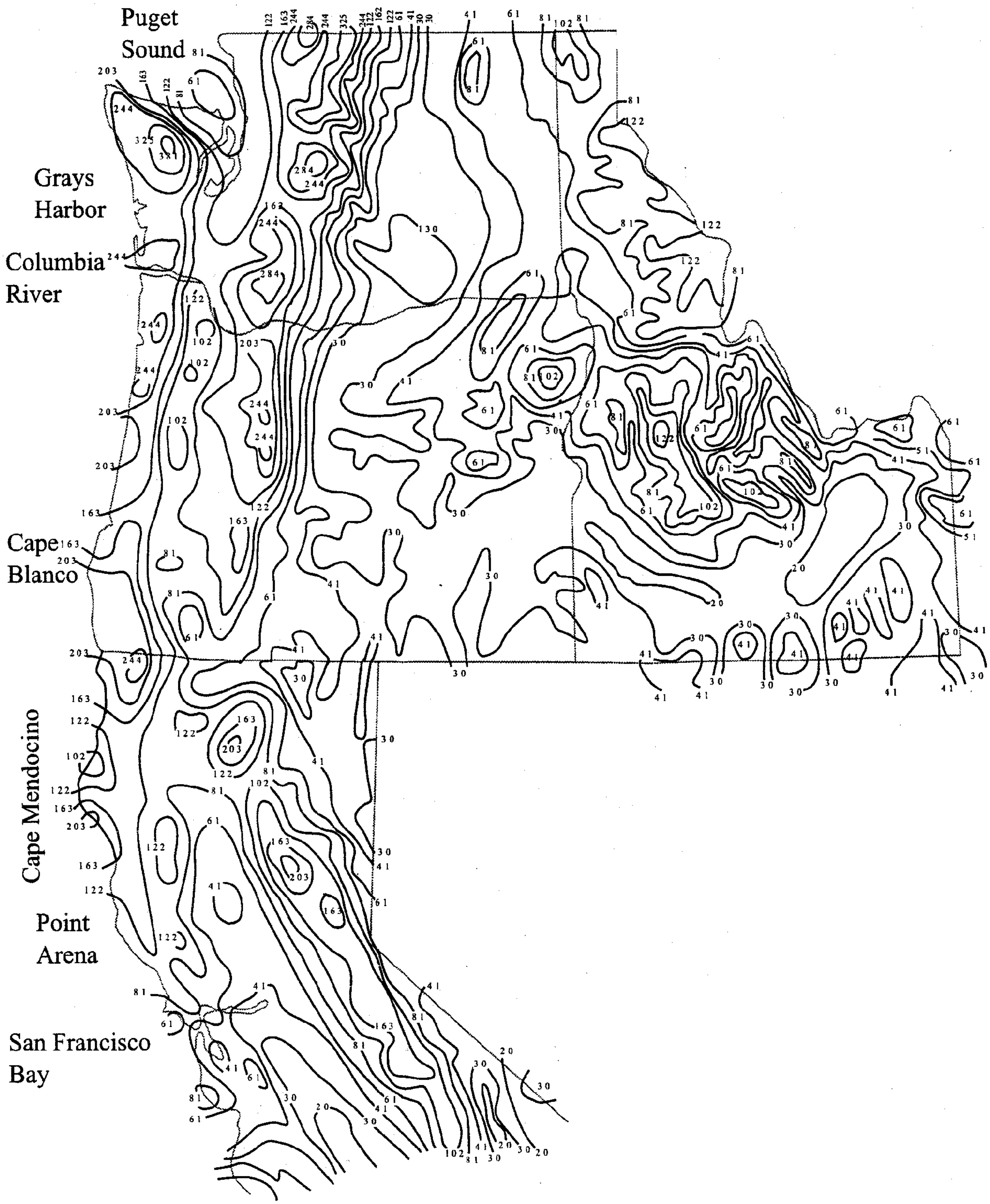

Figure 4. Average annual precipitation (cm) for selected areas of Washington, Oregon, California, and Idaho (U.S. Dep. Commerce 1968).

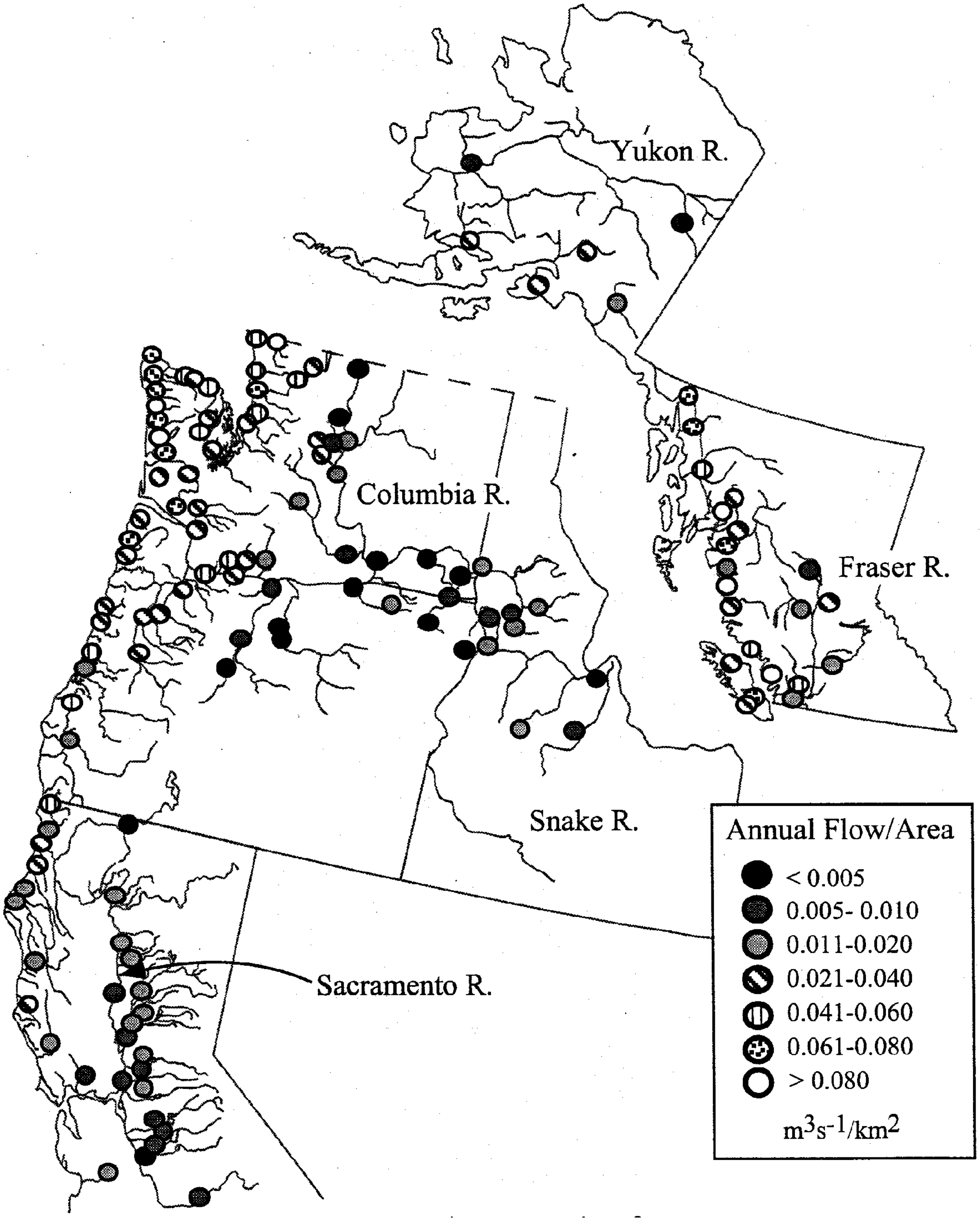

Figure 5. Average annual flow per area (m^{3}seconds(s)$^{-1}$km^{-2}) for selected river basins in Alaska, British Columbia, Washington, Oregon, California, and Idaho. Values were calculated as the average annual flow for each gauging station divided by the reported gauged area. Based on USGS streamflow data (Hydrosphere Data Products, Inc. 1993) and Inland Water Directorate streamflow data (Environment Canada 1991) (modified from Weitkamp et al. 1995).

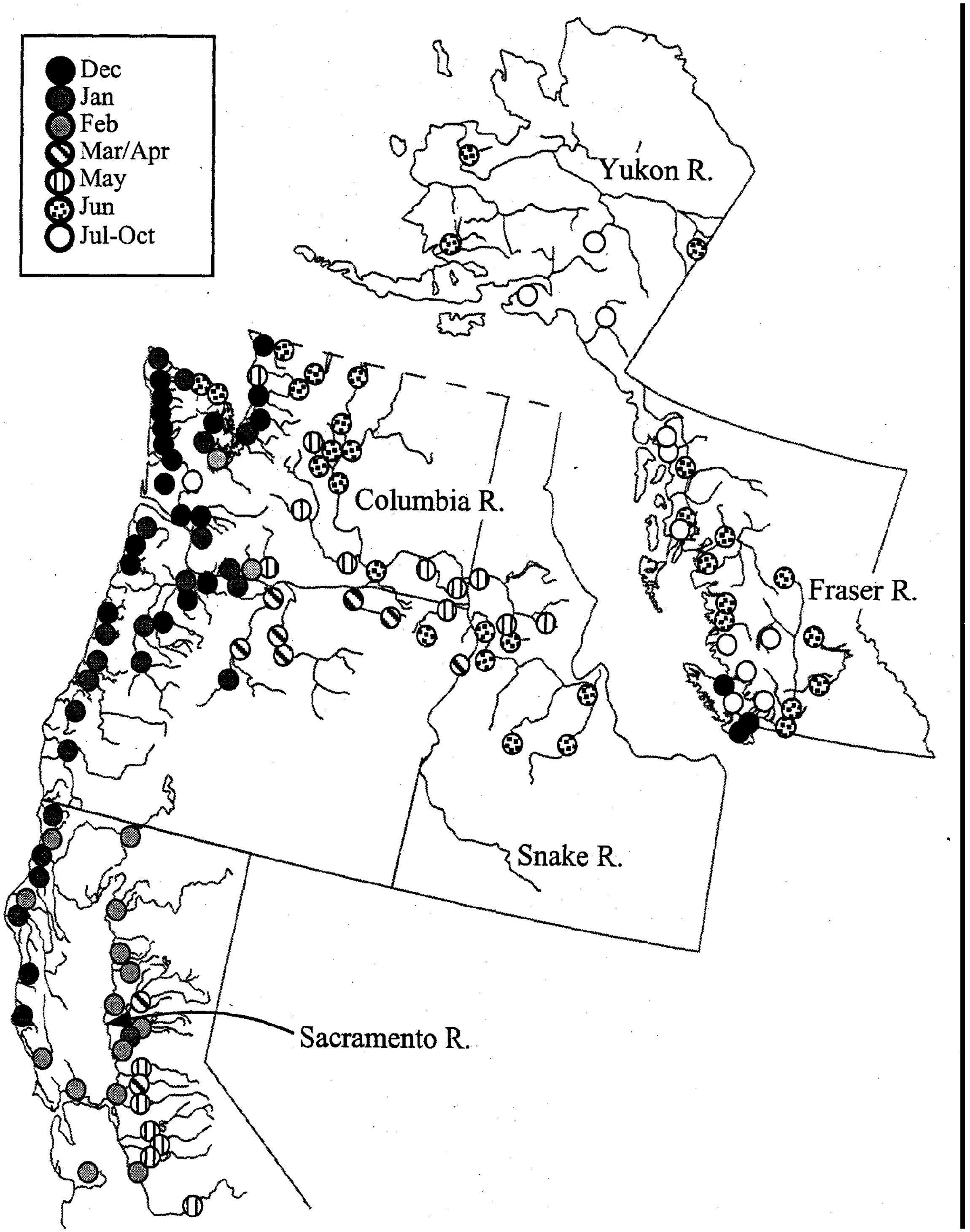

Figure 6. Timing of annual peak flow (by month) for selected river basins in Alaska, British Columbia, Washington, Oregon, California, and Idaho. If two peaks in flow occur, the higher of the two peaks is represented. Based on USGS streamflow data (Hydrosphere Data Products, Inc. 1993) and Inland Water Directorate streamflow data (Environment Canada 1991) (modified from Weitkamp et al. 1995).

there are long periods when the river flows are maintained at least 50% of peak flow (Fig. 7). During July or August there is usually no precipitation; this period may expand to 2 or 3 months every few years. River flows are correspondingly at their lowest (Fig. 8) and temperatures at their highest during August and September (Fig. 9). Oregon coastal rivers have the largest relative difference in minimum and maximum flows, where minimum flows are 2-5% of the maximum flows.

The region is heavily forested primarily with Sitka spruce, western hemlock, and western red cedar. Forest undergrowth is composed of numerous types of shrubs and herbaceous plants.

Puget Lowland (#2)

Situated between the Coast Range and Cascade Range Ecoregion, this region experiences reduced rainfalls (50-120 cm) from the rainshadow effect of the Coast Mountains. The area is generally flat with high hills (600 m) at the southern margin of the ecoregion. Soils are composed of alluvial and lacustrine deposits. These deposits are glacial in origin north of Centralia, Washington. This area tends to have large groundwater resources, with groundwater from the bordering mountain ranges helping sustain river flows during drought periods. Peak river flow varies from December to June depending on the contribution of snowpack to surface runoff for each river system. Rivers tend to have sustained flows (5 to 8 months of flows at 50% of the peak or more), and low flows are generally 10-20% or more of the peak flows.

Douglas fir represent the primary subclimax forest species, with other coniferous species (lodgepole, western white, and ponderosa pines) locally abundant. Prairie, swamp, and oak, birch, or alder woodlands are also common. The land is heavily forested, and wood-cutting activities (including road building, etc.) contribute to soil erosion, river siltation, and river flow and temperature alteration.

The region is heavily urbanized, and domestic and industrial wastes impact local water systems. Urban run-off and sewage treatment influence water quality west of the Cascade Mountains, with the exception of the Olympic Peninsula coastal and northern Puget Sound rivers. Glacial sediment also influences water quality, especially in the Skagit, North Fork Nooksack, Nisqually, and Puyallup/White River Basins.

Willamette Valley (#3)

Adjoining the southern border of the Puget Sound Lowland Ecoregion at the Lewis River, this region was not glacially influenced. A rainshadow effect, similar to the one influencing the Puget Sound Lowlands, limits rainfall to about 120 cm per year. River flows peak in December and January and are sustained for 6 or 7 months of the year. Low flows occur in August and September, although the volume is generally 20% of the peak flow.

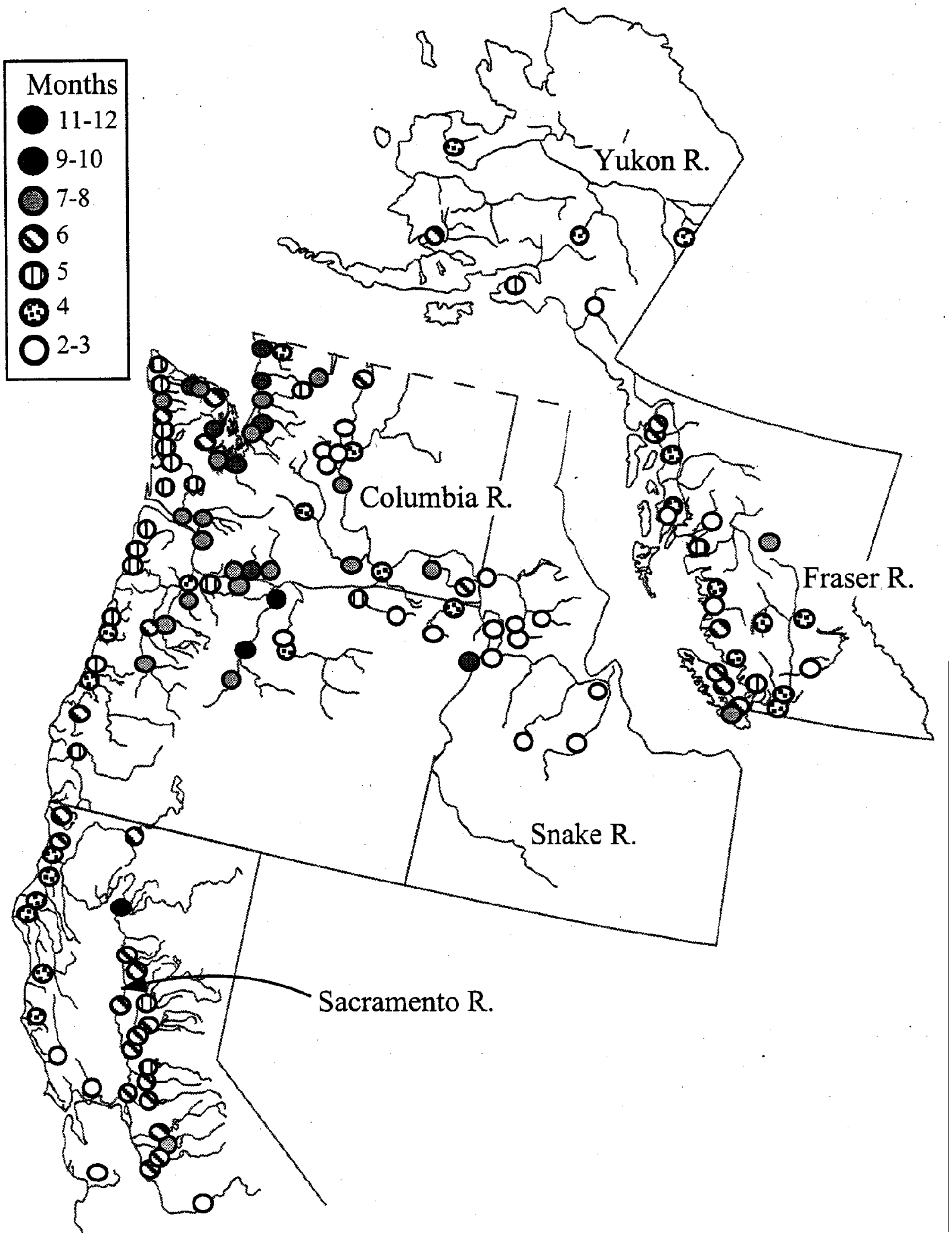

Figure 7. Duration of high flows (number of months when flow is equal to or exceeds 50% of peak monthly flow) for selected river basins in Alaska, British Columbia, Washington, Oregon, California, and Idaho. Based on USGS streamflow data (Hydrosphere Data Products, Inc. 1993) and Inland Water Directorate streamflow data (Environment Canada 1991) (modified from Weitkamp et al. 1995).

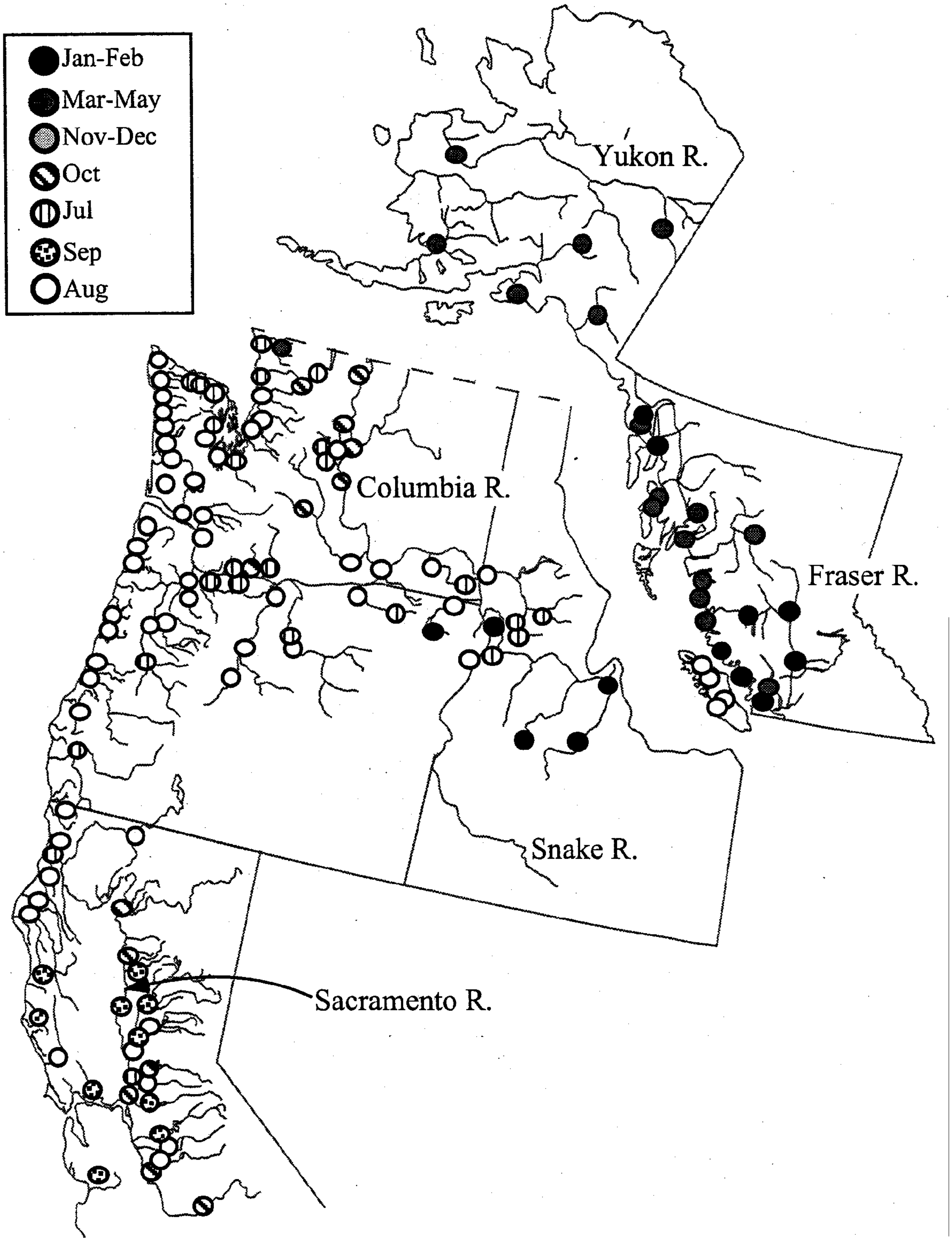

Figure 8. Timing of annual low flow (by month) for selected river basins in Alaska, British Columbia, Washington, Oregon, California, and Idaho. If two peaks in flow occur, (Hydrosphere Data Products, Inc. 1993) and Inland Water Directorate streamflow data (Environment Canada 1991) (modified from Weitkamp et al. 1995).

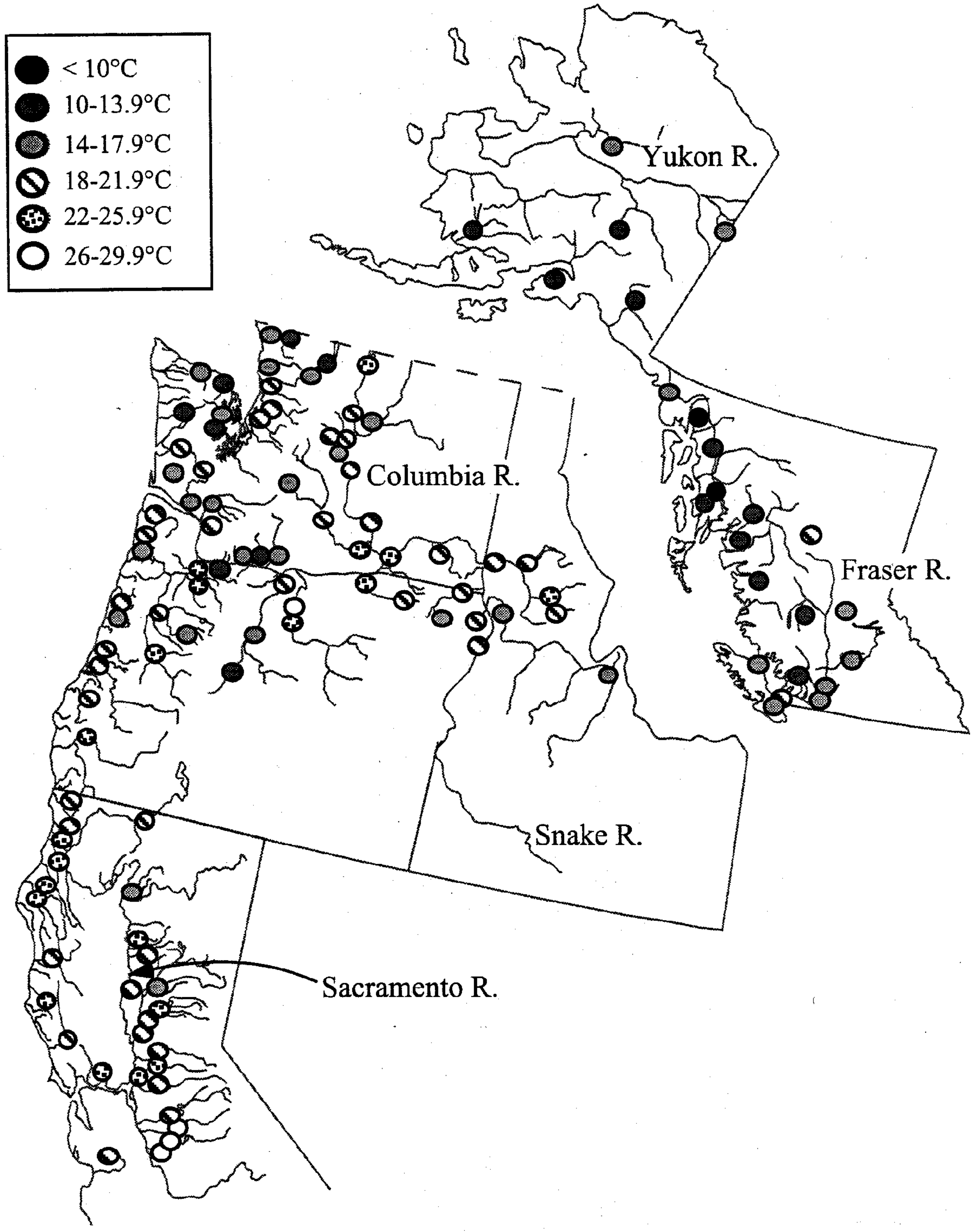

Figure 9. Annual maximum monthly stream temperatures (^{0}C) for selected river basins in Alaska, British Columbia, Washington, California, Oregon, and Idaho. Based on USGS streamflow data (Hydrosphere Data Products, Inc. 1993) and Inland Water Directorate temperature data (Environment Canada 1991) (modified from Weitkamp et al. 1995).

Much of the land has been converted to agricultural use, with Douglas fir and Oregon white oak stands present in less-developed areas. Irrigation is commonly employed, and stream flows, especially in the southern portion of this region, can be significantly affected. Agricultural and livestock practices contribute to soil erosion and fertilizer/manure deposition into stream systems.

Water quality is impacted by agricultural and urban activities. Many water quality problems are exacerbated by low water flows and high temperatures during the summer. Pulp and paper mill discharges of dioxin into the Columbia and Willamette Rivers were cited as another water quality concern, although this situation has been much more serious in the past (USGS 1993).

Cascades (#4)

This region is composed of the Cascade Range in Washington and Oregon and the Olympic Mountains in Washington state. Peaks above 3,000 m are distributed throughout the region. The crest of the Cascade Range (averaging 1,500 m) captures much of the ocean moisture moving eastward in addition to providing a biological barrier. Rainfalls can average 280 cm per year (up to 380 cm in the Olympic Mountains), much of which is in the form of heavy snowpack. Intensive rainstorms, those depositing more than 2.5 cm per hour, are rare. Rainfall is generally spread over the year with the majority occurring between October and March. Except where porous rock substrate exists, there is little capacity for long-term groundwater storage. In these porous rock areas, streams receive 75-95% of their average discharge as groundwater, and are able to maintain their flows during dry periods. Surface water flow originating in the Cascades and Olympic Mountains influences river flows throughout this region.

Currently the area is primarily forested with Douglas fir, noble fir, and Pacific silver fir (all subclimax species), whereas western hemlock and red cedar are common climax species. At higher elevations, these trees are replaced by Englemann spruce, whitebark pine, and mountain hemlock. Forest undergrowth tends to be dense on the western slopes of this region and rather sparse on the eastern slopes. Heavy rainfall, combined with woodcutting activities, has resulted in increased soil erosion.

Sierra Nevada (#5)

To the south of the Cascades Ecoregion lies a similar mountainous ecoregion, comprised of portions of the Klamath, Sierra, Trinity, and Siskiyou Mountains. Annual rainfall varies considerably, from 40 cm to over 150 cm, depending on elevation and the degree of rainshadowing. Most of the rain comes in the winter months, with summers being hot and dry. Topographically, the region rises to over 2,000 m with an average elevation of 1,000 m. This region contains the headwaters for the Rogue, Klamath, and Sacramento Rivers. Peak flows occur in February, with low flows in August, September, or October. As a result of water diversion and impoundment activities, flows are now more evenly apportioned throughout the year. This has occurred primarily through irrigation/flood mitigation-related reductions in peak flows and less so through increased spillage during the historical time of minimum flows.

Douglas fir is the predominant tree species, but mixed coniferous-oak stands are common. Soils tend to be unstable, and timber harvest or livestock grazing can result in severe erosion. Hydraulic placer mining has had a considerable impact on stream quality and hillslope stability.

Southern and Central California Plains and Hills (#6)

To the east and in the rainshadow of the Coastal Mountain range, the tablelands and hills of this region have generally low levels of annual rainfall (40-100 cm). Tributary rivers to the Sacramento and San Joaquin Rivers flow through this region. Vegetation is composed of California oaks and manzanita chaparral with extensive needlegrass steppe. Livestock grazing in the open woodlands is the predominant land use.

Central California Valley (#7)

The Sacramento and San Joaquin Rivers are the key features of the Central California Valley Ecoregion. The broad flat lands that border the river naturally support needlegrass and marshgrasses, although much of the region has been extensively converted to agricultural use. The annual rainfall for the region is 40-80 cm. The Sacramento and San Joaquin Rivers peak in February with a 6-month period of high flows (>50% of peak flow). Low flows occur in September and October. Changes in the hydrology of tributaries and irrigation withdrawals from the mainstem rivers have drastically altered the flow characteristics of these rivers over the course of the last 100 years. An estimated 90% of the surface water withdrawals were used for irrigation in 1990 (USGS 1990). The maintenance of livestock and cultivation, irrigation, and chemical treatment of crop land has resulted in increases in fecal coliform, dissolved nitrate, nitrite, phosphorus, and sulfate concentration levels (USGS 1993). Industrial and mining runoff from sites, such as the copper mines near Spring Creek in the Sacramento River Basin, also impact water quality in the immediate area.

Eastern Cascades Slopes and Foothills (#9)

This ecoregion marks the transition between the high rainfall areas of the Cascades Ecoregion and the drier basin ecoregions to the east. The area receives 30 cm to 60 cm of rainfall per year. Streamflow is intermittent, especially during the summer dry season. Surface and groundwater contributes to flows in the Yakima, Deschutes, Klickitat, and White Salmon Rivers.

Ponderosa and lodgepole pine are common throughout the region, with little forest undergrowth. Soils tend to be volcanic, young, and highly erodible. Primary land uses are timber harvest and mixed grazing/timber areas. Agriculture is limited to valleys and irrigation is commonly employed.

Columbia Basin (#10)

This ecoregion is typified by irregular plains, tablelands, and high hills/low mountains. The plateau spans from the Cascade Mountains to the Blue Mountains in the south and southeast. Much of the basin is covered with glacial and alluvial deposits. The loose surface substrate is prone to erosion. There is little rainfall and the majority of the water discharge comes from the mountains that border the basin. Because tributaries to the mid- and upper Columbia River receive much of their water from snowmelt, peak river flows are in May and June, except for the Deschutes, John Day, and Umatilla Rivers, which peak in April. Peak flows are not as sustained as on the coast, generally lasting 2-3 months. Annual rainfalls of 20-60 cm support sagebrush and wheatlands. Most smaller streams are ephemeral, partially due to irrigation withdrawals (Omernik and Gallant 1986). The Columbia Plateau experiences a prolonged drought of 1 to 3 months every year, with longer events occurring frequently. Low river flows occur during the late summer and early fall, August-October, when irrigation demand is heavy. Nitrates, sulfites, and pesticides commonly associated with crop irrigation are found in most of the rivers in the Columbia River Basin. Heavy metal contamination from Canadian mining operations has been detected at several downstream sites on the Columbia River (USGS 1993).

Sagebrush and wheatgrass constitute the primary natural vegetation for this region. Much of the land has been converted to dryland wheat agriculture, with smaller irrigated areas supporting the cultivation of peas and potatoes. Irrigation and agriculture have changed the flow and course of smaller rivers and streams (Omernik and Gallant 1986).

Blue Mountains (#11)

The Blue, Wallowa, Ochoco, Strawberry, and Aldrich Mountains are contained in this ecoregion. The mountains are a mix of older sedimentary and younger volcanic peaks. Mountainous regions contain ponderosa pine, grand fir and Douglas fir, and Englemann spruce stands. Rainfall varies from 25-50 cm in the lowlands, and as much as 100 cm in the mountains, most of which falls as snow. The aquifers that develop in these mountains feed into numerous river systems: the John Day, Umatilla, and Walla Walla Rivers, which flow into the Columbia River, and the Tucannon, Grande Ronde and Imnaha Rivers, which flow into the Snake River. Peak flows occur from April to June, but only last 2 to 4 months; however, flood events historically have occurred from December through February as rain on snow events (WDFW 1997a). Minimum flows occur predominantly in August or September, except in the mountains where flows are at a minimum in January and February.

Lowlands contain sagebrush, wheatgrass, and bluegrass. Land-use activities correspond to vegetation, with timber harvest more prevalent in the mountains and grazing prevalent in the lowlands. Both of these activities have led to considerable localized stream-side erosion.

Snake River Basin/High Desert (#12)

This region spans southeastern Oregon, southern Idaho, northeastern California, and northern Nevada. Passage of chinook salmon into most of the region has been blocked by dams, but the region still exerts a considerable influence on downstream habitat. This area is geologically very new and contains extensive areas of lava and other volcanic material. The rock substrate is very permeable, streams tend to lose much of their flow through percolation and evaporation, and only the larger rivers that lie below the water table contain substantial flows year round. Rainfalls are generally less than 30 cm annually, but may be as high as 60 cm on the borders of the ecoregion. Extended dry intervals are very common in the Snake River Plateau.

Sagebrush and wheatgrass are prevalent with much of the area utilized as rangeland. Agriculture (potatoes, corn, grains) is sustained where water resources are available. Rivers in the southern half of Idaho are affected by agricultural and urban development. Irrigation return flows, livestock grazing, and urban activities were associated with high nutrient concentrations in the Boise and Snake Rivers (USGS 1993).

Northern Rockies (#15)

Forming the northeast boundary of the Columbia Basin Ecoregion, this region is a mosaic of mountain crestlines (up to 2,500 m) and valleys. Rainfall varies accordingly from 50 to 150 cm or more per year, some of which falls in intense local storms. Winter snowpack is the major contributor to the streamflows; river flows peak with the spring melt in May or June lasting only 2-3 months. One- and 2-month drought periods are fairly common; however, longer periods are quite rare, especially in the higher mountains, where drought periods of even 1 month are rare (once in 5 years). Low flows correspond with low periods of precipitation in August and September except in the higher elevations, where winter temperatures limit flow. In many areas, soil and subsoil development have created important areas for water storage. Seepage is an important water source for major rivers in this area. The Salmon and Clearwater Rivers drain the southern portion of this region and are the only major tributaries to which chinook salmon still have access. The Spokane, Kootenai, and Pend Oreille Rivers drain into the Columbia River from the eastern and northern portions of this ecoregion; however, runs that historically existed on these rivers have been eliminated by impassable dams (Fulton 1968).

Forests are dominated by conifers: western white pine, lodgepole pine, western red cedar, western hemlock, western larch, Englemann spruce, subalpine fir, and Douglas fir. Prairie and mixed forest/grassland are also common. Forestry is the primary land-use activity, although mining and grazing activities are commonplace. Water systems in the northern half of Idaho, the Coeur d'Alene and Clearwater Rivers, are impacted by mining and logging operations; however, containment ponds appear to limit metal concentrations downstream (USGS 1993).

Marine Habitat

The marine habitat can be subdivided into three general regions—estuary, coastal, and ocean. Chinook salmon with different life-history strategies use these regions to different extents; therefore, changes in the conditions in one region may selectively affect some populations more than others.

Ocean-type chinook salmon reside in estuaries for longer periods as fry and fingerlings than do with yearling, stream-type, chinook salmon smolts (Reimers 1973, Kjelson et al. 1982, Healey 1991). The diet of outmigrating ocean-type chinook salmon varies geographically and seasonally, and feeding appears to be opportunistic (Healey 1991). Aquatic insect larvae and adults, *Daphnia*, amphipods (*Eogammarus* and *Corophium spp.*), and *Neomysis* have been identified as important food items (Kjelson et al. 1982, Healey 1991). Rivers with well developed estuaries are able to sustain larger ocean-type populations than those without (Levy and Northcote 1982). Juvenile chinook salmon growth in estuaries is often superior to river-based growth (Rich 1920a, Reimers 1971, Schluchter and Lichatowich 1977). Stream-type chinook salmon move quickly through the estuary, into coastal waters, and ultimately to the open ocean (Healey 1983, Healey 1991). Very limited data are available concerning the ocean migration of stream-type chinook salmon; they apparently move quickly offshore and into the central North Pacific, where they make up a disproportionately high percentage of the commercial catch relative to ocean-type fish (Healey 1983, Myers et al. 1987). The Stikine, King Salmon, and Chilkat Rivers are notable exceptions to this general stream-type migration pattern. Apparently, a portion of fish from these stocks remain in the coastal waters of southeast Alaska throughout their lives (ADFG 1997). In contrast, throughout their ocean residence ocean-type chinook salmon inhabit coastal waters, where coded-wire tag (CWT)-marked fish are recovered in substantial numbers (Healey and Groot 1987).

The utilization of estuaries by ocean-type chinook salmon makes them more susceptible to changes in the productivity of that environment than stream-type chinook salmon. Estuaries may be "overgrazed" when large numbers of ocean-type juveniles enter the estuary en masse (Reimers 1973, Healey 1991). The potential also exists for large-scale hatchery releases of fry and fingerling ocean-type chinook salmon to overwhelm the production capacity of estuaries (Lichatowich and McIntyre 1987). The loss of coastal wetlands to urban or agricultural development may more directly impact ocean-type populations. Dahl (1990) reported that California has lost 94% of its wetlands. Furthermore, an estimated 80-90% of the undiked tidal marshlands in the Sacramento River Delta area, the major nursery area for Central Valley chinook salmon stocks, has been lost (Nichols et al 1986, Lewis 1992). A similar reduction has been reported in Washington and Oregon wetlands: a 70% loss in the Puget Sound, 50% in Willapa Bay, and 85% in Coos Bay (Refalt 1985).

The ocean migrations of chinook salmon extend well into the North Pacific Ocean. The productivity of various ocean regions has been correlated with the degree of wind-driven upwelling (Bakun 1973, 1975). Under normal conditions this upwelling decreases along the coast from California to Washington and British Columbia (Bakun 1973). Changes in wind directions related to sea level pressure (SLP) systems, most notably the Aleutian low pressure (ALP) or Central North Pacific (CNP) pressure indices, can greatly alter upwelling patterns (Ware and Thompson 1991, Beamish and Bouillon 1993). Upwelling brings cold, nutrient-rich waters to the surface, resulting in an increase in plankton and ultimately salmon production (Beamish and Bouillon 1993). Strong ALP measurements (high pressure readings) tend to result in minimal upwelling in the North Pacific. Similarly, atmospheric pressure systems in the Central Pacific can alter trade wind patterns to bring warmer water up along the California coast; this occurrence is better known as an El Niño. El Niño events suppress coastal upwelling off the Washington, Oregon, and California coasts and tend to bring warmer water and warm-water species northward (McLain 1984). One difference between El Niño events and ALP events is that the northerly flow of warm waters associated with El Niño events may stimulate ocean productivity off Alaska (McLain 1984). Ocean migratory pattern differences between and within ocean- and stream-type chinook salmon stocks may be responsible for fluctuations in abundance. Moreover, the evolution of life-history strategies has, in part, been a response to long-term geographic and seasonal differences in marine productivity and estuary availability.

Chinook Salmon Life History and Ecology

Juvenile Life History

The most significant process in the juvenile life history of chinook salmon is smoltification, the physiological and morphological transition from a freshwater to marine existence. The emigration from river to ocean is thought to have evolved as a consequence of differences in food resources and survival probabilities in the two environments (Gross 1987). Salmon juvenile life-history patterns are usually deduced by examining the developmental pattern of circuli on juvenile and adult fish scales (Gilbert 1912, Rich 1920a, Koo and Isarnkura 1967). Within the ocean-type (subyearling) and stream-type (yearling) migrant designations, several subtypes have been described (Gilbert 1912, Reimers 1973, Schluchter and Lichatowich 1977, Fraser et al. 1982). Ocean-type juveniles enter saltwater during one of three distinct phases. “Immediate” fry migrate to the ocean soon after yolk resorption at 30-45 mm in length (Lister et al. 1971, Healey 1991). In most river systems, however, fry migrants, which migrate at 60-150 days post-hatching, and fingerling migrants, which migrate in the late summer or autumn of their first year, represent the majority of ocean-type emigrants. When environmental conditions are not conducive to subyearling emigration, ocean-type chinook salmon may remain in freshwater for their entire first year. Stream-type chinook salmon migrate during their second or, more rarely, their third spring. Under natural conditions stream-type chinook salmon appear to be unable to smolt as subyearlings. The underlying biological bases for differences in juvenile life history appear to be both environmental and genetic (Randall et al. 1987). Distance of migration to the marine environment, stream stability, stream flow and temperature regimes, stream and estuary productivity, and general weather regimes have been implicated in the evolution and expression of specific emigration timing.

The success of different juvenile life-history strategies is linked to the coordinated expression of other traits. Gilbert (1912) noted that ocean-type fish exhibited a faster growth rate relative to stream-type fish. The growth difference between ocean- and stream-type juveniles has also been observed by other researchers (Carl and Healey 1984, Cheng et al. 1987, Taylor 1990a). Some of this difference may be related to differences in rearing environment, although under standardized conditions there was still a significant growth difference between ocean- and stream-type juveniles (Taylor 1990b). Clarke et al. (1992) demonstrated that the growth of stream-type juveniles was strongly associated with photoperiod, while ocean-type juvenile growth appeared to be independent of photoperiod. Juvenile life history appears to be a heritable trait. Hybridization experiments indicated that the stream-type smoltification and growth pattern are recessive relative to the ocean-type pattern (Clarke et al. 1992). Juvenile stream-type chinook salmon have also been shown to be more aggressive than ocean types. This may be a territorial defense mechanism for resource limited freshwater systems (Taylor and Larkin 1986, Taylor 1988, Taylor 1990b). Morphometric differences, such as larger and more colorful fins, observed in some stream-type populations may be related to social displays that maintain territories (Carl and Healey 1984, Taylor and Larkin 1986). Thus, the timing of parr-smolt transition appears to be associated with the expression of a number of other traits in order to maximize individual survival.

Juvenile stream- and ocean-type chinook salmon have adapted to different ecological niches. Ocean-type chinook salmon tend to utilize estuaries and coastal areas more extensively for juvenile rearing. In general, the younger (smaller) juveniles are at the time of emigrating to the estuary, the longer they reside there (Kjelson et al. 1982, Levy and Northcote 1982, Healey 1991). There is also an apparent positive relationship between rivers with large estuary systems and the number of fry migrants (Fraser et al. 1982). Brackish water areas in estuaries also moderate physiological stress during parr-smolt transition. The development of the ocean-type life-history strategy may have been a response to the limited carrying capacity of smaller stream systems and glacially scoured, unproductive watersheds, or a means of avoiding the impact of seasonal floods in the lower portion of many watersheds (Miller and Brannon 1982). In the Sacramento River and coastal California rivers, subyearling emigration is related to the avoidance of high summer water temperatures (Calkins et al. 1940, Gard 1995). Ocean-type chinook salmon may also use seasonal flood cycles as a cue to volitionally begin downstream emigration (Healey 1991). Migratory behavior in ocean-type chinook salmon juveniles is also positively correlated with water flow (Taylor 1990a).

Stream-type juveniles are much more dependent on freshwater stream ecosystems because of their extended residence in these areas. A stream-type life history may be adapted to those watersheds, or parts of watersheds, that are more consistently productive and less susceptible to dramatic changes in water flow, or which have environmental conditions that would severely limit the success of subyearling smolts (Miller and Brannon 1982, Healey 1991). Stream-type chinook salmon juveniles exhibit downstream dispersal and utilize a variety of habitats during their freshwater residence. This dispersal appears to be related to resource allocation and migration to overwintering habitat and is not associated with saltwater osmoregulatory competence (Hillman et al. 1987, Levings and Lauzier 1989, Taylor 1990a, Healey 1991). For example, the migration of subyearling juvenile spring-run chinook salmon in the Wenatchee River (a stream-type population) may be due to competition with hatchery releases or the interspecific interaction between steelhead and chinook salmon juveniles (Hillman and Chapman 1989). There was a tendency for juveniles to move into deeper water, farther from the bank shelter, as they grew older. If suitable overwintering habitat, such as large cobble, is not available then the fish will tend to migrate downstream (Bjornn 1971, Bustard and Narver 1975, Hillman et al. 1987). At the time of saltwater entry, stream-type (yearling) smolts are much larger, averaging 73-134 mm depending on the river system, than their ocean-type (subyearling) counterparts and are therefore able to move offshore relatively quickly (Healey 1991).

The variability in the time of emigration to the marine environment among stocks of chinook salmon, combined with geographic and yearly differences in freshwater productivity, make comparisons of the sizes of smolts among different stocks difficult. Size data may be confounded by the presence within a watershed of multiple native stocks that exhibit different life-history strategies. The possible inclusion of hatchery-reared fish in smolt samples is a further confounding factor. Smolt size, therefore, was not emphasized among the life-history traits used to determine ESU boundaries.

Ocean- and stream-type chinook salmon populations exhibit a geographical distribution that further underscores the ecological adaptation of these two races. Chinook salmon stocks in Asia, Alaska, and Canada north of the 55th parallel, and in the headwaters (upper elevations) of the Fraser River and the Columbia River Basins, exhibit a stream-type life history: emigrating to sea in their second or third spring and generally entering freshwater several months prior to spawning (Healey 1991). A notable exception to this trend includes populations in the Situk River and several Yakutat foreland River Basins in Alaska, which emigrate primarily as subyearlings (Johnson et al 1992a, ADFG 1997). Ocean-type chinook salmon are predominant in coastal regions south of 55°N, in Puget Sound, in the lower reaches of the Fraser and Columbia Rivers, and in California's Central Valley (Gilbert 1912, Rich 1920a, Healey 1983, Taylor 1990b). One analysis of principal components influencing life-history type (distance to the sea, daylight hours during the growing season and air temperature) accounted for 96% of the total observed variation in age at smoltification (Taylor 1990a). However, the abrupt change between stream- and ocean-type life histories at 55°N occurs in the absence of a similarly abrupt change in environmental conditions (Healey 1983) and may be related to patterns of colonization following deglaciation (Taylor 1990b).

Stream-type life histories are most commonly associated with early timed runs of fish (Rich 1920a, Healey 1983). This is partially because the headwater regions south of 55°N are only accessible during peak spring stream flows, additionally, temperatures in more northerly streams and headwater areas are much colder than in other areas and require early deposition of eggs to allow for proper developmental timing. Overall, juvenile smoltification strategies are one expression of a more complicated, genetically based life-history adaptation to ecological conditions (Taylor 1990a, Clarke et al. 1992). Differences in juvenile life-history strategies among chinook salmon stocks were a useful component in helping to determine boundaries between ESUs.

Ocean Distribution

Coastwide, chinook salmon remain at sea from 1 to 6 years (more commonly 2 to 4 years), with the exception of a small proportion of yearling males which mature in freshwater or return after 2 or 3 months in salt water (Rutter 1904, Gilbert 1912, Rich 1920a, Mullan et al. 1992). Differences in the ocean distribution of specific stocks may be indicative of resource partitioning and may be important to the success of the species as a whole. Current migratory patterns may have evolved as a balance between the relative benefits of accessing specific feeding grounds and the energy expenditure necessary to reach them. If the migratory pattern for each population is, in part, genetically based, then the efficiency with which subsequent generations reach and return from their traditional feeding grounds will be increased.

The vast majority of CWT-marked chinook salmon come from hatchery populations; therefore, the migratory routes of many wild fish stocks must be inferred from their corresponding hatchery populations. Furthermore, CWT ocean recoveries are obtained through commercial and sport fishery samples; therefore, the relative intensity of each fishery can bias the interpretation of the oceanic distribution of each stock. Comparisons of oceanic distributions across years can also be influenced by changes in fishing regulations and ocean conditions (such as during an El Niño). Confounding effects were considered in the interpretation of CWT recoveries, and small differences in CWT ocean recoveries between stocks were not considered as a distinguishing factor.

The genetic basis for ocean distribution has been supported by a number of different studies involving the monitoring of CWT-marked fish caught in the ocean fisheries. The relative influence of genetic vs. environmental factors on migratory pattern can be deduced from transplantation studies. Transplanted Elwha River chinook salmon continued to follow their traditional migratory pattern after being reared and released at a site 150 km to the east, except that the actual route had also been shifted 150 km eastward (Brannon and Hershberger 1984). Additionally, hybrids between the Elwha River and Green River (University of Washington) stocks exhibited an intermediate ocean migration pattern. Transplantation studies with coastal stocks in Oregon have yielded similar results (Nicholas and Hankin 1988). Chinook salmon whose natal stream lies south of Cape Blanco tend to migrate to the south, while those to the north of Cape Blanco tend to migrate in a northerly direction. Transplants of south migrating stocks to release sites north of Cape Blanco do not alter the basic southerly direction of ocean migration (Nicholas and Hankin 1988). Recoveries of CWT-marked fish from ocean fisheries indicate that fish stocks follow predicable ocean migration patterns, and that these are based on “ancestral” feeding routes (Brannon and Setter 1987).

Ocean- and stream-type chinook salmon are recovered differentially in coastal and mid-ocean fisheries, indicating divergent migratory routes (Healey 1983, 1991). Ocean-type chinook salmon tend to migrate along the coast, while stream-type chinook salmon are found far from the coast in the central North Pacific (Healey 1983, 1991; Myers et al. 1984). Studies of CWT-marked prerecruit (<71 cm) fish in the marine fisheries off of Southeastern Alaska indicated that differences in migration speed, timing, and growth were related to the life history, age, and general geographic origin of the stocks (Orsi and Jaenicke 1996). The causal basis for this difference in migration pattern is unknown, but may be related to poor coastal feeding conditions during past glacial events for the more northerly (stream-type) populations.

The freshwater component of the adult returning migratory process is also under a significant genetic influence. In one experiment, “upriver bright” chinook salmon were captured, spawned, and the subsequent progeny reared and released from a downriver site (McIsaac and Quinn 1988). A significant fraction of the returning adults from the “upriver bright” progeny group bypassed their rearing site and returned to their “traditional” spawning ground 370 km further upriver. The high degree of fidelity with which chinook salmon return to their natal stream has been shown in a number of studies (Rich and Holmes 1928, Quinn and Fresh 1984, McIsaac and Quinn 1988). Returning to the “home stream” provides a mechanism for local adaptation and reproductive isolation.

Ocean migration patterns represent an important form of resource partitioning and are important to the evolutionary success of the species; therefore, differences in ocean migratory pattern were an important consideration in the determination of ESU boundaries.

Size and Age at Maturation

The age at which chinook salmon begin sexual maturation and undertake their homeward migration is dependent on a number of different factors. Age, body size and composition, and fecundity traits in salmonids have all been shown to be partially under genetic control (Ricker 1972) and genetically and phenotypically correlated (Gall 1975). Because of genetic correlations between these traits, natural selection on one or more of these traits may affect the expression of other traits. The confounding effects of correlated traits make it difficult to identify specific selective (ecologically important) criteria that influence size and age at maturity.

Adult body size in chinook salmon does not appear to be strongly correlated to latitude; however, there appears to be a slight negative correlation between adult body size and length of migration (Roni and Quinn 1995). The relationship between size and length of migration may also reflect the earlier timing of river entry and the cessation of feeding for chinook salmon stocks that migrate to the upper reaches of river systems. Juvenile life history has an apparent influence on the size of returning spawners. Ocean-type fish that have been at sea from 1 to 2 years are generally larger than their respective stream-type counterparts (Roni and Quinn 1995). This may reflect the more productive feeding conditions that exist in the marine environment and/or the additional 3 to 5 months that ocean-type fish remain in the marine environment before beginning their spawning migration.

Body size, which is correlated with age, may be an important factor in migration and redd construction success. Beacham and Murray (1987) reported a correlation between body size and large (< 100 km^2 watershed area) and small river size in chum salmon (*O. keta*). Roni and Quinn (1995) reported that under high density conditions on the spawning ground, natural selection may produce stocks with exceptionally large-sized returning adults. Spawning aggregations may select for large body size in males due to competition between males for females and the “attractiveness” of large males to females (Foote 1990). Large body size may be advantageous for females because of the success of larger fish in establishing, digging, and protecting their redds (Healey and Heard 1984). Competition for redd sites, stream flow, and gravel conditions are also thought to influence adult size in coho salmon (Holtby and Healey 1986).

An alternative strategy for chinook salmon is for males to mature at an early age. “Mini-jack” or “jack” chinook salmon males mature in their first or second ocean years, respectively. Early maturation among male chinook salmon was first described by Rutter (1904). Early maturation offers a reduced risk of mortality, but younger (smaller) males may be at a competitive disadvantage in securing a mate (Gross 1987). The incidence of jack males has underlying genetic determinants and appears to be, in part, a response to favorable growing conditions. A variant of this life-history strategy is maturation without emigrating to the ocean. Rich (1920a) estimated that 10-12% of the juvenile males on the McCloud River were maturing without leaving the river. Mullan et al. (1992) found that early maturing resident males were common in both hatchery and wild populations in the Wenatchee River. Non-migrating mature males have also been observed in the Snake River Basin (Gebhards 1960, Burck 1967, Sankovich and Keefe 1996), Methow and Yakima Rivers (Hubble[5]), and the Deschutes River. Resident males have been observed among some stream- and ocean-type chinook salmon stocks in the Fraser River above Hell’s Gate, which would have historically been a potential barrier to small migrating early maturing males, but not among lower river or coastal populations (Taylor 1989, Foote et al. 1991). The location and physical characteristics of each river may determine the expression of this life-history trait. It is

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unlikely that small jack males would be physically able to undertake the arduous return migration to many upriver areas (Mullan et al. 1992) or that sufficient time exists for the completion of the smolt emigration and return migration. Nonmigrating early maturing males may have a good chance of mating success, especially during poor return years when there may be a shortage of large males on the spawning grounds. The modification of smoltification, a major physiological process, to produce early maturing males in a population is indicative of the importance of this life-history trait to the reproductive success of specific populations.

The heritability of body size and age has been more extensively studied in chinook salmon than have other traits. Crosses between different aged parents have demonstrated that the ages of maturity for parents and progeny were strongly correlated (Ellis and Noble 1961, Donaldson and Bonham 1970, Hershberger and Iwamoto 1984, Withler et al. 1987, Hankin et al. 1993). The expression of early maturation in chinook salmon was found to have a significant genetic component; moreover, different stocks exhibited different levels of early maturation in response to environmental changes (Heath et al. 1994). The positive response of chinook salmon to selective breeding experiments is indicative of a significant genetic component to body size (Donaldson and Menasveta 1961). Chinook salmon stocks exhibit considerable variability in size and age of maturation, and at least some portion of this variation is genetically determined.

From an evolutionary standpoint, the potential increases in size, fecundity, and egg size gained from remaining on the marine feeding grounds an additional year must be weighed against the chances of mortality during that year (Healey and Heard 1984, Healey 1986). The specific conditions that exist in each river must also influence, in part, the expression of these characteristics. The size and age of spawning chinook salmon in any given population may have a significant impact on their survival, and trends in size and age were utilized in determining ESU boundaries. However, the large environmental influence (on a regional and annual basis) on chinook salmon size and age, as well as possible biases resulting from different fishery harvest techniques and the inclusion of hatchery reared fish, would suggest that available size and age data be used with caution.

Run Timing

Early researchers recorded the existence of different temporal “runs” or modes in the migration of chinook salmon from the ocean to freshwater. Two major influxes of chinook salmon were observed returning to the Sacramento-San Joaquin River system, although “...there is no definite distinction between spring and fall runs; there is no time during the summer when there are no salmon running” (Rutter 1904, p. 122). It was also reported that spring-run fish tended to migrate to the upriver portions of the Sacramento River and spawn earlier than the fall run, which spawned in the lower regions of tributaries and in mainstem river areas. A similar distinction was made between spring, summer, and fall or “snow” salmon runs in the Klamath River (Snyder 1931). The underlying genetic influence on run timing was initially demonstrated by Rich and Holmes (1928), when spring-run chinook salmon from the MacKenzie River were reared, marked, and released from a predominantly fall-run watershed. The transplanted chinook salmon displayed no apparent alteration in their normal time of return or spawning, although there was an increase in straying. Subsequent stock transplantations have further substantiated the heritable nature of run timing. Heritability estimates for return timing among early- and late-returning pink salmon (*Oncorhynchus gorbuscha*) runs in Alaska were 0.4 and 0.2 for females and males, respectively (Gharrett and Smoker 1993).

Freshwater entry and spawning timing are generally thought to be related to local temperature and water flow regimes (Miller and Brannon 1982). Temperature has a direct effect on the development rate of salmonids (Alderdice and Velsen 1978). Only one run timing for chinook salmon is found in most rivers in Alaska and northern British Columbia, where summers are short and water temperatures cold (Burger et al. 1985). The Kenai River in Alaska is an exception to this trend, having mid-June and mid-July runs that ultimately spawn in areas with distinct thermal regimes (Burger et al. 1985). Asian rivers are thought to contain only one run of chinook salmon, with the possible exception of the Kamchatka and Bol'shaya Rivers (Vronskiy 1972, Smirnov 1975). Among stream-type stocks, the King Salmon River in Alaska differs from the general trend in that adults return in a relatively mature condition and spawn in the lower river, extending down to the intertidal area (Kissner 1985, ADFG 1997). The majority of multiple run rivers are found south from the Bella Coola and Fraser Rivers.

Runs are designated on the basis of adult migration timing; however, distinct runs also differ in the degree of maturation at the time of river entry, thermal regime and flow characteristics of their spawning site, and actual time of spawning. Early, spring-run chinook salmon tend to enter freshwater as immature or "bright" fish, migrate far upriver, and finally spawn in the late summer and early autumn. Late, fall-run chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry (Fulton 1968, Healey 1991). Summer-run fish show intermediate characteristics of spring and fall runs, spawning in large and medium-sized tributaries, and not showing the extensive delay in maturation exhibited by spring-run chinook salmon (Fulton 1968). Winter-run chinook salmon (which presently exist only in the Sacramento River) begin their freshwater migration at an immature stage and travel to the upper portions of the watershed to spawn in the spring. All stocks, and especially those that migrate into freshwater well in advance of spawning, utilize resting pools. These pools provide an energetic refuge from river currents, a thermal refuge from high summer and autumn temperatures, and a refuge from potential predators (Berman and Quinn 1991, Hockersmith et al. 1994). Furthermore, the utilization of resting pools may maximize the success of the spawning migration through decreases in metabolic rate and the potential reduction in susceptibility to pathogens (Bouck et al. 1975, Berman and Quinn 1991). In the Stilliguamish River, there was a high correlation between the location of pools and redds, suggesting that the pool abundance may limit the amount of spawning habitat available (PSSSRG 1997).

Run timing is also, in part, a response to streamflow characteristics. Rivers such as the Klickitat or Willamette Rivers historically had waterfalls which blocked upstream migration except during high spring flows (WDF et al. 1993). Low river flows on the south Oregon coast during the summer result in barrier sandbars which block migration (Kostow 1995). The timing of migration and, ultimately, spawning must also be cued to the local thermal regime. Egg deposition must be timed to ensure that fry emerge during the following spring at a time when the river or estuary productivity is sufficient for juvenile survival and growth. The strong association between run timing and ecological conditions made this trait useful in considering potential ESU boundaries.

Straying

The high degree of fidelity with which chinook salmon return to their natal stream has been shown in a number of studies (Rich and Holmes 1928, Quinn and Fresh 1984, McIsaac and Quinn 1988). Returning to one’s natal stream may have evolved as a method of ensuring an adequate incubation and rearing habitat. It also provides a mechanism for reproductive isolation and local adaptation. Conversely, returning to a stream other than that of one’s origin is important in colonizing new areas and responding to unfavorable or perturbed conditions at the natal stream (Quinn 1993). High rates of straying by returning Umatilla River fall chinook salmon (an introduced upriver bright stock) into the Snake River in 1987-89 were apparently related to poor acclimation, high water temperatures, and lack of water in the Umatilla River (Waples et al. 1991b). Straying coho salmon (*O. kisutch*) and sockeye salmon have rapidly colonized newly deglaciated habitat (Milner and Bailey 1989), and summer-run chinook salmon may have recolonized the Okanogan River following the cessation of trapping operations at Rock Island Dam, which blocked entry from 1939-43 (Waknitz et al. 1995). The degree of straying in wild populations determines the extent of reproductive isolation and the potential for the formation of ESUs.

Available information on straying rates primarily involves hatchery-reared, transplanted, or transported fish. Rich and Holmes (1928), in one of the earliest studies of homing, released marked chinook salmon juveniles from a number of hatcheries along the lower Columbia River. Of the 104 chinook salmon that were recovered in spawning areas or at hatchery racks, only 5 (4.8 %) had strayed to areas other than their release sites (Rich and Holmes 1928). Quinn and Fresh (1984) reported that only 1.4% of the returning spring-run chinook salmon from the Cowlitz River Hatchery were recovered outside of their natal watershed, and it was suggested that straying was more frequent in older fish and in years when the run-size was low. Olfactory cues provided by conspecifics on spawning grounds, especially large aggregations, may be a powerful attractant to returning salmon (Duker 1981). If these spawning aggregations are an attractant, it may explain the negative correlation between run-size and straying as well as explaining the observed straying of naturally-produced salmon into hatcheries. Chapman et al. (1991, 1994) suggested that straying is more common among fall-run fish than among spring-run fish. Quinn et al. (1991) found that straying rates differed considerably (10-27.5%) between hatcheries releasing fall chinook salmon on the lower Columbia River.

The adult returning migratory process has been shown to be under a significant genetic influence. In one experiment, “upriver bright” chinook salmon were captured, spawned, and the subsequent progeny reared and released from a downriver site (McIsaac and Quinn 1988). A significant fraction of the returning adults from the upriver bright progeny group bypassed their rearing site and returned to their “traditional” spawning ground 370 km further upriver.

Hatchery rearing and release procedures may increase the rate of straying. Wild chinook salmon had significantly lower straying rates than did hatchery-reared fish from the Lewis River (McIsaac 1990). Releasing fish even a short distance from the hatchery can dramatically increase the straying rate (Quinn 1993, Heard 1996). Straying rates as high as 86% resulted from the long-distance transportation and release of fall chinook salmon in the Sacramento River (Cramer 1989). Unfavorable conditions (high water temperature and low flow) at hatchery return facilities may further increase straying rates (Quinn 1993). The use of hatchery stocks founded from a composite of wild stocks (e.g., upriver bright fall chinook salmon) may increase straying if the genetic component to homing is more important than the olfactory (learned) component. Chapman et al. (1994) indicated that Columbia River fall chinook salmon upriver bright hatchery stocks did have a relatively high straying rate. However, Pascual and Quinn (1994) found similar homing success rates for local and introduced stocks of chinook salmon released in the Columbia River.

Any interpretation of straying rates should consider the way in which strays were enumerated. Chapman et al. (1991) made a distinction between “legitimate” strays and “wanderers,” those fish that enter non-native streams as a part of their homing search or as a temporary refuge from unfavorable river conditions. Wanderers will normally retreat from these non-native streams and continue their return migration; however, where weirs or hatchery traps are present, wanderers will be unable to return and are often considered strays. Additionally, straying rates can be influenced by the effort placed on surveying sites other than the release site.

The use of cut-off dates by hatcheries to separate run-times can result in “temporal” straying. Cope and Slater (1957) found that 16% of the fish returning as “spring-run” adults to Coleman NFH were produced from fall-run parents, and 19% of the returning “fall-run” adults came from spring-run parents. The use of fixed return or spawning dates to distinguish runs at adult collection facilities may have resulted in the introgression of previously distinct stocks (Mullan 1987, WDF et al. 1993, Waknitz et al. 1995).

Straying by hatchery fish, especially those from non-native hatchery stocks, increases the potential for interbreeding and genetic homogenization. This may result in the loss of regionally distinct life-history characteristics.

Fecundity and Egg Size

Fecundity and egg size differences between stocks of salmon occur on a geographic basis. In salmon, fecundity tends to increase while egg size decreases with latitude (Healey and Heard 1984, Kaev and Kaeva 1987, Fleming and Gross 1990). Variation between and within regions can be considerable.

The anadromous life history of salmon is thought to be a response to the relatively poor productivity of glacially influenced or unstable freshwater environments relative to the nearby marine habitat (Neave 1958, Miller and Brannon 1982). In order to maximize the success of their emigration to saltwater, salmon juveniles must obtain a relatively large size in productivity-limited freshwater environments. One strategy for accomplishing this is through the production of large eggs and thereby large embryos (Taylor 1991, Kreeger 1995). Larger eggs produce larger fry (Fowler 1972), which may be more successful at migrating to saltwater than smaller fry (Kreeger 1995). Ocean-type chinook salmon stocks in British Columbia were reported to have larger eggs than stream-type stocks (Lister 1990). Rich (1920b) found that some chinook salmon returning to coastal streams in Oregon and Washington had larger eggs than fish returning to the Columbia River. In general, Smironov (1975) suggested that latitudinal differences existed in egg size, with southern stocks having larger eggs. Furthermore, he speculated that this was because embryonic development at higher temperatures is less efficient; southern stocks need more energy stores (larger eggs) to complete development. Alternatively, this trend may be related to the need for more southerly, predominantly ocean-type, chinook salmon to produce larger-sized fry for migration to estuary areas. In general, stream-type stocks of chinook salmon have smaller eggs than ocean-type stocks. However, there is no apparent latitudinal cline in egg size among stream-type nor ocean-type stocks (Appendix C).

Older (larger) year classes of salmon tend to produce larger sized eggs but not proportionately larger numbers of eggs than their younger (smaller) counterparts; this may be a life-history strategy to improve the survival of individual progeny rather than producing more of them (Gray 1965, Iwamoto 1982, Beacham and Murray 1985, Healey 1986, Nicholas and Hankin 1988). Factors affecting egg size in chinook salmon appear to be operating on a between- and within-population basis. Variability in egg size within populations appears to be most directly related to fish size and, to a lesser extent, age (Healey and Heard 1984, Hankin and McKelvey 1985), whereas between-population differences may represent an adaptation to regional environmental and geographic conditions.

Physiological and ecological factors have been identified that may limit the potential minimum and maximum egg sizes, 0.12 and 0.47 g, respectively (Quinn and Bloomberg 1992). The physical limitations of large eggs in absorbing oxygen due to a reduced surface area-to-volume ratio and the generally high physiological oxygen demands of salmonids may limit the maximum size of chinook salmon eggs. Stream flow, gravel quality, and silt load all significantly influence the survival of developing chinook salmon eggs. Therefore, behavioral traits such as spawning site selection would need to be correlated with physical fecundity traits. Healey (1991) showed that suboptimum habitat conditions delay or discourage spawning at a specific site.

Variation in fecundity and egg size among different stocks of chinook salmon appears to be related to geography and life-history strategy. Chinook salmon females sampled from the Sacramento River had 68% more eggs than females from the Klamath River, after adjusting for differences in body size (Snyder 1931, Healey and Heard 1984). Fecundity is related to body size, although this relationship is also dependent on a number of other factors—age, migration distance, latitude—and varies between stocks (Healey and Heard 1984, Kaev and Kaeva 1987, Fleming and Gross 1990). Galbreath and Ridenhour (1964) found that linear length-fecundity regressions for the Columbia River chinook salmon stocks were not significantly different when compared on a seasonal (monthly) run timing, total age, or smolt age basis; however, differences in body size and a small sample size may have obscured racial differences in fecundity. A further complication in the analysis of fecundity traits is the difference in body weight devoted to gonadal tissue in coastal and inland populations. Populations which undertake extended migrations may not be able to devote the same percentage of body weight toward gonad (especially ovary) development (Lister 1990). Linley (1993) found a significant negative correlation for adult sockeye salmon between the percentage of body weight devoted to gonads and the length and duration of the freshwater migration. Ivankov (1983) determined that differences in the fecundity of masu salmon (*O. masu*) females within and among rivers were correlated with juvenile growth rate and the rate of gonadal development prior to saltwater emigration, although he did not specifically evaluate the relative contributions of genetic and environmental effects.

Correlations between fecundity and body size and age, in addition to environmental fluctuations over several years, complicate the interpretation of fecundity differences. Furthermore, the majority of fecundity information comes from hatchery populations. Differences in selection on fecundity and egg size traits under hatchery conditions relative to the natural environment may limit the representative value of hatchery populations for their wild counterparts (Fleming and Gross 1990).

Other Life-History Traits

Information concerning the variability, adaptiveness, and heritability of other life-history traits in salmon is extremely limited. Genetically based differences in the rate of Pacific salmon embryonic and alevin development between run times in the same river (Tallman 1986), and between rivers (Iwamoto 1982, Beacham and Murray 1987, 1989) represent important adaptations to ensure emergence occurs at a time for optimal survival. The heritability estimates for embryonic development to hatch in chinook salmon range from 0.25 to 0.40 (Hickey 1983). Smirnov (1975) suggested significant differences in the embryonic development exist between Asian and North American stocks of chinook salmon.

Pathogen resistance is another locally adapted trait. Chinook salmon from the Columbia River drainage exhibited reduced susceptibility to *Ceratomyxa shasta*, an endemic pathogen, relative to stocks from coastal rivers where the disease is not known to occur (Zinn et al. 1977). Differences in susceptibility to the infectious hematopoietic necrosis virus (IHNV) were detected between Alaskan and Columbia River stocks of chinook salmon (Wertheimer and Winton 1982). Variability in temperature tolerance between populations is also probably due to adaptation to local conditions; however, information on the genetic basis of this trait is lacking (Levings 1993).

Regional Variation in Life-History Traits

Comparisons of life-history traits among chinook salmon populations revealed regional differences in many traits. The definition of geographic regions which contained populations with similar life-history attributes was an important step in the establishment of tentative ESU boundaries. The following discussion includes information on anthropogenic changes in habitat quality, stock transfers, and artificial propagation efforts. The impacts of these activities on genetic integrity, abundance, and other potential risks to chinook salmon populations are discussed in later sections in more detail and are included here only to the extent that these activities may have altered the expression of life-history traits in presumptive native populations.

Puget Sound to the Strait of Juan de Fuca

Chinook salmon are found in most of the rivers in this region. WDF et al. (1993) recognizes 27 distinct stocks of chinook salmon: 8 spring-run, 4 summer-, and 15 summer/fall- and fall-run stocks. The existence of an additional five spring-run stocks has been disputed among different management agencies (WDF et al. 1993). The Skagit River and its tributaries—the Baker, Sauk, Suiattle, and Cascade Rivers—constitute what was historically the predominant system in Puget Sound containing naturally spawning populations (WDF et al. 1993). Spring-run chinook salmon are present in the North and South Fork Nooksack Rivers, the Skagit River Basin, the White, and the Dungeness Rivers (WDF et al. 1993). Spring-run populations in the Stillaguamish, Skokomish, Dosewallips, and Elwha Rivers are thought to be extinct (Nehlsen et al. 1991). Summer-run chinook salmon are present in the Upper Skagit and Lower Sauk Rivers in addition to the Stilliguamish and Snohomish Rivers (WDF et al. 1993). Fall-run stocks (also identified by management agencies as summer/fall runs in Puget Sound) are found throughout the region in all major river systems. The artificial propagation of fall-run stocks is widespread throughout this region. Summer/fall chinook salmon transfers between watersheds within and outside the region have been commonplace throughout this century; thus, the purity of naturally spawning stocks varies from river to river. Captive broodstock/recovery programs for spring-run chinook salmon have been undertaken on the White River (Appleby and Keown 1994), and the Dungeness River (Smith and Sele 1995b). Supplementation programs currently exist for spring-run chinook salmon on North Fork Nooksack River and summer-run chinook salmon on the Stillaguamish and Skagit Rivers (Marshall et al. 1995, Fuss and Ashbrook 1995). Hatchery programs also release Suiattle River spring-run chinook salmon and Snohomish River (Wallace River) summer-run chinook salmon (Marshall et al. 1995, Fuss and Ashbrook 1995). The potential impacts of artificial propagation and rearing programs (especially delayed-release programs) on the expression of life-history traits were taken into account when comparing the characteristics of each stock.

Adult spring-run chinook salmon in the Puget Sound typically return to freshwater in April and May (Table 1) and spawn in August and September (Fig. 10) (Orrell 1976, WDF et al. 1993). Adults migrate to the upper portions of their respective river systems and hold in pools until they mature. In contrast, summer-run fish begin their freshwater migration in June and July and spawn in September, while summer/fall-run chinook salmon begin to return in August and spawn from late September through January (WDF et al. 1993). Studies with radio-tagged fish in the Skagit River indicated that river-entry time was not an accurate predictor of spawning time or location (SCC 1995). In rivers with an overlap in spawning time, temporal runs on the same river system maintain a certain amount of reproductive isolation through geographic separation. For example, an 18-km river section (at river kilometer (RKm) 35-53) of poor spawning habitat separates the spawning areas for summer and spring runs on the Sauk River (Williams et al. 1975).

Table 1. Freshwater migration (hatched areas) and spawning timing (gray areas) for selected chinook salmon from Washington, Oregon, California, and Idaho. Run designations are Sp-spring, Su-summer, F-Fall, LF-late fall, and W-winter. Spring run designations for White and Dungeness River stocks have been reclassified by local management agencies, but "sp" labels have been retained for historical consistency. The designation "P" represents peak spawning. Due to variability in spawning times within a stock, some fish may still be entering freshwater during the spawning time intervals. Stocks in italics are thought to be extinct but are included for comparative purposes.

								MONTH						
Stock	**Run**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Reference**
1. Puget Sound and Hood Canal														
N.F. Nooksack R.	Sp	▨	▨	▨	▨	▨■	■	■ P						WDF et al. 1993
S.F. Nooksack R.	Sp	▨	▨	▨	▨	▨	■	■ P	■					WDF et al. 1993
Upper Skagit R.	Su				▨	▨	▨■	■ P	■					Orrell 1976, WDF et al. 1993
Lower Skagit R.	F					▨	▨	▨■	■ P					WDF et al. 1993
Upper Sauk R.	Sp		▨	▨	▨	▨■	■ P	■						Orrell 1976, WDF et al. 1993
Lower Sauk R.	Su				▨	▨	▨■	■ P	■					WDF et al. 1993, WDFW 1995
Suiattle R.	Sp		▨	▨	▨	▨■	■ P	■						WDF et al. 1993, WDFW 1995
Upper Cascade R.	Sp		▨	▨	▨	▨■	■ P	■						WDF et al. 1993, WDFW 1995
Stillaguamish R.	Su				▨	▨	▨■	■ P	■					WDF et al. 1993, WDFW 1995
Stillaguamish R.	F						▨	■	■ P					WDF et al. 1993
Snohomish R.	Su						▨	▨■	■	■				WDF et al. 1993
Snohomish R.	F							▨■	■ P	■				WDF et al. 1993
Cedar R.	F						▨	■	■	■	■			WDF et al. 1993
Green R.	F						▨	▨■	■ P	■				WDF et al. 1993
White R.	Sp			▨	▨	▨	▨	■	■					WDF et al. 1993
Nisqually R.	F					▨	▨	▨■	■	■				WDF et al. 1993
Duckabush/ Dosewalips R.	F						▨	▨■	■ P					PNPTC 1995
Skokomish R.	F						▨	■ P	■					WDF et al. 1993
2. Washington Coast and the Strait of Juan de Fuca														
Dungeness R.	Sp			▨	▨	▨	■	■ P	■					PNPTC 1995, WDFW 1995
Elwha R.	F					▨	▨	■ P	■	■				PNPTC 1995, WDFW 1995
Hoko R.	F						▨	▨■	■ P	■				WDF et al. 1993, WDFW 1995
Sooes R.	F						▨	▨■	■ P	■ P				WDF et al. 1993
Sol Duc R.	Sp		▨	▨	▨	▨	▨■	■ P	■					WDF et al. 1993, QTNR 1995
Sol Duc R.	F						▨	▨■	■	■ P	■			WDF et al. 1993
Bogachiel R.	Su		▨	▨	▨	▨	▨■	■ P	■					QTNR 1995
Bogachiel R.	F						▨	▨■	■	■ P	■			WDF et al. 1993
Calawah R.	Su		▨	▨	▨	▨	▨■	■ P	■					WDF et al. 1993
Calawah R.	F						▨	▨■	■	■ P	■			WDF et al. 1993

Table 1 (Cont.).

		MONTH												
Stock	**Run**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Reference**
Hoh R.	Sp		▨	▨	▨	▨	▨■	■ P	■					WDF et al. 1993, HIT 1995
Hoh R.	F						▨	▨	■	■ P	■			WDF et al. 1993
Queets R.	Sp		▨	▨	▨	▨	▨■	■	■ P					WDF et al. 1993, QTNR 1995
Queets R.	F							▨■	■	■	■			WDF et al. 1993, QTNR 1995
Quinault R.	Sp		▨	▨	▨	▨	▨■	■	■					WDF et al. 1993, QTNR 1995
Quinault R.	F						▨	■	■	■	■			WDF et al. 1993, QTNR 1995
Chehalis R.	Sp	▨	▨	▨	▨	▨	■	■	■ P	■				WDF et al. 1993
Chehalis R.	F							▨	■	■				WDF et al. 1993
Wynoochee R.	Sp	▨	▨	▨	▨	▨	■	■	■ P	■				
Wynoochee R.	F							▨	■	■				WDF et al. 1993
Satsop R.	Su						▨	▨■	■					WDF et al. 1993
Satsop R.	F						▨	▨	▨■ P	■				WDF et al. 1993
Elk R.	F								■ P	■				WDF et al. 1993
Wilapa Bay R.	F						▨	▨	■ P	■	■			WDF et al. 1993
North R.	F						▨	▨■	■ P					WDF et al. 1993
3. Columbia River Basin (excluding the Snake River Basin)														
Lower Col R.	F						▨	■ P	■ P	■				Howell et al. 1985, WDF et al. 1993
Cowlitz R.	Sp	▨	▨	▨	▨	▨	■	■ P	■					Howell et al. 1985, WDF et al. 1993
Kalama R.	Sp	▨	▨	▨	▨	▨	■	■ P	■					Howell et al. 1985, WDF et al. 1993
Kalama R.	F						▨	▨	▨■	■				Howell et al. 1985, WDF et al. 1993
Lewis R.	Sp	▨	▨	▨	▨	▨	■	■ P	■					Howell et al. 1985, WDF et al. 1993
Lewis R.	F						▨	▨	▨■	■ P	■			WDF et al. 1993, WDFW 1995
Washougal R.	F						▨	▨	■ P	■				Howell et al. 1985, WDF et al. 1993
Clackamas R.	Sp	▨	▨	▨	▨			■ P	■					Galbreath 1965, Howell et al. 1985
Santiam R.	Sp	▨	▨	▨	▨			■ P	■					Howell et al. 1985, Olsen et al. 1992
Willamette R.	Sp	▨	▨	▨	▨			■ P	■					Howell et al. 1985, Bennett 1988
Sandy R. (Late)	F										■	■		Howell et al. 1985
Wind R.	Sp	▨	▨	▨	▨		■ P	■						Schreck et al. 1986, WDF et al. 1986
Klickitat R.	Sp	▨	▨	▨	▨		■ P	■						Howell et al. 1995, WDF et al. 1993
Deschutes R.	Sp		▨	▨	▨		■	■ P						Lindsay et al. 1989, Olsen et al. 1992
Deschutes R.	F				▨	▨	▨	▨	■	■ P	■			Jonasson and Lindsay 1988

Table 1 (Cont.).

Stock	Run	MONTH												Reference
		March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	
John Day R.	Sp		▨	▨	▨		■	■ P						Burck et al. 1979, Olsen 1994d
John Day R.	*F*							▨	▨ ■	■	■			Howell et al. 1985
Yakima R.	Sp		▨	▨	▨		■	■ P	■					Howell et al. 1985, WDF et al. 1993
Naches R.	Sp	▨	▨	▨	▨		■ P	■ P	■					Major and Mighell 1969, WDFW 1995
American R.	Sp	▨	▨	▨	▨		■ P	■						Major and Mighell 1969, WDFW 1995
Yakima R.	F						▨	▨	■	■	■ P			WDF et al. 1993, WDFW 1995
Marion Drain	F						▨	▨ ■	■	■ P	■			WDF et al. 1993, WDFW 1995
Hanford Reach	F						▨	▨	■	■ P				Howell et al. 1985, WDF et al. 1993
Wenatchee R.	Sp	▨	▨	▨			■ P	■						French and Wahle 1959, Chapman et al. 1995
Wenatchee R.	Su			▨	▨	▨		■	■ P P					WDF et al. 1993, Peven and Truscott 1995
Entiat R.	Sp	▨	▨	▨			■	■ P						WDF et al. 1993, Chapman et al. 1995
Methow R.	Sp	▨	▨	▨			■ P	■						WDF et al. 1993, Chapman et al. 1995, USFS 1995
Methow R.	Su			▨	▨	▨		■	■ P P	■				WDF et al. 1993, Chapman et al. 1994
Okanogan R.	Su			▨	▨	▨			■ P P	■				WDF et al. 1993, Chapman et al. 1994
4. Snake River														
Tucannon R.	Sp		▨	▨			■	■						WDF et al. 1993
M.S. Snake R.	Sp		▨	▨			■	■						Keifer et al. 1992
Snake R.	F						▨	▨	▨ ■	■ P	■			Chapman et al. 1991, Garcia et al. 1996
Grande Ronde R.	Sp			▨	▨	▨ ■	■ P	■						Howell et al. 1985
Grande Ronde R.	F							▨	▨ ■	■	■			Olsen et al. 1992
Wenaha R.	Sp			?			■	■ P						Chapman et al. 1990
Imnaha R.	Sp		▨	▨	▨		■ P	■						Howell et al. 1985
M.F. Clearwtr. R.	Sp	▨	▨	▨			■	■						Keifer et al. 1992
Rapid R.	Sp	▨	▨	▨			■ P	■ P						Howell et al. 1985, Schreck et al. 1986
M.F. Salmon R.	Sp			?		■	■ P	■						Keifer et al. 1992
Little Salmon R.	Su			▨	▨	▨		■ P	■					Keifer et al. 1992
Salmon R.	Su				▨	▨	■	■						Keifer et al. 1992
Pahsimeroi R.	Su				▨	▨		■						Keifer et al. 1992
5. Oregon Coast (to the Elk River and Cape Blanco)														

Table 1 (Cont.).

		MONTH												
Stock	**Run**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Reference**
Nehalem R.	Su					▨	▨	▨	■	■ P				Nicholas and Hankin 1988
Miami R.	F							▨	▨■	■ P	■	■	■	Nicholas and Hankin 1988
Klichis R.	F							▨	▨■	■	■ P	■	■	Nicholas and Hankin 1988
		■												Nicholas and Hankin 1988
Wilson R.	F							▨	▨■	■	■ P	■	■	Nicholas and Hankin 1988
		■												Nicholas and Hankin 1988
Trask R.	Sp		▨	▨	▨			■ P	■ P	■				Nicholas and Hankin 1988
Trask R.	F							▨	▨■	■	■	■	■	Nicholas and Hankin 1988
		■												Nicholas and Hankin 1988
Tillamook R.	F							▨	■	■ P	■	■		Nicholas and Hankin 1988
Nestucca R.	Sp		▨	▨	▨	▨		■ P	■	■	■			Nicholas and Hankin 1988
Nestucca R.	F						▨	▨■	■	■	■ P	■		Nicholas and Hankin 1988
Salmon R.	F						▨	▨	■	■ P	■	■		Nicholas and Hankin 1988
Siletz R.	Sp		▨	▨	▨	▨		■	■ P	■				Nicholas and Hankin 1988
Siletz R.	F							▨	■	■ P	■	■		Nicholas and Hankin 1988
Yaquina R.	F						▨	▨	■	■ P	■			Nicholas and Hankin 1988
Alsea R.	Sp		▨	▨	▨	▨		■	■ P	■				Nicholas and Hankin 1988
Alsea R.	F							▨	■	■ P	■	■		Nicholas and Hankin 1988
Suislaw R.	F							▨	■	■ P	■			Nicholas and Hankin 1988
Umpqua R. (Up.)	F					▨	▨	▨	■	■ P				Nicholas and Hankin 1988
Umpqua R. (Smith)	F							▨	■	■ P				Nicholas and Hankin 1988
Umpqua R.	Sp	▨	▨	▨	▨	▨		■	■ P					Nicholas and Hankin 1988
Coos R.	F					▨	▨	▨	■	■ P	■			Nicholas and Hankin 1988
Coquille R.	F					▨	▨	▨	■	■ P	■	■		Nicholas and Hankin 1988
Euchre Ck.	F									■	■	■		Nicholas and Hankin 1988
Floras Ck.	F									■	■ P	■		Nicholas and Hankin 1988
Sixes R.	F								▨■	■	■ P	■	■	Uremovich 1977, Nicholas and Hankin 1988
Elk R.	F								▨	■	■ P	■ P	■	Burck and Reimers 1978
		■												Nicholas and Hankin 1988
6. Southern Oregon and California Coast and Klamath River Basin														
Rogue R.	Sp	▨	▨	▨	▨			■	■ P	■				Nicholas and Hankin 1988, ODFW 1991
Rogue R.	F					▨	▨	▨	■ P	■				Nicholas and Hankin 1988, ODFW 1991
Hunter Ck.	F								▨	■	■ P	■		Nicholas and Hankin 1988, ODFW 1991
Pistol R.	F								▨	■	■ P	■		Nicholas and Hankin 1988, ODFW 1991
Chetco R.	F							▨	■	■	■ P	■		Nicholas and Hankin 1988, ODFW 1991

Table 1 (Cont.).

		MONTH												
Stock	**Run**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Reference**
Winchuck R.	F							▨	■	■	■ P	■		McLeod 1995
Smith R.	Sp		▨	▨	▨				■	■				Leidy and Leidy 1984
Smith R.	F									■	■ P	■	■	Waldvogel 1995
Klamath R. Basin	Sp		▨	▨	▨	▨	▨	■	■					HVTC 1997
Klamath R. Basin	F						▨	▨	■	■				HVTC 1997
Klamath R.	Sp		▨	▨	▨				■ P	■				Snyder 1931, USFWS 1994, Tuss et al. 1987
Klamath R.	F					▨	▨	▨ ■	■	■ P	■	■	■	Leidy and Leidy 1984, Synder 1931, USFWS 1994
Klamath R.	LF									■	■ P	■	■	Synder 1931
Shasta R.	F							▨	▨ ■	■ P	■			CDFG 1995
Trinity R.	Sp		▨	▨	▨	▨	▨	■	■	■				Moffett and Smith 1950, CDFG 1995, Dean 1995
Trinity R.	F							▨	▨ ■	■ P	■			USFWS 1994
Little R.	F								▨	▨ ■	■	■ P	■	Mosser 1995
Mad R.	F								▨	▨ ■	■	■ P	■	McLeod 1995
Eel R.	F							▨	▨	▨ ■	■ P	■	■	Grass 1995
Mattole R.	F							▨	■	■	■	■		Young 1987, Busby 1991
Garcia R.	F								■	■ P	■ P	■	■	Nielsen et al. 1995
Russian R.	F								▨ ■	■ P	■ P	■	■	Gunter 1995
7. Sacramento and San Joaquin Rivers														
San Joaquin R.	F						▨	▨	■	■ P	■	■		Neillands 1995
San Joaquin R.	*Sp*		▨	▨	▨			■	■ *P*	■				Hallock and Van Woert 1959
Mokelumne R.	F						▨	▨	■	■ P	■	■		EBMOD 1995, CDFG 1997f
Stanislaus R.	F						▨	▨	■	■ P				Fisher 1994, CDFG 1997f
Merced R.	F						▨	▨	■	■ P	■	■		Neillands 1995, CDFG 1997f
Sacramento R.	Sp	▨	▨	▨	▨	▨	■ P	■ P	■					Calkins et al. 1940,
Sacramento R.	F						▨	▨	■	■ P	■			Calkins et al. 1940, Kjelson et al. 1982
American R.	F							▨	▨ ■	■ P	■			Clark 1929, Ducey 1995
Sacramento R.	LF	■	■					▨	▨	▨	▨ ■	■	■	Clark 1929, Fisher 1994
Sacramento R.	W	■	■	■	■ P P	■	■							Fisher 1994
Deer Ck.	Sp			▨	▨	▨	■	■ P	■					

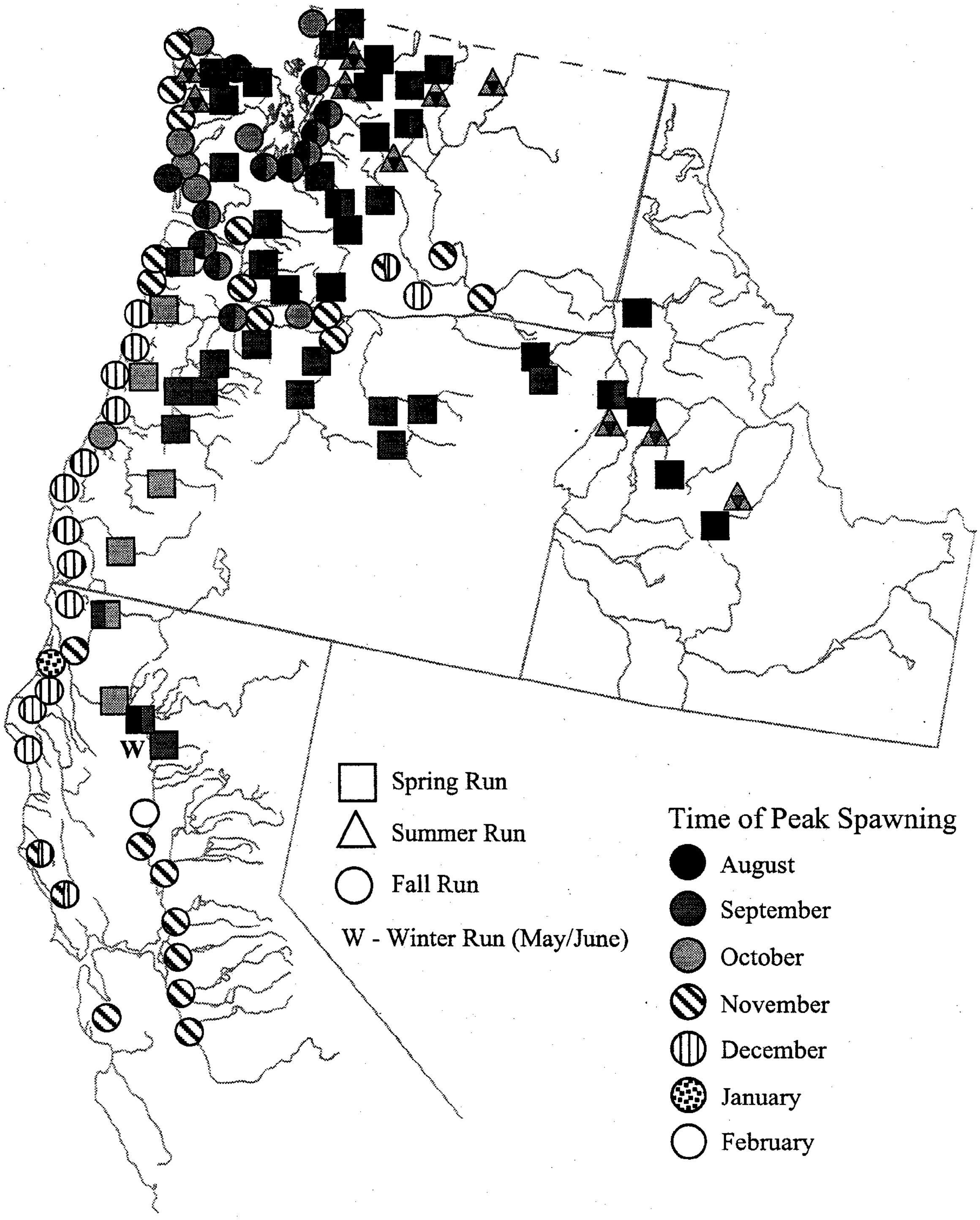


Figure 10. Month of peak spawning activity for spring-, summer-, fall-, and winter-run chinook salmon in Washington, Oregon, California, and Idaho. Shapes with two shades or patterns indicate that the peak occurs at the end of the earlier month and the beginning of the later month.

The majority of Puget Sound fish emigrate to the ocean as subyearlings. Many of the rivers have well-developed estuaries that are important rearing areas for emigrating ocean-type smolts. Puget Sound stocks also tend to have relatively large eggs, with average diameter being greater than 8.0 mm, which may be an adaptation for their subyearling smolting strategy. In contrast, the Suiattle and South Fork Nooksack Rivers have been characterized as producing a majority of yearling smolts (Fig. 11) (Marshall et al. 1995). Analysis of scales from adults returning to the South Fork Nooksack in 1994 and 1995 indicated that 69.1% of the fish had emigrated as yearlings (WDFW 1995); however, analysis of adults returning in 1980-85 showed only 16.4% of the fish had emigrated as yearlings and 75% of these were hatchery fish (WDFW, unpublished). The reason for this difference is unknown. Glacially influenced conditions on the Suiattle River may be responsible for limiting juvenile growth, delaying smolting, and producing a higher proportion of 4- and 5-year-olds compared to other chinook salmon stocks in Puget Sound, which mature predominantly as 3- and 4-year-olds (Fig. 12). Puget Sound stocks exhibit a similarity in marine distribution based on CWT recoveries in ocean fisheries. Tagged fish have been primarily captured in Canadian coastal and Puget Sound waters (Fig. 13). Marine recoveries of CWTs from Nooksack River spring-run chinook salmon have occurred to a lesser extent in the Puget Sound fishery than in other Puget Sound stocks. This may be due to the geographical position of the Nooksack River Basin at the northern end of Puget Sound and/or the allocation of effort by fishers in Puget Sound. Additionally, Elwha River summer/fall chinook salmon CWT recoveries in Alaska and Puget Sound appear to be intermediate in their frequencies between Puget Sound stocks and Washington coast stocks.

Anthropogenic activities have limited the access to historical spawning grounds and altered downstream flow and thermal conditions. Water diversion and hydroelectric dams haveprevented access to portions of several rivers. Furthermore, the construction of Cushman Dam on the North Fork Skokomish River may have resulted in a residualized population of chinook salmon in Lake Cushman. Watershed development and activities throughout Puget Sound, Hood Canal, and Strait of Juan de Fuca regions have resulted in increased sedimentation, higher water temperatures, decreased large woody debris (LWD) recruitment, decreased gravel recruitment, a reduction in river pools and spawning areas, and a loss of estuarine rearing areas (Bishop and Morgan 1996). These impacts on the spawning and rearing environment may also have had an impact on the expression of many life-history traits and masked or exaggerated the distinctiveness of many stocks.

Life-history similarities—emigration timing, age at maturation, and ocean migration—among spring-, summer-, and fall-run chinook salmon may be related to the relatively recent deglaciation (10,000 b.p.) of the Puget Sound region. It is unclear when suitable freshwater habitats for chinook salmon became available in the Puget Sound area following deglaciation (Busack and Marshall 1995). However, chinook salmon in Oregon coastal rivers, which were not glaciated, also show little differentiation in life-history characteristics, except for run timing. The life history exhibited may instead represent an optimized strategy for stocks in

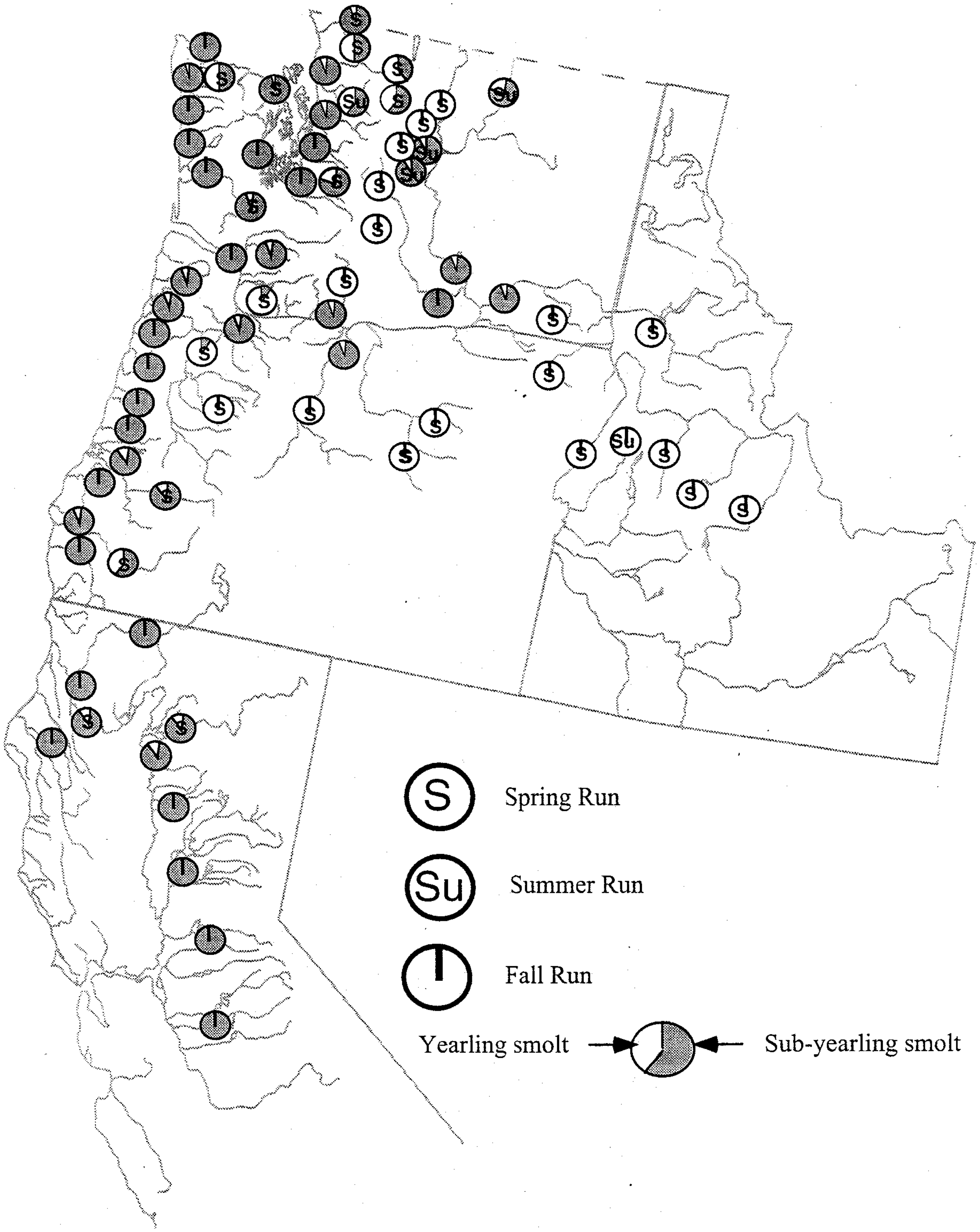


Figure 11. Proportional distribution of subyearling and yearling smolts for selected runs of chinook salmon in Washington, Oregon, California, and Idaho. References for data points can be found in Appendix A.

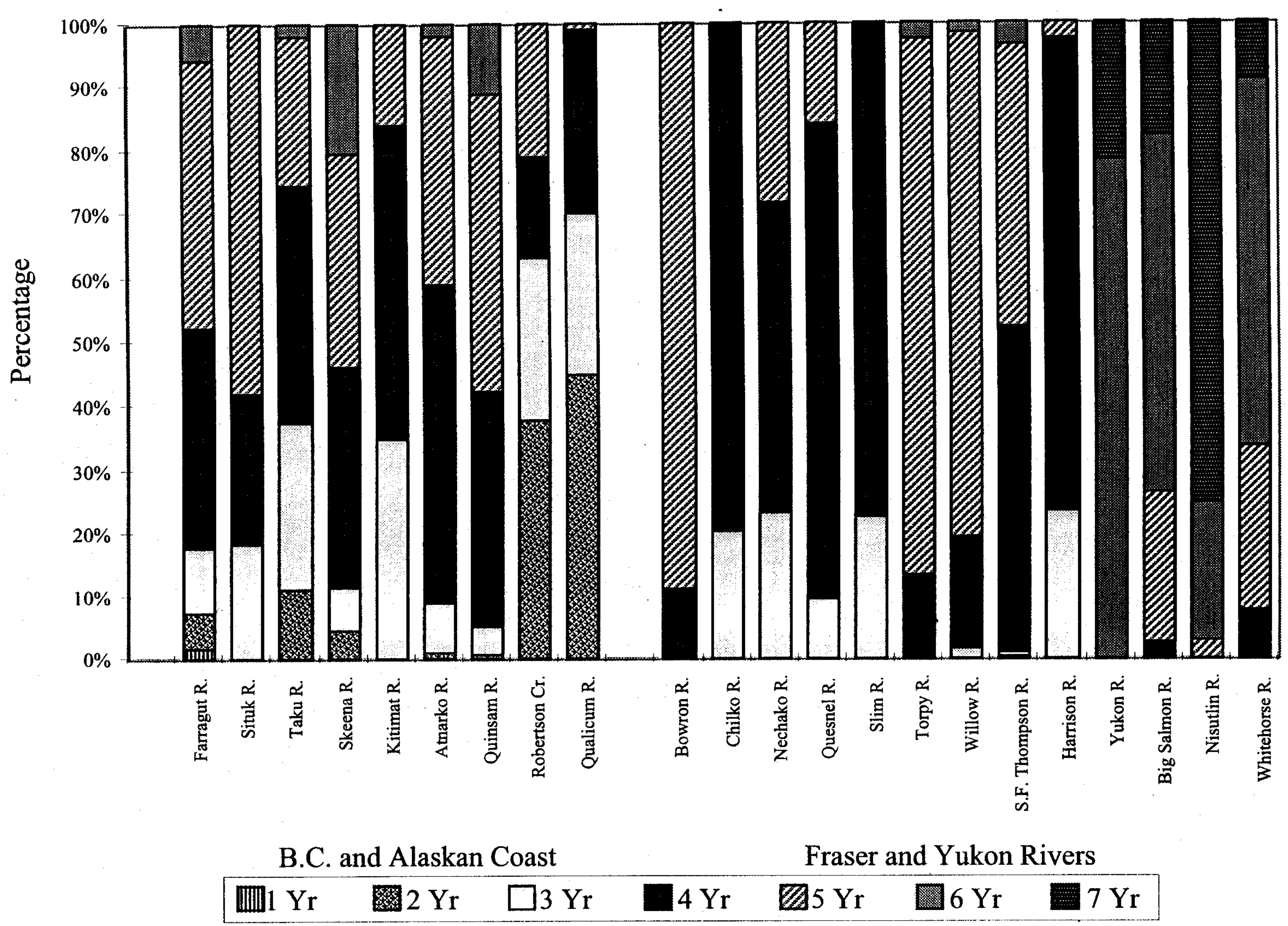


Figure 12. Distribution of age at maturation for selected populations of chinook salmon in Alaska, Yukon, British Columbia, Washington, Oregon, California, and Idaho. Ages are based on scales sampled from adults captured in terminal fisheries, sampled from spawning grounds, or returning to hatcheries. Further information can be found in Appendix B.

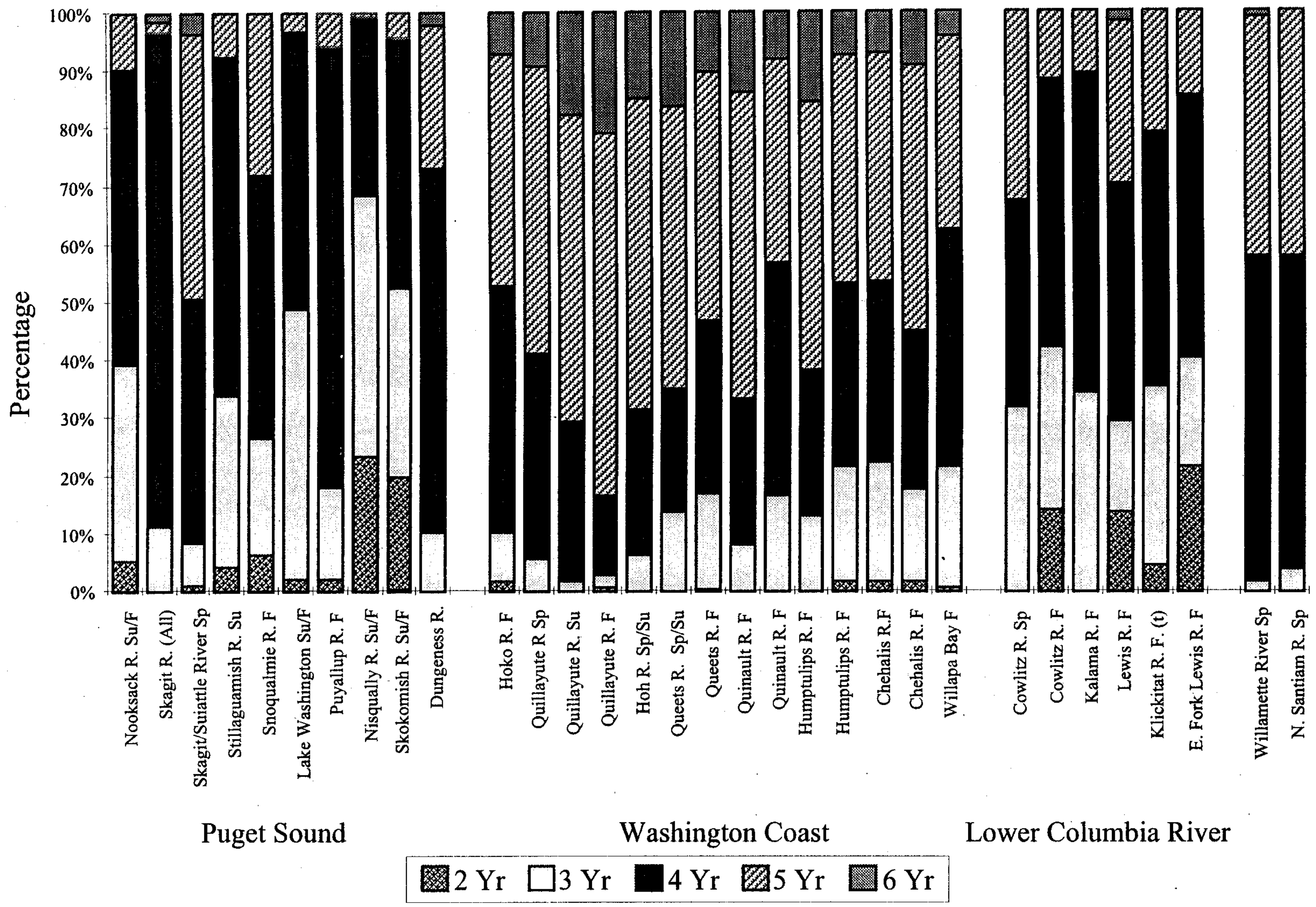
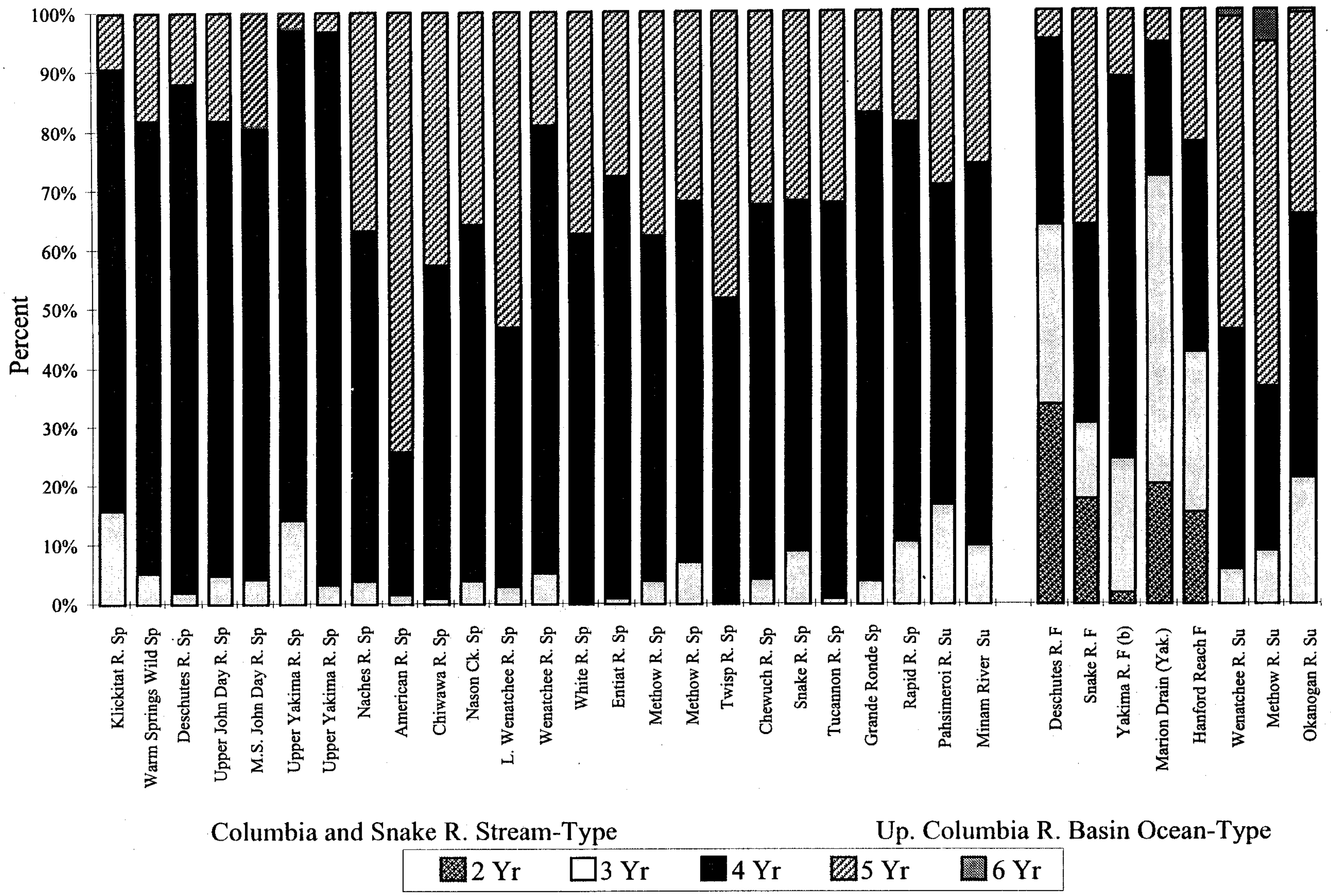


Figure 12. cont.



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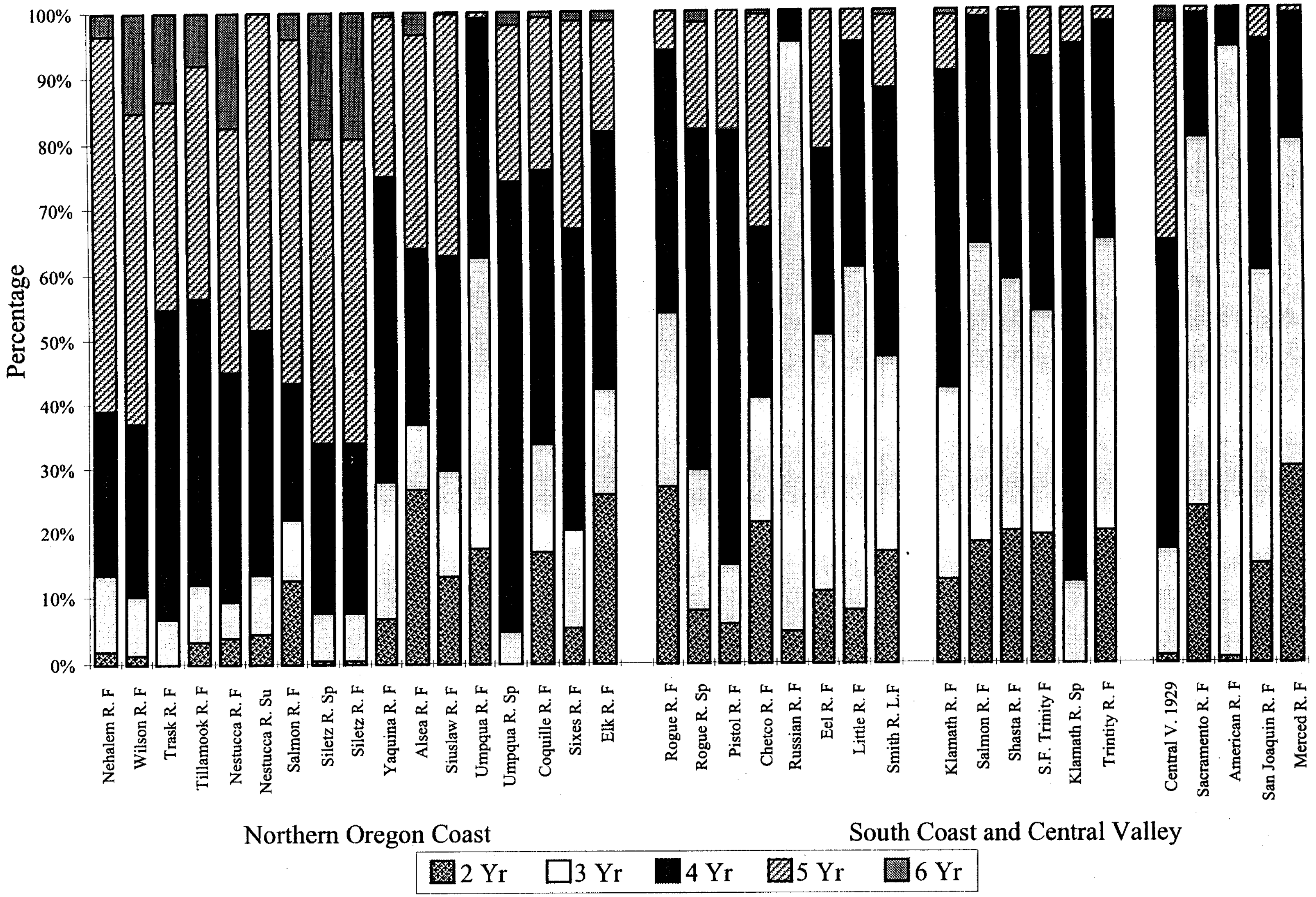

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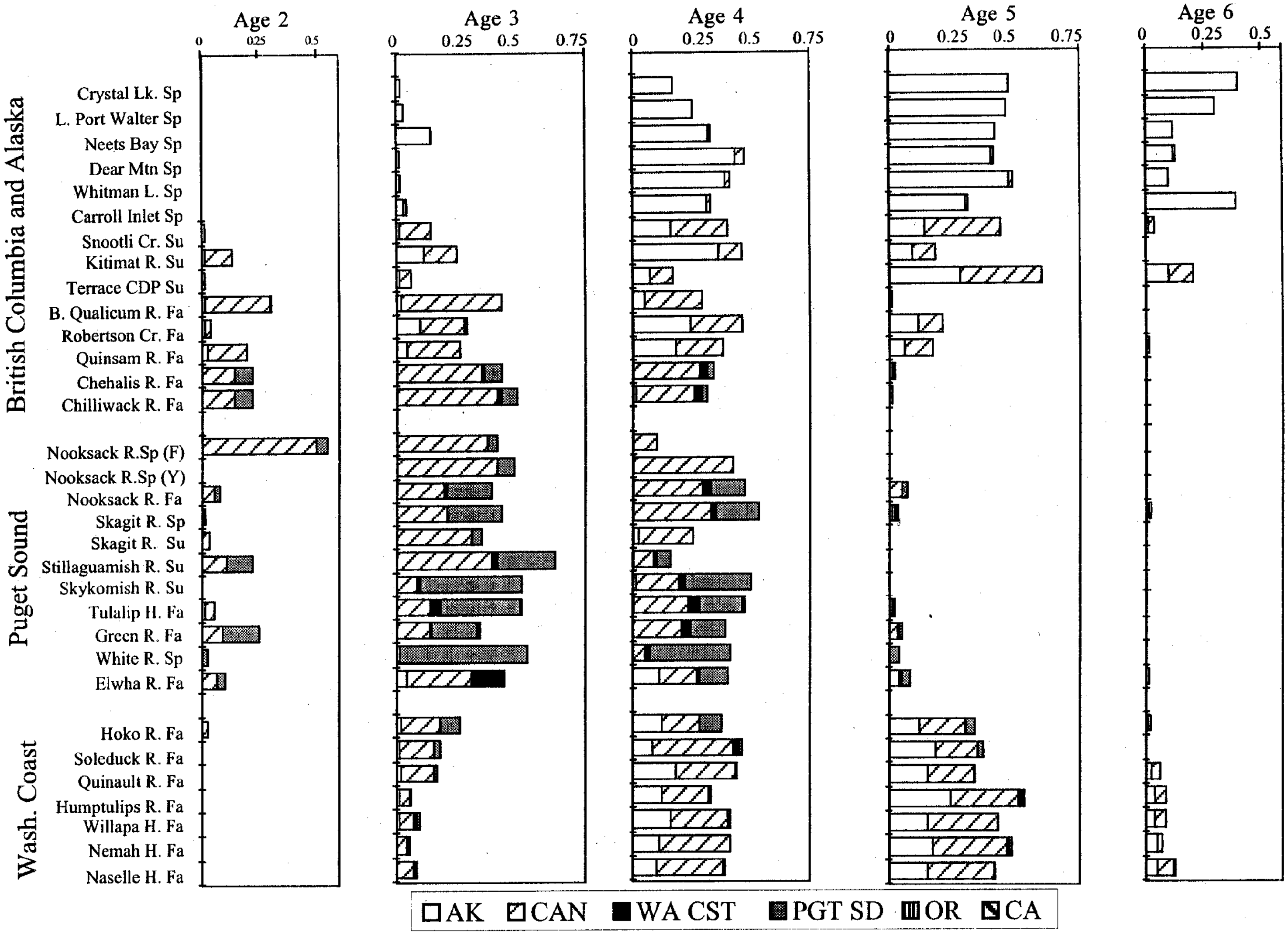

Figure 13. Marine recoveries by age and state or province of coded-wire-tagged chinook salmon from selected hatchery and wild populations. Run-timing designations are Sp-spring, Su-summer, and F-fall. Yearling and subyearling "fingerling" releases are indicated by (Y) and (F), respectively. Data and statistical analysis are presented in Bishop (1995).

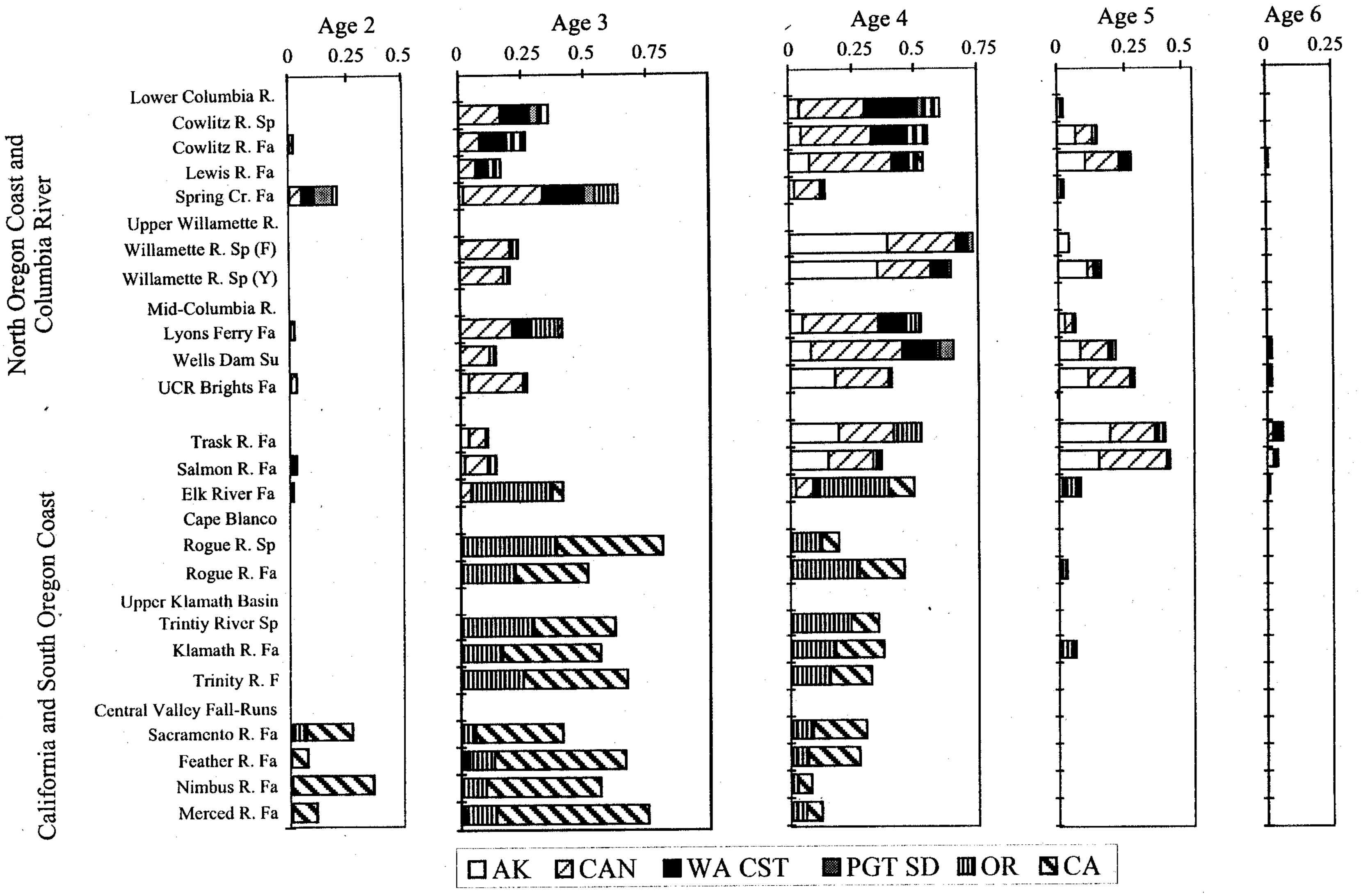

Figure 13. cont.

the Puget Sound area regardless of run timing or simply the homogenization of stocks due to artificial propagation.

Washington and Oregon coasts (Hoko River to Cape Blanco)

Fall-, summer-, and spring-run chinook salmon are found in this region. Rivers in this region tend to be short with low gradients near the coast. These low gradient areas are preferred spawning sites for chinook salmon. The relatively small size of the rivers limits the amount of spawning habitat available and minimizes the likelihood of spatial separation of run times. The Chehalis and Umpqua Rivers are physically much larger than any of the other basins, although they do not maintain proportionately larger chinook salmon runs. WDF et al. (1993) recognized 2 spring-run, 4 summer-run, 4 spring/summer-run, and 23 fall-run “stocks” on the Washington coast. According to the Oregon Department of Fish and Wildlife (ODFW), the Oregon coast from the mouth of the Columbia River to Cape Blanco contains 11 spring-run, 1 summer-run, and 33 fall-run populations (Kostow 1995). Peak spawning periods for spring, spring/summer, and summer-run populations occur from mid-September to early October which is somewhat later than in Puget Sound and the Strait of Juan de Fuca. Peak river-entry times for spring- and summer-run stocks range from May to August. In general, populations considered spring, spring/summer, and summer runs return to the river at an immature stage and hold in the river for an extended period before spawning. In contrast, fall-run fish enter freshwater at an advanced stage of maturation. Peak spawning periods for coastal fall runs occur from late-October to early-December, with a tendency for later spawning in more southerly rivers. The existence of multiple runs on many of the smaller coastal river systems is associated with low summer flows that physically limit access or result in high summer water temperatures in the lower river reaches (Nicholas and Hankin 1988).

Chinook salmon from the Washington and Oregon coasts emigrate to saltwater primarily as subyearlings and utilize the productive estuary and coastal areas as rearing habitat. The limited size of many coastal watersheds mandates the reliance on extended estuary or coastal rearing by juveniles. Furthermore, high summer water temperatures and related low flows may be responsible for early emigration. Chinook salmon from coastal populations (ocean-type) tend to have much larger eggs than inland, predominantly stream-type, populations (Rich 1920b , Nicholas and Hankin 1988, Lister 1990). Larger eggs result in larger juveniles and may enable an earlier and more successful emigration to marine rearing habitat (Fowler 1972, Kreeger 1995). The Washington and Oregon coasts contain numerous large estuary areas: Grays Harbor, Willapa Bay, Tillamook Bay, Coos Bay, Winchester Bay (Umpqua R.), and Yaquina Bay. Emigrating juveniles from rivers without well-developed estuary systems may undertake coastal migrations to estuary feeding areas or find sufficient rearing habitat in coastal areas, but it is unclear which strategy they undertake. Coastal chinook salmon from this region also mature at a later age than stocks from Puget Sound, the lower Columbia River and southern Oregon coastal areas (Nicholas and Hankin 1988, SCC 1995, QFD 1995, WDFW 1995). The majority of the runs are composed of 4- and 5-year-old fish, with a small proportion of 6-year-olds. The numerically large populations of chinook salmon on smaller coastal rivers may create competition for mates and select for larger (older) male chinook salmon (Roni and Quinn 1995).

Marine recoveries of CWTs indicate a similar ocean migration distribution for Washington and northern Oregon coastal stocks. The majority of the recoveries are from 4- and 5-year-old fish in British Columbia and Alaska fisheries. This is a more northerly oceanic distribution than is observed for Puget Sound, Lower Columbia River, and Southern Oregon and California stocks. A proportion of fish from stocks in the vicinity of Cape Blanco tend to exhibit a “north-and-south” migration pattern, with a proportion of recoveries occurring in Oregon and California coastal waters (Nicholas and Hankin 1988). The existence of a transition zone in migratory patterns may be due to natural and/or anthropogenic factors. CWT ocean recoveries of Umpqua River spring-run chinook salmon, specifically Rock Creek Hatchery fish, show a north and south distribution. The mouth of the Umpqua River is almost 100 km north of Cape Blanco; however, the Umpqua River has received transfers of Rogue River spring-run chinook salmon, a south migrating stock, during rebuilding programs over the past decades. The north-south migratory pattern may be the result of hybridization of Rogue and Umpqua River stocks. Differences in age and oceanic migration pattern between the Washington and Oregon coast and neighboring regions were among the most pronounced of any life-history comparisons.

California and southern Oregon coast (south of Cape Blanco)

The coastal drainages south of Cape Blanco are dominated by the Rogue, Klamath, and Eel Rivers. The Chetco, Smith, Mad, Mattole, and Russian Rivers and Redwood Creek are smaller systems that contain sizable populations of fall-run chinook salmon (Campbell and Moyle 1990, ODFW 1995). Presently, spring runs are found in the Rogue, Klamath, and Trinity Rivers; additionally, a vestigial spring run may still exist on the Smith River (Campbell and Moyle 1990, USFS 1995). Historically, fall-run chinook salmon were predominant in most coastal river systems south to the Ventura River; however, their current distribution only extends to the Russian River (Healey 1991). There have also been spawning fall-run chinook salmon reported in small rivers draining into San Francisco Bay (Nielsen et al. 1994).

Chinook salmon populations south of Cape Blanco all exhibit an ocean-type life history. The majority of fish emigrate to the ocean as subyearlings, although yearling smolts can constitute up to approximately a fifth of outmigrants from the Klamath River Basin, and to a lesser proportion in the Rogue River Basin; however, the proportion of fish which smolted as subyearling vs. yearling varies from year to year (Snyder 1931, Schluchter and Lichatowich 1977, Nicholas and Hankin 1988, Barnhart 1995). This fluctuation in age at smoltification is more characteristic of an ocean-type life history. Furthermore, the low flows, high temperatures, and barrier bars that develop in smaller coastal rivers during the summer months would favor an ocean-type (subyearling smolt) life history (Kostow 1995).

Run timing for spring-run chinook salmon in this area typically begins in March and continues through July, with peak migration occurring in May and June. Spawning begins in late August and can continue through October, with a peak in September. Historically, spring-run spawning areas were located in the river headwaters (generally above 400 m). Run timing for fall-run chinook salmon varies depending on the size of the river. Adult Rogue, Upper Klamath, and Eel River fall chinook salmon return to freshwater in August and September and spawn in late October and early November (Stone 1897, Snyder 1931, Nicholas and Hankin 1988, Barnhart 1995). In other coastal rivers and the lower reaches of the Klamath River, fall-run freshwater entry begins later in October, with peak spawning in late November and December—often extending into January (Leidy and Leidy 1984, Nicholas and Hankin 1988, Barnhart 1995). Late-fall or “snow” chinook salmon from Blue Creek, on the lower Klamath River, were described as resembling the fall-run fish from the Smith River in run and spawning timing, as well as the degree of sexual maturation at the time of river entry (Snyder 1931).

Populations in this region are readily distinguished from more northerly coastal populations by their oceanic migration patterns. Recoveries of CWTs in ocean fisheries occur primarily off the Oregon and California coasts. The majority of the spring and fall runs are composed of 3- and 4-year-old fish, with a small proportion of 5-year-olds (Snyder 1931, Kutkuhn 1963, Nicholas and Hankin 1988, Barnhart 1995). Analysis of scales from “late-fall run” fish returning to the lower Klamath River indicated that there was a higher proportion of 5-year-old fish (up to 51%) compared with spring- or fall-run fish returning to the upper Klamath River (Snyder 1931). In general, fish from coastal populations south of Cape Blanco mature earlier than those to the north.

Other morphological and physiological differences between geographic regions have been observed. McGregor (1923a) and Snyder (1931) described significant differences between Klamath and Sacramento River fish in gill arch and pyloric caeca counts, in addition to body size and fecundity. Dorsal fin ray, anal fin ray, and branchiostegal counts for the Klamath River chinook salmon were significantly lower than for Columbia River ocean- or stream-type chinook salmon stocks (Snyder 1931, Schreck et al. 1986). Rich (1920b) found that coastal stocks from the Umpqua and Rogue Rivers had larger eggs than Columbia River stocks. Egg diameters for fall-run chinook salmon on the Klamath River averaged 9 mm (Snyder 1931), which is similar to ranges presented by Nicholas and Hankin (1988) for Oregon coast chinook salmon but much larger than for populations in the Sacramento River (see California Central Valley section). Furthermore, data collected by McGregor (1922, 1923b) indicated that for a given length, Sacramento River fish have a higher average fecundity and smaller egg size than fish from the Klamath River. While coastal populations south of Cape Blanco are substantially different from those to the north, there is some finer scale differentiation between shorter coastal system and the two larger river basins, the Rogue and Klamath Rivers.

Agricultural, logging, and mining activities, in combination with periodic flood events (e.g. 1955, 1969), have affected all of the coastal river systems to some degree. Mining activities have also caused severe habitat degradation. The construction of dams on the Rogue, Klamath, and Eel River Basins has restricted the distribution and potentially altered the life history of chinook salmon, especially spring-run fish that historically utilized upstream habitat. Lost Creek Dam (RKm 253) eliminated one-third of the spawning habitat of spring-run chinook salmon in the Rogue River (Kostow 1995). Additionally, changes in river flow and temperature have allowed fall-run chinook salmon to spawn in more upstream locations and increased the opportunities for interbreeding between fall and spring runs (ODFW 1990). Similarly, dam construction on the Klamath River Basin has eliminated much of the spawning habitat for spring-run fish and increased the potential for interbreeding between spring and fall runs. Fish passage to the upper Klamath River was blocked at Klamath Falls by the Link River hydroelectric dam in 1895. Several dams have subsequently been constructed on the mainstem Klamath River. Historically, the largest spring-run population in the Klamath River Basin was in the Shasta River; however, this population was extirpated in the early 1930s as a result of land use practices and water diversion dams. Since 1962, the upper limit to anadromous migration has been the Iron Gate Dam (RKm 306). Additionally, the Lewiston water diversion dam (RKm 249) on the Trinity River has prevented access of spring-run chinook salmon to their historical spawning grounds on the East Fork, Stuart Fork, and Upper Trinity River and Coffee Creek (Campbell and Moyle 1990). Hatchery-reared smolts, especially yearling smolts, from mitigation hatcheries on the Klamath River (Iron Gate Hatchery) and Trinity River (Trinity River Hatchery) have probably altered age of maturation and smoltification estimates derived from the scales of unmarked returning adults. The life-history attributes of coastal chinook salmon south of Cape Blanco are quite distinct from those to the north, in the Upper Klamath River Basin, and those in the Central Valley. These differences exist in spite of artificial propagation and the loss of ecologically distinct spawning and rearing habitat areas.

California Central Valley

The Sacramento and San Joaquin Rivers and their tributaries contain several different groups of chinook salmon based on run timing and habitat utilization. Historically, spring-run fish were predominant throughout the Central Valley, occupying the upper and middle reaches (450-1,600 m in elevation) of the San Joaquin, American, Yuba, Feather, Sacramento, McCloud, and Pit Rivers, with smaller populations in most other tributaries with sufficient cold-water flow to maintain spring-run adults through the summer prior to spawning (Stone 1874, Rutter 1904, Clark 1929). Winter-run populations historically utilized the upper watersheds (450-900 m in elevation) of the upper Sacramento, Pit, McCloud, and Calaveras Rivers and were not as numerous as the spring or fall runs (Slater 1963, Reynolds et al. 1993). Fall and late-fall runs spawn in the lower reaches (60-600 m) of most rivers and streams in the Central Valley (Clark 1929, Hallock and Fry 1967, Reynolds et al. 1993). Fall-run chinook salmon are currently the most numerous of the runs in the Central Valley. Habitat degradation due to dams, water diversions, and placer mining, as well as past and present land-use practices have severely reduced the range and number of spring- and winter-run chinook salmon and to a lesser extent fall and late-fall runs (Clark 1929, Needham et al. 1940, Reynolds et al. 1993, Fisher 1994).

Central Valley chinook salmon exhibit an ocean-type life history. Large numbers of fry have been observed emigrating during the winter and spring (Rutter 1904, Rich 1920a, Calkins et al. 1940, Kjelson et al. 1982, Gard 1995). High summer water temperatures in the lower Sacramento River (temperatures in the Sacramento-San Joaquin Delta can exceed 22°C) present a thermal barrier to up- and downstream migration and may be partially responsible for the evolution of the fry migration life history (Rich 1920a, Kjelson et al. 1982). Water withdrawals for agricultural and municipal purposes, have occasionally been of a sufficient magnitude to result in reverse flows in the lower San Joaquin River.

Age estimates from scales of returning adults in 1919 and 1921 indicated that 89% of the fish had emigrated as subyearlings (Clark 1929). Scale samples in Clark's study were from returning adults taken below the confluence of the Sacramento and San Joaquin Rivers. Scale samples were made throughout the year during the course of the in-river fishing season (there were two closures during early June to early July and late September to early November) and would have included all of the runs. Calkins et al. (1940) sampled both the fall and spring runs on the upper Sacramento River and determined that the proportion of adults that emigrated as subyearlings in both runs was 90%. Gard (1995) stated that the majority of smolts from all four runs on the upper Sacramento River currently emigrate as subyearlings. The emigration of spring, fall, and late-fall runs is completed prior to high summer temperatures in the lower river, while winter-run emigration does not begin until after the summer temperatures have started to diminish in August (Fig. 14). In contrast, Fisher (1994) suggested that a large proportion of late-fall and spring-run juveniles emigrate as yearlings, the average length for late-fall-run and spring-run smolts being 160 and 115 mm, respectively. Using scales from returning adults, Calkins et al. (1940) estimated that the average size of subyearling fall- and spring-run smolts at the time of ocean entrance was 88 and 83 mm, respectively. Emigrating juveniles sampled in the upper Sacramento River are, on average, less than 70 mm in length (Gard 1995). Vast numbers of fry (<70 mm) were observed rearing in the Sacramento-San Joaquin River estuary, but relatively few larger smolts were found in the late spring or fall (Kjelson et al. 1982). Fry tend to remain in the estuary for an extended period of almost 2 months (Kjelson et al. 1982). The tendency for fish to emigrate as fry appears to be characteristic of this region and is linked to summer water conditions (low flow and high temperatures).

As with the timing of smolt emigration, the timing of the adult return migration and spawning is dictated by high summer temperatures. Fall- and late-fall runs enter freshwater at an advanced stage of maturity and move quickly to their spawning sites. The return migration does not begin until late August or September (fall run) or December (late-fall run) after summer temperatures have declined (Hallock and Fry 1967). Fall-run and late-fall-run chinook salmon peak spawning occurs in late October and early February, respectively (Fisher 1994). Winter-run and spring-run fish enter freshwater well in advance of spawning. Winter-run adults historically

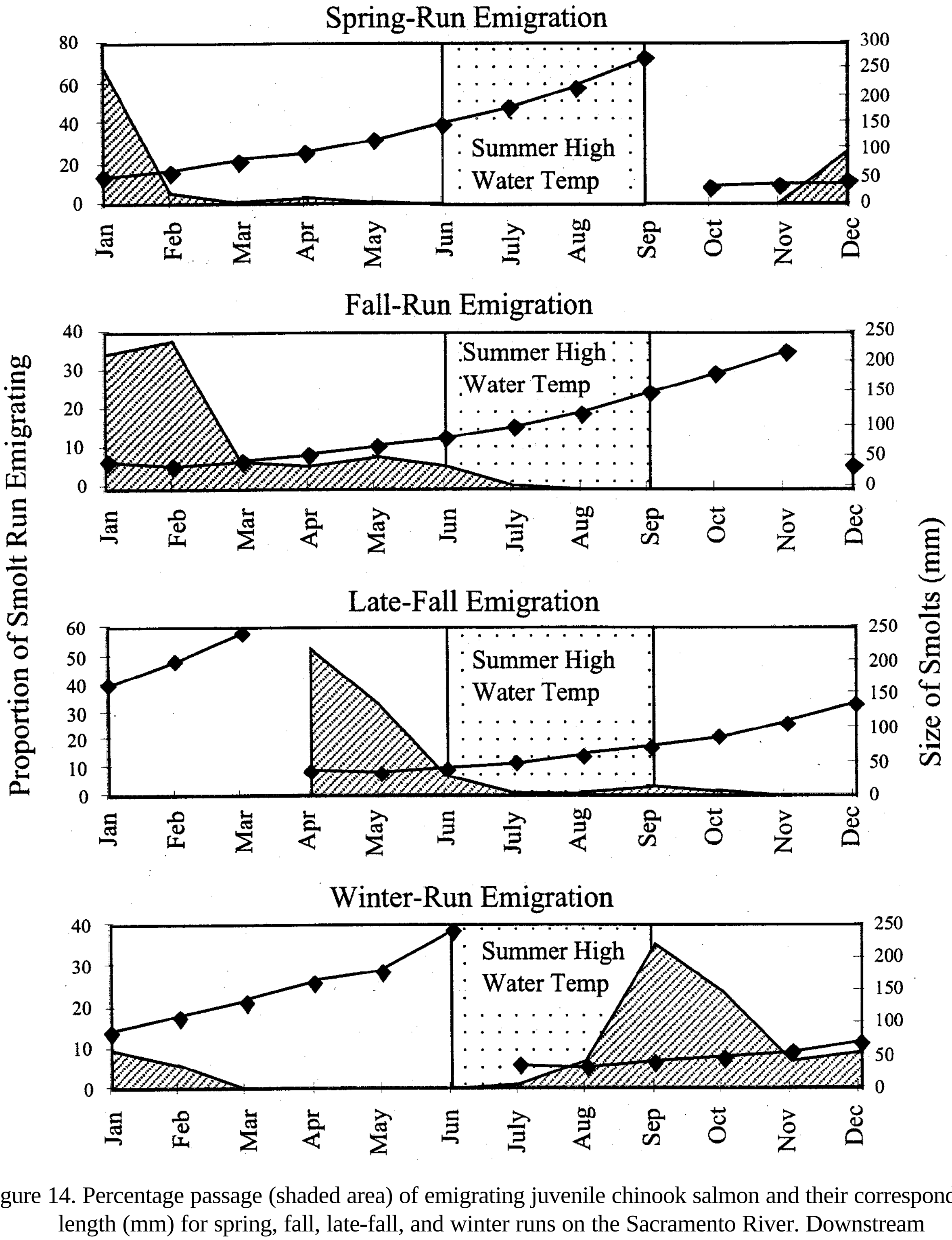

Figure 14. Percentage passage (shaded area) of emigrating juvenile chinook salmon and their corresponding length (mm) for spring, fall, late-fall, and winter runs on the Sacramento River. Downstream migrants were sampled at Red Bluff Diversion Dam (Rkm 391) and assigned to specific run designations based on growth models for each run timing (Gard 1995). Summer high-water temperatures in the lower Sacramento River create a thermal block to downstream migration.

would have migrated upstream at a time of high river flows in late November through January and held in upriver areas until spawning sometime in April-July (Slater 1963, Fisher 1994). The eggs deposited would have developed during the summer months in the cold headwaters of the Sacramento, Pit, McCloud, and Calaveras Rivers. Fry would then emigrate in the fall after temperatures in the lower river had cooled. The migration of the spring run began in March and April, later than the winter run, when river flows were still sufficient for these fish to gain access to the cool, spring- and snow-fed upper reaches of rivers. Spawning did not typically start until late August (lasting through early October), and fry did not emigrate until river flows had risen in early winter. Winter- and spring-run fish no longer have access to the vast majority of their historical spawning and juvenile rearing grounds, but their migration and spawning timing still reflect the appropriate timetable to utilize these areas.

Estimates of the age at maturation for Central Valley stocks differ between studies; this may be due to differences in scale pattern interpretation, or there may have been a shift to younger spawners. Fish gill-netted in 1919 and 1921 below the confluence of the Sacramento and San Joaquin Rivers were primarily 4 years old (46.5%), with 5- and 3-year olds comprising 32.5 and 17.0% of the spawners, respectively. The use of fish collected in gill nets introduces a considerable bias; differences observed in the percentage of 5-year-olds between 1919 and 1921 (24.0% vs. 41.0%), was thought to be due to a change in the gill-net mesh size from 14 cm to 19 cm. Additionally, the large mesh size would potentially explain the low incidence, 1.1%, of 2-year-old fish in 1921. Rich (1921) estimated females caught in the troll fishery off Monterey Bay in 1918 would mature in their third or fourth year. The predominant age classes among returning fall- and spring-run adults sampled at Redding in 1939 were 3- and 4-year-old fish (Calkins et al. 1940). Furthermore, the incidence of 2-year-old males (jacks) was 8.8 and 27.3% for the spring- and fall-run fish, respectively. Five- and 6-year old fish contributed less than 5% of the return for both runs (Calkins et al. 1940). Near the turn of the century, Rutter (1904) observed large numbers of small male “grilse” (jacks) in Battle Creek, a tributary to the upper Sacramento River. Samples taken from the McCloud River from 1909-12 suggested that approximately 10% of the males matured as 2-year olds without leaving freshwater (Rich 1920a). The mean age composition for fall-run chinook salmon from the upper Sacramento River, for the 1973-79 brood years, was 24, 57, 19, and <1% for 2-, 3-, 4-, and 5-year-olds, respectively (Reisenbichler 1986). Hallock and Fisher (1985) estimated that for winter-run chinook salmon, 3-year-old returning adults constituted the majority of returning fish (67%), with 2-year-old and 4-year-old fish representing the remainder of the age classes (25 and 8%, respectively). More recently, Fisher (1994) estimated that the 3-year-old age class was predominant among all runs, being 77, 57, 91, and 87% of each run for fall-, late-fall-, winter-, and spring-runs, respectively. The age structure of fish from the San Joaquin River Basin appears to be much younger than that of the Sacramento River (Neillands 1995). Up to 30% of the returning adults in the Merced and Tuolumne Rivers are 2 years of age; this includes a number of 2-year-old females, “Jills,” which are not normally observed in other river systems. The younger age of maturation is probably related to warmer water temperatures in the San Joaquin River rather than being genetically influenced, given the genetic similarity between Sacramento and San Joaquin River fall-runs.

Furthermore, analysis of chinook salmon age structure in the San Joaquin River is complicated by the influence of river flow on the survival of emigrating juveniles. During extreme drought years, there has been a near failure of the corresponding year class of smolts. It has yet to be determined whether the shift toward a younger age structure in the Central Valley during this century is environmentally-mediated, due to the selective harvest of older (larger) adults, or reflects an underlying genetic change.

Sacramento River chinook salmon reproductive traits are very different from coastal California and the Klamath River populations. Information on Sacramento River chinook salmon eggs sizes is limited. Page (1888) estimated the average egg diameter was 6.7 mm for eggs collected at the Baird NFH on the McCloud River. The average egg diameter for winter-run eggs in 1992 was 6.91 mm (USFWS 1996a). Quinn and Bloomberg (1992) found that chinook salmon in New Zealand (from Sacramento River transplants in 1901-07) have considerably smaller eggs, (0.17 g), relative to coastal stocks in British Columbia, (0.47 g). The fecundity of Central Valley females was also considerably higher for a given body size than for females from the Klamath River (Snyder 1931).

Historically, low summer flows and associated high temperatures have been major factors in determining the life-history characteristics for each of the four runs in the Central Valley. Winter- and spring-run adults utilized colder mountain streams to provide a suitable holding, incubation, and fry-rearing environment during months when the environment on the lower river was inhospitable. Fall- and late-fall-run fish delayed the adult return migration and spawning until temperatures had declined to acceptable levels. Differences in habitat utilization provided a spatial separation between runs in addition to temporal differences. The duration of freshwater rearing appears to have been minimized to allow emigration to estuarine rearing habitat before temperatures rose to deleterious levels.

Anthropogenic activities have primarily affected the spring and winter runs. Placer mining in the 1800s destroyed spawning and rearing habitats either directly or through increased sedimentation. Mine wastes still affect water quality. Water diversion and hydroelectric dams have limited or prevented access to most of the upriver areas that were historically utilized by spring and winter runs (Clark 1929). Agricultural and municipal water withdrawals have reduced river flows and increased temperatures during the critical summer months, or in some cases even reversed river flows (Reynolds et al. 1993). Changes in the thermal and water flow profiles for Central Valley rivers have presumably subjected chinook salmon to strong selective forces. The degree to which current life-history traits reflect predevelopment characteristics is largely unknown, especially since most of the habitat degradation occurred before chinook salmon studies were undertaken late in the nineteenth century.

One consequence of dam construction has been alteration of the river thermal profile. The completion of Shasta Dam (RKm 505) in 1944 eliminated access to the McCloud, Pit, and Upper Sacramento Rivers. However, water subsequently released from Shasta Dam has had a more uniform, cooler, thermal regime, 12-15°C, than prior to dam construction (Moffett 1949). This cool water provided new spawning habitat for spring- and winter-run adults attempting to migrate to their historical spawning grounds. The released water was also significantly warmer than historical levels during the autumn and winter, thereby accelerating egg development and fry emergence (Moffett 1949). Accelerated embryonic development may effect subsequent smolt emigration timing and reduce estuarine survival. Additionally, dam construction has eliminated the spatial and temporal barriers that once separated the fall run from the spring run and increase the potential for hybridization. The expected loss of spawning habitat above Shasta Dam led to efforts to salvage fall- and spring-run adults destined for the upper Sacramento River (Calkins et al. 1940). In a program that paralleled the GCFMP recovery effort, fish were intercepted at Balls Ferry (RKm 446) or Keswick Dam (RKm 486) and transferred to the Coleman NFH for spawning, to Deer Creek (RKm 353) for natural spawning (spring run only), or allowed to remain in the Sacramento River (primarily fall run) to spawn naturally. The primary criteria for separating spring and fall runs was a late June cut-off date that varied from year to year (Moffett 1949). In all, some 15,972 “spring-run” chinook salmon were hauled to Deer Creek from 1941-46. A considerable proportion of transferred fish died shortly after transfer to Deer Creek because of high water temperatures (Moffett 1949). There was no provision in the plan to identify winter-run adults, and a number were incidentally hauled to Deer Creek (Slater 1963). The absence of baseline information on spring-run fish from the mainstem Sacramento River and Deer Creek prevents any estimate of the impact of these fish transfers, nor is there any information for estimating potential interbreeding between winter and spring runs. The loss of spring-run spawning habitat in the headwater areas has eliminated the spatial separation that once maintained the genetic isolation between spring- and fall-run populations, and a certain amount of mixing has probably occurred in both hatchery and naturally spawning populations (Fisher 1994). Stock transfers and high straying rates may have resulted in the loss of distinctive life-history characteristics between fall-run populations. Perhaps because fall-run fish utilize mainstem areas and rear in freshwater for a limited period, there has been little selective pressure for geographic adaptation within the Central Valley. Alternatively, local extinctions and recolonizations due to natural drought cycles may have prevented distinct populations from forming among fall-run chinook salmon. Nevertheless, differences in the life-history traits of winter, spring, fall, and late-fall runs are still apparent in spite of massive changes in their spawning and rearing habitat, and these differences underscore the distinctiveness of these stocks.

Columbia River ocean type

Lower Columbia River (to the Cascade Crest)—The Columbia River is the third largest river system in the United States. The Columbia River exerts a dominant influence on the biota of the Pacific Northwest, although smaller, regional, distinctions exist within the basin. In the lower Columbia River, the Cowlitz, Kalama, Lewis, White Salmon, and Klickitat Rivers are the major river systems on the Washington State side, while the Willamette and Sandy Rivers are foremost on the Oregon State side. Spring-run chinook salmon, which spawn above the Willamette Falls, will be discussed separately because of their geographic and life-history distinctiveness. The

Clackamas River is the major tributary to the Willamette River below the Willamette Falls and is included in the discussion of this region.

The fall run is predominant in this region. Fall-run fish return to the river in mid-August and spawn within a few weeks (WDF et al. 1993, Kostow 1995). These fall-run chinook salmon are often called “tules” and are distinguished by their dark skin coloration and advanced state of maturation at the time of freshwater entry. Tule fall-run chinook salmon populations may have historically spawned from the mouth of the Columbia River to the Klickitat River (RKm 290). Whatever spawning grounds were accessible to fall-run chinook salmon on the Klickitat River (below Lyle Falls at RKm 3) would have been inundated following the construction of Bonneville Dam (RKm 243) in 1938 (Bryant 1949, Hymer et al. 1992a, WDF et al. 1993). There is no record of fall chinook salmon utilizing this lower portion of the Klickitat River (Fulton 1968). A significant fall run once existed on the Hood River (RKm 272) prior to the construction of Powerdale Dam (1929) and other diversion and irrigation dams (Fulton 1968); however, this run has become severely depleted and may have been extirpated (Howell et al. 1985, Nehlsen et al. 1991, Theis and Melcher 1995). The Big White Salmon River (RKm 270) supported runs of chinook salmon prior to the construction of Condit Dam (RKm 4) in 1913 (Fulton 1968). Although some fall-run salmon spawning occurs below Condit Dam, there have been substantial introductions of non-native stocks (WDF et al. 1993), and the persistence of a discrete native stock is unlikely. Fall-run fish from the Big White Salmon River were used to establish the nearby Spring Creek National Fish Hatchery (NFH) in 1901 (Hymer et al. 1992a). Spring Creek NFH is one component of the extensive hatchery system in Washington and Oregon producing fall chinook salmon (Howell et al. 1985). “Tule fall-run” chinook salmon begin the freshwater phase of their return migration in late August and October and the peak spawning interval does not occur until November (WDF et al. 1993).

Among other fall-run populations, a later returning component of the fall chinook salmon run exists in the Lewis and Sandy Rivers (WDF et al. 1993, Kostow 1995, Marshall et al. 1995). Because of the longer time interval between freshwater entry and spawning, Lewis and Sandy River fall chinook salmon are less mature at freshwater entry than tule fall chinook salmon and are commonly termed lower river “brights” (Marshall et al. 1995).

The Cowlitz, Kalama, Lewis, Clackamas, and Sandy Rivers presently contain both spring and fall runs, while the Big White Salmon River historically contained both spring and fall runs but presently only contains fall-run fish (Fulton 1968, WDF et al. 1993). The Klickitat River probably contained only spring-run chinook salmon due to falls that blocked access to fall-run chinook salmon during autumn low flows (Fulton 1968). The spring run on the Big White Salmon River was extirpated following construction of Condit Dam (Fulton 1968), while a variety of factors may have caused the decline and extinction of spring-run chinook salmon on the Hood River (Nehlsen et al. 1991, Kostow 1995).

Spring-run chinook salmon on the lower Columbia River, like those from coastal stocks, enter freshwater in March and April well in advance of spawning in August and September.

Historically, fish migrations were synchronized with periods of high rainfall or snowmelt to provide access to upper reaches of most tributaries where fish would hold until spawning (Fulton 1968, Olsen et al. 1992, WDF et al. 1993). Dams have reduced or eliminated access to upriver spawning areas on the Cowlitz, Lewis, Clackamas, Sandy, and Big White Salmon Rivers. A distinct winter-spawning run may have existed on the Sandy River (Mattson 1955) but is believed to have been extirpated (Kostow 1995).

Hatchery programs are widespread throughout the region, and most populations, with the possible exception of fall chinook salmon on the Lewis and Sandy Rivers, are maintained to a significant extent via artificial propagation (Howell et al. 1985, WDF et al. 1993, Kostow 1995). The life-history characteristics of spring- and fall-run populations in many rivers have probably been influenced, to varying degrees, by transfers of non-indigenous stocks. This is especially true of the stream-type chinook salmon spring-run established in the Wind River at the Carson NFH and of upriver bright fall-run chinook salmon transferred into various systems.

The majority of fall-run chinook salmon emigrate to the marine environment as subyearlings (Reimers and Loeffel 1967, Howell et al. 1985, Hymer et al. 1992a, Olsen et al. 1992, WDF et al. 1993). A portion of returning adults whose scales indicate a yearling smolt migration may be the result of extended hatchery-rearing programs rather than of natural, volitional yearling emigration. It is also possible that modifications in the river environment may have altered the duration of freshwater residence. The natural timing of spring-run chinook salmon emigration is similarly obscured by hatchery releases of spring-run chinook salmon juveniles late in their first autumn or early in their second spring. Age analysis based on scales from naturally spawning spring-run adults from the Kalama and Lewis Rivers indicated a significant contribution to escapement by fish that entered saltwater as subyearlings (Hymer et al. 1992a). This subyearling smoltification pattern may also be indicative of life-history patterns for the Cowlitz River spring run, because both the Kalama and Lewis Rivers have received considerable numbers of transplanted fish from the Cowlitz River. Life-history data from the Clackamas and Sandy Rivers is very limited, and transplantation records indicated that these rivers have received overwhelmingly large numbers of upper Willamette River spring-run chinook salmon (Nicholas 1995). In 1898, eggs from returning spring-run chinook salmon were collected from the Clackamas River (near Clear Creek) from 15 September to 24 October, and from the upper Clackamas River from 17 July to 26 August (Ravenel 1899). The upper Clackamas River spring-run chinook salmon spawning peak has apparently shifted from mid-August (1899) to the present day peak interval from late September to early October (Nicholas 1995, Willis et al. 1995). This later spawning peak is more consistent with upper Willamette River stocks (Nicholas 1995, Willis et al. 1995). Smoltification patterns for fish from the upper Willamette River are discussed in a later section.

Comparisons of historical data on the age structure of fish returning to the Columbia River are also informative in analyzing natural smoltification traits without the impact of large hatchery programs. Analysis of scales from returning adult chinook salmon sampled in the lower Columbia

River and at Bonneville Dam indicate that the proportion of yearling migrants contributing to escapement was much lower for spring-run fish in the 1920s than at present (Fig. 15) (Rich 1925; Young and Robinson 1974; Fryer and Schwartzberg 1991a, 1991b, 1992, 1993, 1994; Fryer et al. 1992). This decrease over time in the proportion of subyearling smolts may be due to increased hatchery releases of yearling smolts, increased use of stream-type spring-run stocks in hatcheries, decline in Columbia River summer-run populations, or the decreased survival/abundance of naturally-reared subyearling smolts related to changing freshwater habitat or smolt passage problems.

Adults return to tributaries in the lower Columbia River at 3 and 4 years of age for fall-run fish and 4 to 5 years of age for spring-run fish. This may be related to the predominance of yearling smolts among spring-run stocks. Marine CWT recoveries for lower Columbia River stocks tend to occur off the British Columbia and Washington coasts, with a small proportion of tags recovered from Alaska.

Upper Willamette River—Willamette Falls (RKm 42) has historically limited access to the upper river and thus defines the boundary of a distinct geographic region. High flows over the falls provided a window for returning chinook salmon in the spring, while low flows prevented fish from ascending the falls in the autumn (Howell et al. 1985). The predominant tributaries to the Willamette River that historically supported spring-run chinook salmon—the Molalla (Rkm 58), Santiam (RKm 174), McKenzie (RKm 282), and Middle Fork Willamette Rivers (RKm 301)—all of which drain the Cascades to the east (Mattson 1948, Nicholas 1995). Since the Willamette Valley was not glaciated during the last epoch (McPhail and Lindsey 1970), the reproductive isolation provided by the falls probably has been uninterrupted for a considerable time period. This isolation has provided the potential for significant local adaptation relative to other Columbia River populations.

Three major populations of spring-run chinook salmon are presently located above Willamette Falls (McKenzie River, and North and South Forks of the Santiam River) (Kostow 1995). Within-basin transfers associated with increased artificial propagation efforts since the turn of the century have reduced the genetic diversity between upper Willamette River stocks (Kostow 1995, Nicholas 1995). Fall-run chinook salmon are present in the upper Willamette River, but these fish are the result of transplants subsequent to the construction of fish passage facilities in 1971 and 1975 (Bennett 1988). Adult spring-run chinook salmon enter the Columbia River in March and April, but they do not ascend the Willamette Falls until May or June. The migration past the falls generally coincides with a rise in river temperatures above 10°C (Mattson 1948, Howell et al. 1985, Nicholas 1995). Spawning generally begins in late August and continues into early October, with spawning peaks in September (Mattson 1948, Nicholas 1995, Willis et al. 1995). Recent analysis of scales from returning adults indicated that the

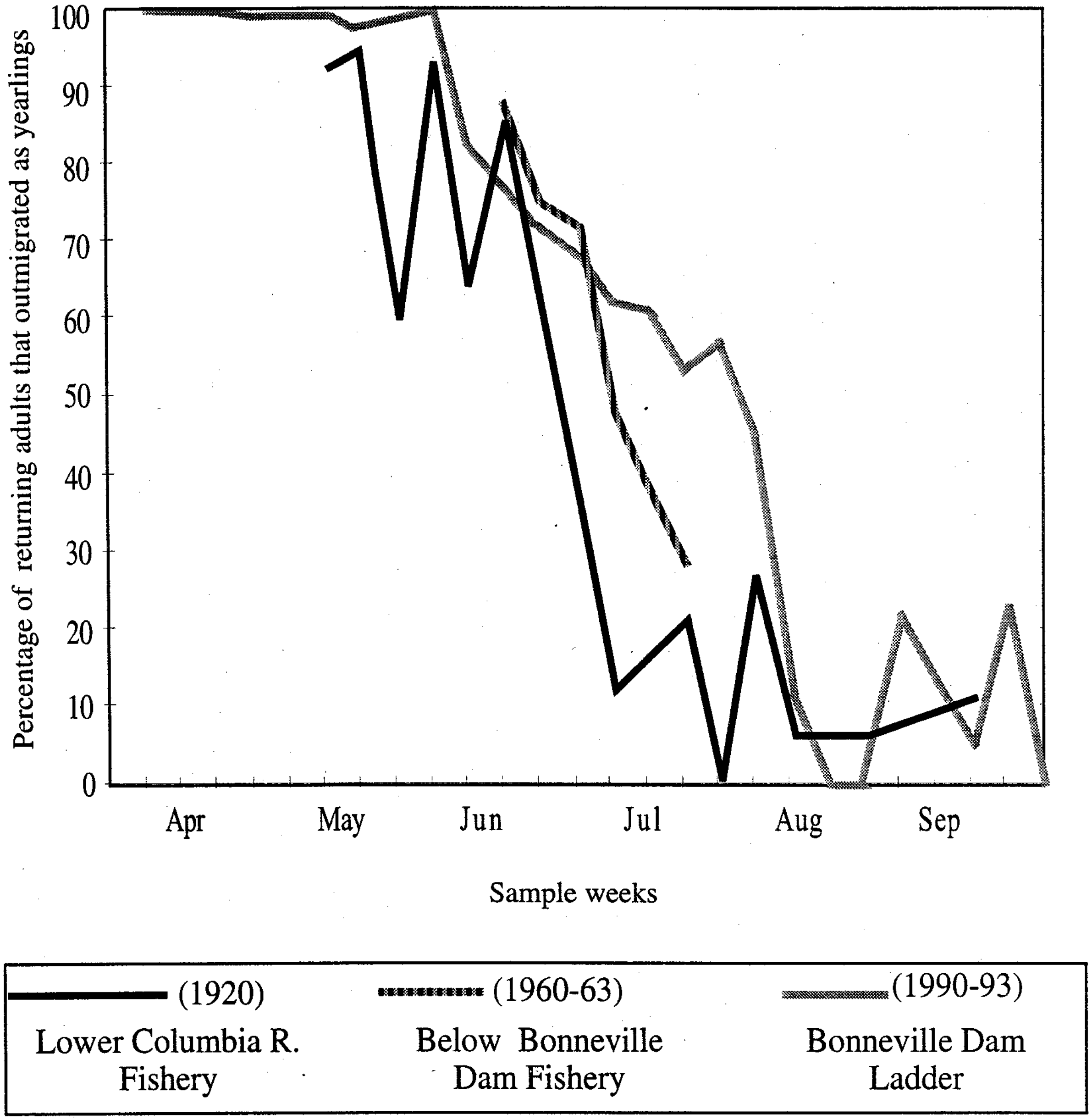

Figure 15. Percentage of adults sampled at various times during their return migration to the Lower Columbia River that had emigrated as yearling smolts. Age at smoltification was estimated by analysis of scales removed from returning adults sampled weekly in the fishery or at the Bonneville Dam ladder. Samples were taken from different locations during different time periods: 1920, 1960-63, 1990-93 (Rich 1925; Young and Robinson 1974; Fryer and Schwartzberg 1991a, 1991b, 1992, 1993, 1994; Fryer et al. 1992).

majority of fish had emigrated to saltwater as yearlings, but this is certainly biased by the overwhelming hatchery contribution to escapement (90+%) and the hatchery strategy of releasing fish late in their first autumn or in their second spring (Nicholas 1995, Willis et al. 1995). Scales sampled from returning adults in 1941 indicated that the fish had entered saltwater during the autumn of their first year (Craig and Townsend 1946). Mattson (1963) found that returning adults which had emigrated as “fingerling” (subyearling) smolts made up a significant proportion of the 3-year-old age class, with fingerling emigrants making up a smaller proportion of the older age classes. A recent study indicated that Willamette River spring-run chinook salmon have a physiological smoltification window during their first autumn (Beckman[6]). Large numbers of fry and fingerlings have been observed migrating downriver from the Willamette River and its tributaries (Craig and Townsend 1946, Mattson 1962, Howell et al. 1988). Based on the examination of scale patterns from returning adults, it would appear that these fry do not immediately enter the estuary or do not survive the emigration. Emigrating fry would have been severely affected by the high water temperatures and industrial waste discharges that were common throughout much of this century in the lower Willamette River, especially during periods of low river flow in the late spring and early summer (Craig and Townsend 1946, Mattson 1962, USGS 1993). More recently, fry migrants constitute a relatively small proportion of the smolt emigration (especially when compared to the artificially propagated fingerling and yearling contribution); thus their potential contribution to returning adults would be expected to be quite low. Alternatively, these fry migrants could be rearing in the Columbia River prior to emigrating to the marine environment (Craig and Townsend 1946, Mattson 1962).

In general, Willamette River spring-run chinook salmon mature in their fourth and fifth year of life, with the majority maturing at age 4. Historically, 5-year-old fish comprised the dominant portion of the run (Nicholas 1995, Willis et al. 1995). Marine recoveries of CWT-marked fish occur off the British Columbia and Alaska coasts, and a much larger component (>30%) of the recoveries is from Alaska relative to other lower Columbia River stocks. Age of release (subyearling vs. yearling) does not appear to influence the general oceanic distribution of fish. Morphologically, Willamette River spring-run fish are similar to other lower Columbia River chinook salmon (Schreck et al. 1986). Vertebral counts for several Willamette River “wild” and hatchery samples average 68.3-69.5, which is similar to other ocean-type chinook salmon from the Columbia River, but it is significantly less than vertebral counts for upper Columbia River stream-type spring- and summer-run chinook salmon, 71.3-72.5 (Schreck et al. 1986). These vertebral counts suggest that past transplants of Carson NFH spring-run chinook salmon (a stream-type stock) did not have a significant genetic impact on Willamette River stocks. Although Willamette River spring-run chinook salmon can generally be categorized as Columbia River ocean-type chinook salmon, they do exhibit some distinct life-history attributes relative to other stocks in this general group.

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Water diversions, dam placements, and river channelizations may have altered the abundance, spawning and rearing distribution, and smolt timing of populations of spring-run chinook salmon from historical levels. Although the Willamette River was once highly braided with numerous side channels offering ideal rearing habitat for juvenile salmonids (Kostow 1995), approximately 75% of that river shoreline has been lost (Sedell and Froggatt 1984). Irrigation withdrawals began in the 1800s; additionally, timber harvest activities and the construction of splash dams had a severe impact on spawning and rearing habitat access and quality (Kaczynski and Palmisano 1993). Water diversion and hydroelectric dam construction in the 1950s and 1960s limited access to significant portions of the major spring-run chinook salmon bearing tributaries to the Willamette River. In all, water storage projects eliminated access to 707 stream kilometers (Cramer et al. 1996). In addition to loss of habitat, the dams have altered the natural thermal regime. The premature emergence of spring-run chinook salmon fry due to releases of warmer reservoir water in the autumn may have caused high mortalities among naturally spawning fish (Kostow 1995). Furthermore, cooler than normal waters released in the spring limit the growth of naturally rearing fish. Habitat changes may have created selective pressures that would alter the expression of historical life-history traits, primarily impacting naturally spawning and rearing salmonids.

Despite the homogenization of spring-run chinook salmon stocks through intrabasin transfers and the impact of large scale artificial propagation efforts, the distinctiveness of Willamette River spring-run chinook salmon life-history traits relative to other ocean-type populations appears to have been retained

Columbia River (east of the Cascade Crest)—East of the Cascade Crest, many river systems support populations of both ocean- and stream-type chinook salmon. Fall-run (ocean-type) fish return to spawn in the mainstem Columbia and Snake Rivers and their tributaries, primarily the Deschutes and Yakima Rivers (Hymer et al. 1992b, Olsen 1992). Historically, numerous other Columbia River tributaries in Washington, Oregon, and Idaho supported fall runs, but for a variety of reasons these are now extinct (Fulton 1968, Nehlsen et al. 1991, Hymer et al. 1992a, Olsen et al. 1992, WDF et al. 1993). Fall-run salmon historically migrated as far as Kettle Falls (RKm 1,090) on the Columbia River prior to the completion of Grand Coulee Dam (RKm 961) in 1941 (Mullan 1987). Chapman (1943) observed chinook salmon spawning in deep water just below Kettle Falls in October 1938. Similarly, fall-run chinook salmon migrated up the Snake River to Shoshone Falls (RKm 976), although Augur Falls (RKm 960) probably blocked the passage of most fish (Evermann 1896, Fulton 1968).

Summer-run chinook salmon populations on the Columbia River exhibit an ocean-type life history, while summer-run fish on the Snake River exhibit a stream-type life history (Taylor 1990a, Chapman et al. 1991, Chapman et al. 1994, Matthews and Waples 1991, Waknitz et al. 1995). Summer-run fish return to freshwater in June through mid-August—slightly earlier than the fall-run fish, which return from mid-August through October (Fulton 1968). Summer-run fish were able to ascend Kettle Falls (Evermann 1896, Bryant and Parkhurst 1950) and probably migrated as far as Lake Windermere in British Columbia (Hymer et al. 1992b, Chapman et al. 1994). With the completion of the Grand Coulee Dam in 1941 (RKm 961) and Chief Joseph Dam in 1955 (RKm 877), the farthest that summer-run chinook salmon can migrate upriver is the Okanogan River (RKm 859). Currently, naturally spawning ocean-type summer-run chinook salmon are also found in the Wenatchee (RKm 753) and Methow Rivers (RKm 843) (Waknitz et al. 1995). Summer-run chinook salmon are also reported to spawn in the lower Entiat and Chelan Rivers, in addition to below mainstem Columbia River dams (Marshall et al. 1995); however, it has not been determined whether or not these are self-staining populations.

There are numerous differences between ocean-type fish east and west of the Cascade Crest. Celilo Falls (RKm 320), which was submerged under Lake Celilo following the building of the Dalles Dam (RKm 309) in 1957, was located where the Cascade Crest line intersects the Columbia River and may have historically been a barrier to returning tule (lower river) fall-run chinook salmon. The Cascade Crest also marks the boundary between the maritime ecoregions to the west and the arid ecoregions to the east. Historically, summer-run and “upriver bright” fall-run fish in the Columbia River were not found below this demarcation (Fulton 1968). “Upriver brights” are so named because they enter freshwater prior to the expression of secondary maturation characteristics (darkening of skin and formation of the kype) and 1 to 3 months prior to actual spawning (WDF et al. 1993, Marshall et al. 1995). Among ocean-type Columbia River populations above Celilo Falls, summer-run chinook salmon spawn in the mid- and lower reaches of tributaries with peak spawning occurring in October, whereas fall-run chinook salmon spawn in the mainstem Columbia and Snake Rivers and the lower reaches of the Deschutes and Yakima Rivers with peak spawning occurring in November (Howell et al. 1985, Marshall et al. 1995, Mullan 1987, Garcia et al. 1996). Additionally, fall-run chinook salmon in the mainstem Columbia and Snake Rivers have been observed spawning in water 10 m deep or more (Chapman 1943, Bruner 1951, Swan et al. 1988, Hymer et al. 1992b, Dauble et al. 1995).

Ocean-type fry west of the Cascade Crest emerge in April and May, and the majority rear from 1 to 4 months in freshwater prior to emigrating to the ocean (Mullan 1987, Olsen et al. 1992, Hymer et al. 1992a, WDF et al. 1993, Chapman et al. 1994, Marshall et al. 1995). A small proportion of summer- and fall-run fish remain in freshwater until their second spring and emigrate as yearlings (Chapman et al. 1994, Waknitz et al. 1995). The proportion of yearling outmigrants varies from year to year due, perhaps, to environmental fluctuations. Among summer-run populations, the lowest incidence of yearling outmigrants is found in the Okanogan River, where the waters are relatively warm and highly productive (Chapman et al. 1994).

The age of maturation for ocean-type chinook salmon varies considerably among rivers in this region. Naturally spawning summer-run fish in the Wenatchee, Methow, and Okanogan Rivers mature primarily in their fourth or fifth year (Chapman et al. 1994, Waknitz et al. 1995, Marshall et al. 1995). The age distribution for fall-run chinook salmon returning to the Hanford Reach section of the Columbia River (RKm 292) and the lower Yakima River (below Prosser Dam RKm 75.8) includes higher proportions of 2-year-old “jacks” and 3-year-old adults relative to summer-run fish (Hymer et al. 1992b, WDFW 1995). However, the Hanford Reach and lower Yakima River populations contain higher proportions of 4- and 5-year-old spawners than other fall-run stocks (the Deschutes River and the Marion Drain) found above the Cascade Crest (Hymer et al. 1992b, WDFW et al. 1995). The Deschutes River and Marion Drain systems support fall-runs with very high incidences of 2-year-old "jack" chinook salmon (Hymer et al. 1992b, ODFW 1995, WDFW 1995). A significant proportion of the Snake River fall run is presently reared at the Lyons Ferry Hatchery and limited information is available on naturally spawning fish. The age distribution for fish returning to Lyons Ferry includes a large proportion (20%) of 2-year-old jacks relative to other stocks, although the majority return as 4- and 5-year olds (Hymer et al. 1992b, Marshall et al. 1995). The high incidence of jacks may be related to the release of yearling smolts, which constitute approximately one-half of all releases (Howell et al. 1985, Chapman et al. 1991); however, size distributions for Snake River fall-run fish intercepted at Little Goose Dam (RKm 113) in 1976 (NMFS 1996a) and at Salmon Falls (RKm 922) in 1894 (Evermann 1896) were very similar (Fig. 16) and included a large number of smaller jacks.

Ocean recoveries of CWTs describe two basic patterns. Fall-run fish from the lower Yakima River and summer- and fall-run fish from the mainstem Columbia River and its tributaries (above the confluence of the Yakima and Columbia Rivers) are recovered primarily in Alaska and British Columbia coastal waters. In contrast, a significant number of tagged fall-run chinook salmon from the Snake and Deschutes Rivers are recovered in southerly waters off the Oregon and California Coast, and recovery of CWT-marked Snake and Deschutes River fall-run chinook salmon off Alaska is not large (Howell et al. 1985, Waples et al. 1991b). Thus, among ocean-type populations east of the Cascade Crest, there appears to be some degree of divergence in maturation rates and migration.

Anthropogenic influences have had a great impact on the life history and distribution of ocean-type chinook salmon in the Columbia River Basin. Access to spawning habitat on the mainstem Snake River was blocked to migrating salmonids beginning in 1910 with Swan Falls Dam (RKm 734) and most recently by the Hells Canyon Dam (RKm 459) in 1967 (Fulton 1968, Waples et al. 1991b). An additional four mainstem dams (Ice Harbor Dam [1961; RKm 16], Lower Monumental Dam [1969; RKm 67], Little Goose Dam [1970; RKm 113], and Lower Granite Dam [1975; RKm 173]) on the Snake River have inundated spawning areas and impeded adult and smolt migrations (Fulton 1968, Chapman et al. 1991, Waples et al. 1991b). Nine dams exist on that portion of the mainstem Columbia River that is still accessible to migrating salmon, and numerous historical spawning sites were probably inundated by reservoirs created by those dams upriver from the present Dalles Dam (Smith 1966, Waknitz et al. 1995).

The construction of Grand Coulee Dam and the concurrent Grand Coulee Fish Maintenance Project (GCFMP) also influenced the present distribution of summer/fall-run chinook salmon. To compensate for the loss of spawning habitat above the dam, spring- and summer-run chinook salmon were intercepted at Rock Island Dam (RKm 730) from 1939-43 and

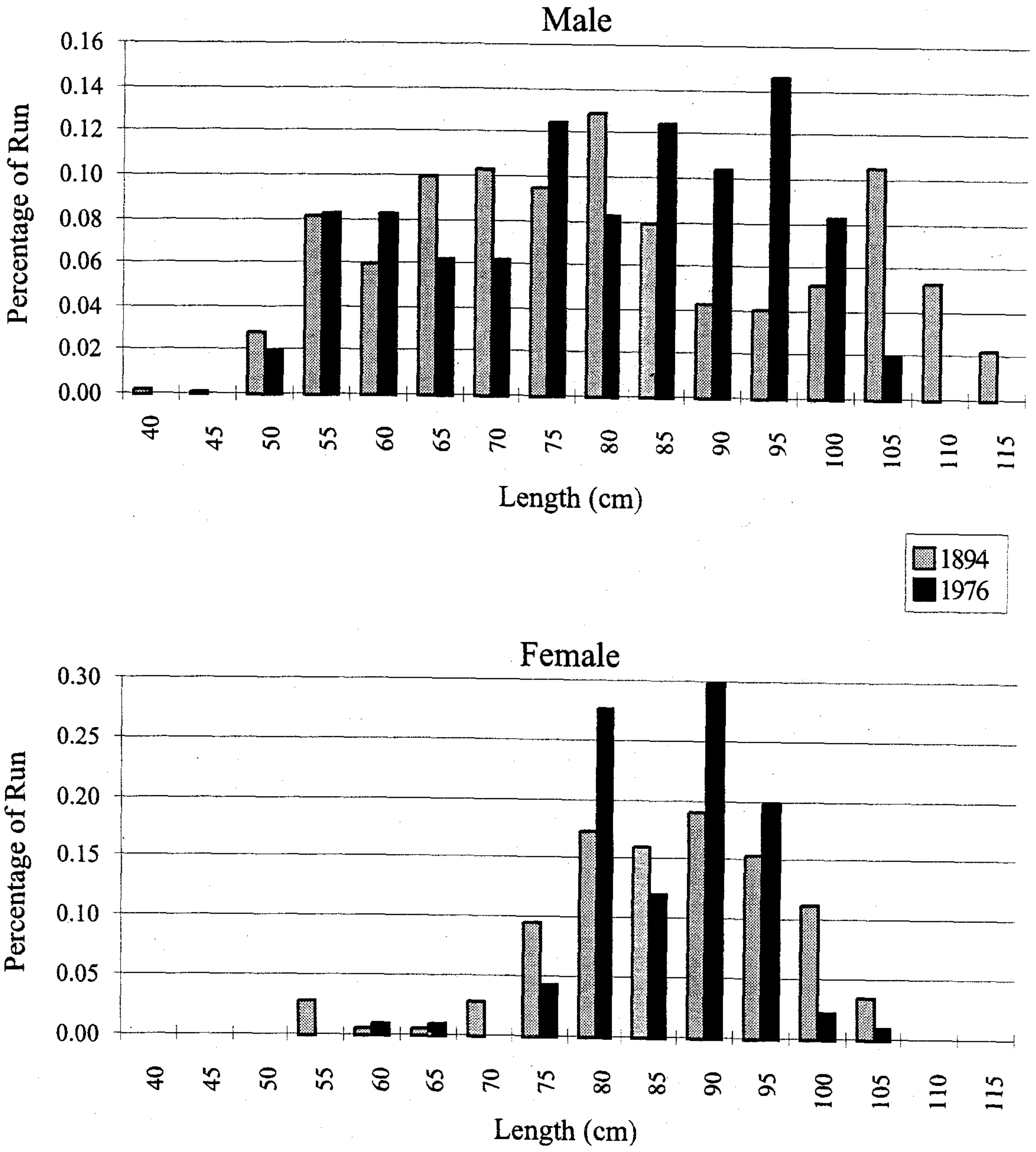

Figure 16. Length distribution (cm) for Snake River male and female chinook salmon sampled at Salmon Falls, Rkm 922 in Sept./Oct. 1894 (Evermann 1986) and Little Goose Dam, Rkm 113 in Sept./Oct. 9176 (NMFS 1996a). Salmon Falls distributions are based on 732 males and 170 females; Little Goose Dam distributions are based on 48 males and 91 females.

either transported to surrogate spawning sites or held in hatchery facilities for artificial propagation (Fish and Hanavan 1948). Returning summer-run adults were transported to enclosed sections of the Wenatchee or Entiat Rivers to spawn naturally (Fish and Hanavan 1948). Captive spawning began in 1940 at the Leavenworth NFH on Icicle Creek and subsequently at other facilities on the Entiat and Methow Rivers. Artificially propagated fry and fingerlings were planted in the Wenatchee, Entiat, and Methow Rivers during the GCFMP, but neither adults nor juveniles were introduced into the Okanogan River. The reintroduction of summer-run fish into the Okanogan River resulted from later transplantations or recolonization by straying fish after the termination of trapping activities at Rock Island Dam in late 1943 (Waknitz et al. 1995). Prior to the GCFMP, Craig and Suomela (1941) reported that summer-run chinook salmon above Rock Island Dam were found in fairly low numbers in the Wenatchee and Okanogan Rivers. Emigrating young-of-year chinook salmon trapped in the Methow River in 1937 (WDF 1938) may have been ocean-type summer-run juveniles migrating to the ocean or stream-type spring-run juveniles moving to winter feeding ground downstream. Given the small numbers of returning adults reported by WDF (1938) and Craig and Suomela (1941) native fish populations were probably swamped by later releases. Another consequence of the GCFMP was the potential mixing of spring-run (stream-type) and summer/fall-run (ocean-type) fish. Runs were discriminated based on a 9 July cut-off date at the Rock Island Dam trap, and no distinction was made between later returns of summer- and fall-run fish (Fish and Hanavan 1948).

Historically, a substantial population of summer-run chinook salmon once existed on the Yakima River; however, the last summer-run redd was observed in 1970 and this stock appears to be extirpated (BPA et al. 1996). A summer run may also have existed on the Deschutes River. Recoveries of returning adults tagged at Bonneville Dam in June and July (a migration timing that is generally associated with summer runs) were made in the Deschutes and Metolius (a tributary to the upper Deschutes River) Rivers (Galbreath 1966). Jonasson and Lindsay (1988) speculated that a distinct summer run spawned in the upper Deschutes River prior to the construction of Pelton Dam (RKm 166) in 1958 and Round Butte Dam (RKm 177) in 1964, and that subsequently the run was eliminated or assimilated into the fall-run. Presently, fall-run chinook salmon on the Deschutes River return much earlier than any other fall-run stock on the Columbia River (Olsen et al. 1992), suggesting that some assimilation may have taken place.

Fall-run chinook salmon populations have been extirpated in the John Day, Umatilla, and Walla Walla Rivers (Kostow 1995). Information on the historical life-history traits for these rivers is limited. Rich (1920b) remarked that Umatilla River fall chinook salmon were unusually small, with average weights of 4.5-5.5 kg compared to 9.0 kg for the fall run in the Columbia River. Deschutes River fall-run chinook salmon are similarly described as having a small size for their age (Kostow 1995) which suggests some degree of relatedness with the extirpated Umatilla River fish.

The expression of fall-run life-history strategies in the Yakima River are potentially biased by changes in spawning and rearing habitat and introductions of non-native populations.

The development of agricultural irrigation projects on the Yakima River during the last century has resulted in lower river flows, higher water temperatures, river eutrophication, and limited or impeded migration access (Davidson 1953, BPA et al. 1996). Several million “upriver brights” and smaller numbers of lower Columbia River fall-run hatchery chinook salmon have been released into the Yakima River (Howell et al. 1985, Hymer et al 1992b). The “upriver brights” stocks represent a composite of Columbia and Snake River populations and were generally founded by random samples of fall-run chinook salmon intercepted at a number of mainstem dams (Howell et al. 1985). The majority of these introductions on the Yakima River have occurred below Prosser Dam (RKm 76) and may be responsible for genetic and life-history differences between Marion Drain and lower Yakima River fall-run fish (Marshall et al. 1995). Water temperatures in the Yakima River have increased significantly, such that returning fall-run adults must delay river entry, and juveniles must emigrate from the river sooner than occurred historically (Watson[7]). Conditions above Prosser Dam are such that only in the Marion Drain (RKm 134), a 27-km long irrigation return water canal which is supplied with more thermally stable groundwater, is it possible for fall-run chinook salmon to naturally produce smolts in any number (BPA et al. 1996, Watson see footnote 7). It has been speculated that the Marion Drain fish are representative of “native” Yakima River fish (Marshall et al. 1995); if this is the case, then the phenotypic expression of their life-history traits (spawn timing, age at smoltification, age at maturation, size at maturation) may have been altered by the artificial environment in which they currently exist. For example, warmer winter temperatures and high stream productivity contribute to the production of large, 95 mm, outmigrating subyearling smolts in late April (Watson see footnote 7) which, in turn, result in the high incidence of 2-year-old mature males observed. The persistence of life-history differences among some populations of ocean-type chinook salmon in the Columbia River Basin, despite extensive stock transfers and geographic constriction of available habitat, is indicative of the significance of these traits.

Columbia River Stream Type—Stream-type chinook salmon in the Columbia River are represented by spring-run fish from the Klickitat River upriver to the accessible tributaries of the Columbia and Snake Rivers and summer-run fish in the Snake River Basin. With the exception of the Klickitat River, all of these rivers are located upriver from the historical location of Celilo Falls, near the present Dalles Dam.

In the Columbia Basin, the Klickitat, Deschutes, John Day, Yakima, Wenatchee, Entiat, and Methow Rivers contain “native” stream-type chinook salmon. Marshall et al. (1995) reported that the spring run on the Klickitat River has some genetic and life-history similarities to lower Columbia River (ocean-type) spring-runs. However, this run exhibits classical stream-type characteristics—yearling smolt migration and limited recoveries of CWTs from coastal fisheries (Howell et al. 1985, Hymer et al. 1992b, WDF et al. 1993). Scale samples taken from Klickitat River spring-run fish early in the 1900s (prior to extensive artificial propagation efforts) indicated a 1-year freshwater residence prior to emigration to the ocean (Rich 1920b). Transplants of

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[7] B.D. Watson, Yakama Fisheries Project, 771 Pence Rd, Yakima WA 98902. Pers. commun., February 1996.

Cowlitz and Willamette River spring-run chinook salmon to the Klickitat River (Howell et al. 1985) may be responsible for the few ocean recoveries of CWT-marked fish released from the Klickitat River Hatchery. Finally, vertebral counts from Klickitat River spring-run fish (average 71.3) clustered with stream-type (71-73 vertebrae) and not ocean-type populations (66-69 vertebrae) (Schreck et al. 1986).

Tributaries to the Snake River that contain “native” stream-type populations include the Tucannon, Grande Ronde, Imnaha, and Salmon Rivers. A stream-type run in Asotin Creek existed until recently, but may now be extinct (WDFW 1997a). In a previous status review, stream-type chinook salmon in the Clearwater River system were determined to have been introduced from a number of Snake River and Columbia River sources (see Appendix D) and were not considered for listing under the ESA (Matthews and Waples 1991). Stream-type fish in the Columbia River and Snake River Basins spawn across a large geographic area that encompasses several diverse ecosystems.

Stream-type fish remain in freshwater throughout their first year and sometimes second year following emergence (Healey 1991). Typically, stream-type chinook salmon undertake extensive offshore ocean migrations; therefore, few CWT-marked fish from stream-type stocks are recovered in coastal or high seas fisheries (Healey 1983, Howell et al. 1985, Olsen et al. 1992, Hymer et al. 1992b). Spring runs enter the Columbia River from March through mid-May, and summer runs from mid-May to mid-July (Galbreath 1966). Fish passing over Bonneville Dam (RKm 235) prior to 1 June are designated by the U.S. Army Corps of Engineers (USACE) as belonging to the spring-run, although there is considerable overlap (Galbreath 1966). The majority of stream-type fish mature at 4 years of age, with the exception of fish returning to the American and upper Salmon Rivers, which return predominantly as 5-year-olds. Fish ascend to the upper reaches of most river systems, and in some cases access to these areas is only possible during the high spring river flows from snowmelt and spring storms. The return migration and spawning timing for summer-run (stream-type) fish on the Snake River is somewhat later than, and in somewhat lower reaches than used by the spring runs, although this distinction is apparently not always clear (Chapman et al. 1991). The use of smaller tributaries for spawning and extended juvenile rearing by stream-type chinook salmon increases the potential for adaptation to local ecosystems through natural selection relative to ocean-type populations (which spawn in mainstem areas and migrate more quickly to the marine environment).

An important adaptation by stream-type chinook salmon in the Columbia and Snake River Basins is the early maturation of resident males (Gebhards 1960, Burck 1967, Mullan et al. 1992, Sankovich and Keefe 1996). These resident males may play a crucial role during years with low numbers of returning adults by ensuring returning females spawn successfully. The expression of this life-history trait may vary depending on the location and physical characteristics of each river, but the fact that all stream-type populations appear to express this trait is indicative of its importance. Additionally, stream-type females produce much smaller eggs, generally less than 8 mm in diameter, than Columbia River or coastal ocean-type females. Reductions in egg size are compensated for by increases in total egg number; however, perhaps due to the energetic costs of their extensive migrations and/or their prolonged residence in freshwater prior to spawning, the percentage of body weight devoted to gonads appears to be less in stream-type stocks than in coastal ocean-type stocks (Lister 1990, Bartlett 1995). Producing a greater number of smaller eggs may be an appropriate strategy to maximize long-term survival in response to the environmental fluctuations of high-altitude spawning habitats. Furthermore, large eggs may not be as important to stream-type fish, which smolt as yearlings.

Comparisons of chinook salmon populations in the Columbia River Basin indicated some morphological differences between life-history types (Schreck et al. 1986). Samples showed stream-type populations averaged 71.2-72.5 vertebrae, significantly more than the typical ocean-type population with 65.9-69.45 vertebrae, except for “fall-run” fish taken from the lower Yakima River (70.6 vertebrae). Electrophoretic analysis of these fish by Schreck et al. (1986) placed the lower Yakima River fall-run with Snake River stream-type populations, in contrast to subsequent studies by other researchers. When the lower Yakima River sample is excluded, there is a clear distinction in the average vertebral counts of ocean- and stream-type populations.

Stream-type chinook salmon spawn in rivers whose headwaters are located in one of three major mountain systems: the Cascade, Blue, and Rocky Mountains. The Salmon River lies in the Northern Rockies Ecoregion and spawning areas for stream-type fish are predominantly above 1,000 m and average approximately 1,500 m. The Grande Ronde and Imnaha Rivers, tributaries to the Snake River, originate in the Blue Mountains with spawning areas at approximately 1,000 m and higher. The John Day River, a tributary to the Columbia River, has its headwaters in the Strawberry Mountains and contains spawning areas on the North, Middle, and South Forks at approximately 1,000 m. Even prior to the construction of Pelton Dam, spawning areas for spring-run chinook salmon on the Deschutes River lay below 1,000 m (Nehlsen 1995). The Klickitat, Yakima, Wenatchee, Entiat, and Methow Rivers all contain stream-type spawning areas at relatively lower elevations, 500-1,000 m. Differences in elevation and geography are correlated with differences in temperature, rainfall, and productivity, with obvious impacts on salmon development rate, growth, and carrying capacity. Schreck et al. (1986) analyzed several aspects of spawning and rearing habitat for different rivers in the Columbia River Basin. Differences were most apparent between upper (Klickitat River and upstream) and lower Columbia River tributaries. There are two geographically-defined clusters of stream-type chinook salmon rivers: relatively low elevation rivers in the Columbia River Basin and the higher elevation rivers in the Snake River Basin.

Anthropogenic activities have significantly influenced the distribution of stream-type chinook salmon. Not included in this review is the spring run on the Wind River, which is a hatchery stock founded by intercepting spring-run fish at Bonneville Dam destined for upriver tributaries (Howell et al. 1985, Hymer et al. 1992b, Marshall et al. 1995). Stream-type chinook salmon on the Methow, Entiat, and Wenatchee Rivers were influenced by GCFMP transfers of fish destined for rivers above Rock Island Dam. River surveys undertaken prior to the onset of the GCFMP indicated that spring-run (stream-type) fish historically existed in the Wenatchee, Entiat, and Methow Rivers, but the run size had diminished considerably by the 1930s, and the run on the Entiat River may have been extirpated (Craig and Suomela 1941, Mullan 1987). Returning adults intercepted at Rock Island Dam each year prior to 9 July were classified as spring run and either transferred to spawning sites on the Wenatchee or Entiat River, or to hatcheries for spawning (Fish and Hanavan 1948). Hybridizations between late-returning stream-type (spring-run) and early-returning ocean-type (summer-run) fish probably occurred under this system (Chapman et al. 1991, Waknitz et al. 1995). Alternatively, Fish and Hanavan (1948) observed that presumptive spring-run fish transferred to impounded stream sections and allowed to naturally spawn all did so within the normal spawning period recorded for spring-run chinook salmon. Given the small size of the spring-run populations that existed on these rivers prior to the GCFMP, the majority of the fish intercepted at Rock Island Dam were probably destined for rivers above Grand Coulee Dam (Fish and Hanavan 1948, Chapman et al. 1991). Subsequent increases in run-size in the Wenatchee, Entiat, and Methow Rivers following the GCFMP suggest that introduced fish became established in these rivers (Mullan 1987).

The construction of the Hermiston Power and Light (1910) and Three Mile Dams (1914) on the Umatilla River and the Lewiston Dam (1927) on the Clearwater River were largely responsible for the extirpation of native stocks of stream-type chinook salmon on those systems (Olsen et al 1992, Keifer et al. 1992). Fish from a number of sources have since been used to reestablish stream-type chinook salmon stocks on the Umatilla and Clearwater Rivers. Certain spring-run chinook salmon stocks, such as the Carson NFH stock, have been widely transferred to rivers throughout the Columbia and Snake River Basins, and their integration into many local populations is likely.

Hydroelectric dams and/or irrigation diversions affect virtually every river containing stream-type chinook salmon (although irrigation effects are less significant in much of the Snake River Basin) and have produced changes in thermal regime, loss of spawning and rearing habitat, or direct mortality by stranding or upstream and downstream passage injury (Lindsay et al. 1989, Matthews and Waples 1991). Identifying regional life-history differences among stream-type populations is complicated by stock transfers and the difficulty in separating hatchery and naturally produced fish. Culture practices and differences in water conditions, primarily temperature, may alter the observed expression of numerous life-history traits, such as body size and age of smoltification and maturation.

Genetic Information

Background

The previous section examined evidence for phenotypic and life-history differences between populations or groups of populations that might be used to identify distinct population segments. The genetic basis of many phenotypic and life-history traits, however, is weak or unknown, and it is difficult to infer the amount of reproductive isolation from population differences in these traits. In this section, we consider biochemical and molecular genetic evidence that might be used to define reproductively isolated populations or groups of populations of chinook salmon. We focus on genetic markers that have been shown to follow or are assumed to follow Mendelian inheritance, so that an analysis of the geographical distributions of these markers can reveal historical levels of gene flow and isolation. The bulk of this evidence consists of frequencies of protein variants (allozymes), or of naturally occurring mutations in minisatellite and microsatellite loci (variable numbers of short tandem repeats) and mitochondrial (mt) DNA. Because of high mutation rates in minisatellite and microsatellite loci, and in some sections of mtDNA, the analysis of these loci permits a greater resolution of the effects of more recent population events than does the analysis of allozyme loci, which generally have lower mutation rates. The different temporal perspectives of population structure from these various techniques were considered in our attempts to define distinct population segments. Analyses of populations of chinook salmon have been examined for genetic variability throughout most of the geographical distribution of this species with allozyme electrophoresis, and in some regions with the analysis of mtDNA or microsatellite loci.

Statistical Methods

Several standard statistical methods have been used to analyze molecular genetic data to test various hypotheses of reproductive isolation. Comparisons between observed genotypic frequencies in a sample with frequencies expected with random mating (Hardy-Weinberg proportions) can be used to infer the breeding structure of a population or to detect population mixing. Contingency-table comparisons of allozyme or microsatellite allele frequencies among population samples with the chi-square statistics or G-statistic have been widely used to detect significant differences between populations. The finding of significant frequency differences between populations may be evidence of reproductive isolation.

Another way of measuring genetic isolation between populations is to calculate genetic distances from allele-frequency estimates. Several genetic distance measures (e.g. Cavalli-Sforza and Edwards 1967, Rogers 1972, Nei 1972, 1978) have been used to study the population genetic structure of chinook salmon. It is unclear, however, which measure is best, or whether there is one measure that is always best. An attractive feature of Rogers' and Cavalli-Sforza and Edwards' distances is that they satisfy the triangle inequality; that is, given three populations (A, B, C), the sum of the distances between A and B and between B and C is always greater than or equal to the distance between A and C. On the other hand, neither of these genetic-distance measures employs a correction for sample size, so distances are biased upward, especially for small sample sizes. In contrast, Nei's (1978) distance (*D*) is unbiased, but does not always satisfy the triangle inequality. When sample sizes used to estimate allelic frequencies are 50 individuals or more, the difference between Nei's genetic distance (Nei 1972) and Nei's unbiased genetic distance (Nei 1978) is small, but still might be a substantial proportion of *D*, if *D* is small. Another consideration is that Nei's and Rogers' distance measures can be affected by different levels of heterozygosity between populations, whereas Cavalli-Sforza and Edwards' measure is not. Discussions of these and other features of genetic distances appear in Nei (1978), Hillis et al. (1996), and Rogers (1991).

Most of the discussion on genetic distances has focused on the merits of the various measures for phylogenetic reconstruction among species and higher taxa. No one has quantitatively evaluated the performances of these distances in assessing the genetic population structures of species like salmon, which typically show relatively small genetic distances between conspecific populations. Since it is unclear which distance measure is "best" in any given application, we analyzed each set of data with Nei's unbiased, Rogers', and Cavalli-Sforza and Edwards’ genetic distances to identify results that were robust to the choice of the distance measure. In most cases, the different genetic-distance measures yielded highly correlated results. For simplicity, we report only results based on Cavalli-Sforza and Edwards' distance measure. This measure ranges from 0.0 (identity) to 1.0 (complete dissimilarity).

The degree of reproductive isolation was inferred from an analysis of the pattern of genetic distances between populations. Clustering methods, such as the unweighted pair group method with arithmetic averages (UPGMA; Sneath and Sokal 1963) and the neighbor-joining method (Saitou and Nei 1987), produce hierarchical groupings of genetically similar populations. Multivariate methods, such as multidimensional scaling (MDS; Kruskal 1964) or principal components analysis (PCA) cluster populations in two or three dimensions. When the geographical distribution of genetic variability is continuous and not hierarchical or disjunct, such as in a clinal or reticulate pattern, MDS and PCA more accurately depict relationships among samples than does agglomerative clustering such as the UPGMA (Lessa 1990). Since the latter algorithm compares the genetic distance of an incoming sample to the average genetic distance between samples already in a cluster, the information about the relationship between the incoming sample and the samples already in the cluster is lost. MDS, on the other hand, is a non-metric ordination technique that minimizes the distortion of pairwise genetic distances between samples in *n*-dimensional space without averaging. Principal component analysis of allelic frequencies can also be used to examine genetic relationships among populations. In the present analyses, the results of a PCA were usually similar to MDS ordinations for a set of data. Reproductive isolation between populations was inferred from a visual examination of these plots, whenever clusters of related populations were consistent with the geographies of the samples in the clusters.

Levels of genetic variability within populations were also considered, because the level of within-population variability may reflect evolutionary or historical differences in population size and migration patterns between populations. Within-population genetic diversity (*H*) is usually measured by the expected (with random mating) proportion of heterozygous individuals in a population and is averaged over the number of loci examined. Estimates of heterozygosity based on a small number of individuals are usually accurate, as long as a large number of loci (>30 loci) are surveyed for variability (Nei 1978).

Genetic differentiation between populations at various hierarchical levels has been estimated in many studies with a gene diversity analysis (Nei 1973, Charkraborty 1980), which apportions allele-frequency variability among populations into its geographical or temporal components. For example, the proportion of genetic subdivision among populations may be estimated with $G_{ST} = (H_T - H_S)/H_T$, where H_S is the average within-population heterozygosity and H_T is the total heterozygosity disregarding geographical subdivision. F_{ST} is equivalent to G_{ST} when there are only two alleles at a locus. Most genetic variability in salmonids occurs as genotypic differences among individuals within a population (Ryman 1983). A smaller proportion of the total variability is due to hierarchical differences between regions, river systems, tributaries and streams within a river system, between years, or between run types. Estimates of G_{ST} or F_{ST} among natural populations ranges from 0.0 (no genetic differentiation among populations) to about 0.25 (strong differentiation among populations). These statistics facilitate comparisons among groups of populations that may reveal regional differences in gene flow between populations, or the effects of hatchery strays on levels of differentiation between populations.

In the present status review, we first present the results of previous population genetic studies of chinook salmon, then present the results of an analysis of allele-frequency data that constitute an interagency, coast-wide data base. The primary purpose of the review is to present genetic evidence of reproductive isolation between populations or groups of populations. Allele-frequency differentiation among populations and differences in levels of gene diversity constitute the bulk of this evidence.

Previous Genetic Studies

Alaska

Gharrett et al. (1987) studied genetic variability among populations of chinook salmon in 13 river drainages in western, south-central, and southeastern Alaska. They examined electrophoretic variability in proteins encoded by 28 loci, 8 of which had at least moderate levels of polymorphism (frequency of the common allele less than 0.90 in at least 1 of the population samples). In most drainages, collections were made at more than one site or in more than one year, or both. Allele-frequency heterogeneity was observed among three areas in the Yukon River drainage, and among lower and upper Stikine River samples. On a larger geographic scale, significant overall heterogeneity was present among tributaries of western, south-central, and southeastern Alaska. A gene diversity analysis showed that 94.1% of the total variability over samples was contained, on average, within the genetically-homogeneous river drainages, 3.3% was due to differences among river drainages within the three regions, and 2.6% was due to differences among regions. A comparison of these results with other studies (Pacific Northwest, Utter et al. 1989; Oregon-California, Bartley and Gall 1990), indicates the amount of genetic differentiation between Alaskan populations may be smaller than that for chinook salmon populations in other regions. A maximum-likelihood cluster analysis of Cavalli-Sforza and Edwards (1967) genetic distances between samples showed that populations in western and south-central Alaska were closely related to one another, but were distinct from southeastern Alaska populations. Samples from southeastern Alaskan populations were genetically intermediate between samples from western and south-central Alaska as well as those from southern British Columbia and Washington.

Pacific Northwest overview

Utter et al. (1989) examined allozyme variability at 25 polymorphic loci in samples from 86 populations extending from the Skeena River, British Columbia to the Sacramento and San Joaquin Rivers, California. Geographically proximate samples not showing significant allele-frequency differences ($P<0.01$) were pooled, and this reduced the data set to 65 units for geographical analyses. A PCA of allelic frequencies and cluster analysis of Nei's (1972) genetic distances between samples indicated the existence of nine genetically distinct regional groups of populations (Fig. 17). The first region consisted of populations in the upper Fraser River and tentatively included a single sample from the Babine River, a tributary of the Skeena River. A second region included populations in rivers draining into Georgia Strait in southern British Columbia. Region 3 included populations around Puget Sound, and a fourth group included populations on the west coast of Vancouver Island, along the Strait of Juan de Fuca, and on the coasts of Washington, Oregon, and California. In the Columbia River basin, Region 5 included populations in the lower Columbia River and its tributaries, and Region 6 included populations in rivers above Bonneville Dam, except those in the Snake River, which constituted Region 7. Farther to the south, Region 8 consisted of populations in the Klamath River Basin, and Region 9 included populations in the Sacramento and San Joaquin Rivers.

A gene diversity analysis of the 65 population units in the 9 regions indicated that 87.7% of the total observed variability was contained, on average, within the units. Of the remaining 12.3%, 1.5% was due to differences among the 9 regions, 6.2% was due to differences among or between river drainages within regions, and 4.6% was due to genetic differences among

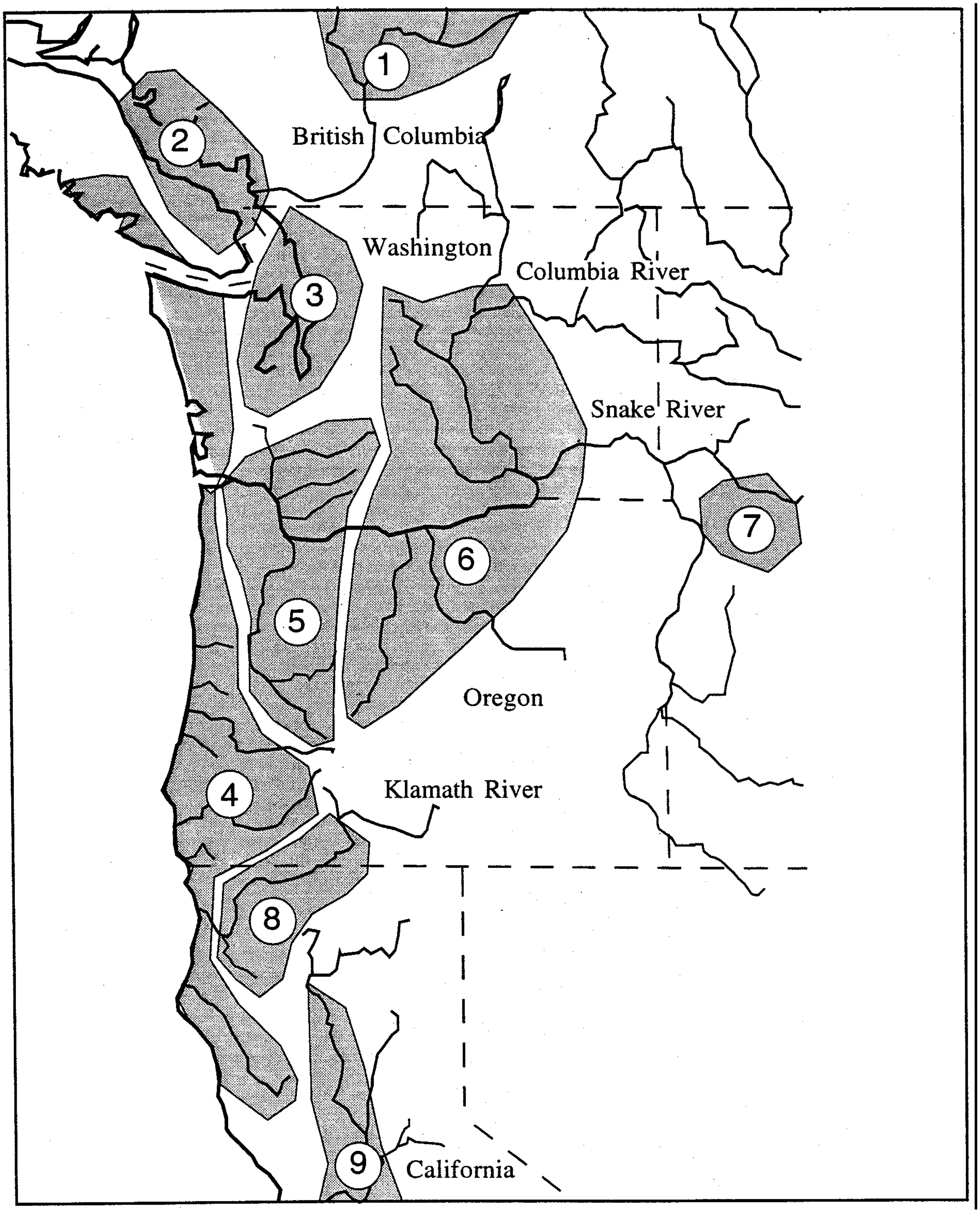


Figure 17. The nine genetically defined regional groups of chinook salmon proposed by Utter et al. (1989). Number designations are further explained in the text.

populations within areas. Utter et al. (1989) re-analyzed the same set of allelic frequencies to estimate the gene diversity components due to differences among adult run times (spring, summer, and fall). Allele-frequency differences among populations within the run times accounted for 11.4% of the total variability, whereas only 0.9% of the total variability was due to differences among run times. The authors concluded that neither clustering nor the gene diversity analyses supported the concept that chinook salmon adult run times represented distinct "races" with separate ancestries, but rather that "genetic divergence into temporally distinct units tend[ed] to occur within an area from a common ancestral stock ..." (p. 247).

The genetic survey of Utter et al. (1989) failed to distinguish clearly between Snake River (Region 7) and Klamath River (Region 8) populations of chinook salmon, even though the mouths of these rivers are geographically widely separated, and recent gene flow between them is unlikely. The authors speculated that this similarity was an artifact that would be resolved as more data became available. Subsequently, Utter et al. (1992) added allelic frequencies for 15 additional polymorphic loci to the data of Utter et al. (1989) and included allelic frequencies of Bartley et al. (1992) and Waples et al. (1991b). The re-analysis indicated a clear genetic separation between populations in the Snake and Klamath River Basins.

In a regional study of mitochondrial DNA variability, Wilson et al. (1987) used 14 type II restriction enzymes (enzymes with cleavage sites located within the recognition sequence) to survey geographical variability in 6 samples from wild and hatchery populations of chinook salmon extending from Bristol Bay, Alaska to southern British Columbia. Four of the enzymes showed restriction fragment length polymorphisms (RFLPs), and 6 composite haplotypes were found among 76 fish. The most abundant haplotype occurred in 43 of the 55 (79%) fish from southern British Columbia. The second most abundant haplotype (N=20) was shared between Alaskan (N=4) and British Columbian (N=6) samples. A third haplotype was found only in Alaska (N=10). Three additional haplotypes were found in single fish from three different localities. Although the lack of sharing of 5 of 6 haplotypes between Alaska and British Columbia indicated substantial reproductive isolation between these populations, average sequence divergence between haplotypes from Alaska and British Columbia (P=0.43%) was not greater than that between haplotypes within Alaska (P=0.45%) and within British Columbia (P=0.54%). A comparison with the RFLP haplotypes for 10 restriction enzymes that were in common with those of Berg and Ferris (1984) in a study of chinook salmon in California indicated a sequence divergence of 2.2%, a value as large as the sequence divergence between chinook salmon and coho salmon reported by Thomas et al. (1986).

Yukon and British Columbia

Beacham et al. (1989) examined genetic variability at 20 allozyme loci among samples from 15 populations of chinook salmon in the Canadian Yukon River system, and one sample from the Alsek River drainage. Chinook salmon returning to natal spawning sites in the upper reaches of the Yukon River in Canada must travel at least 1,200 km. Tests for allele-frequency heterogeneity at 16 polymorphic loci showed a highly significant difference between the Yukon

River samples and the sample from the Alsek River system. Although the headwaters of these two river systems are in close proximity, the Yukon River flows into the Bering Sea and the Alsek River flows into the Gulf of Alaska several hundreds of kilometers away. Among the upper Yukon River samples, the samples from Whitehorse and Takhini Rivers were genetically distinct from the other samples. The rest of the Yukon River samples were not clustered into clear geographical groups. These results show that many of the geographically isolated populations in major tributaries of the upper Yukon River are also genetically distinct from one another.

In another study, Beacham et al. (1996) surveyed variability at three minisatellite loci among populations of chinook salmon extending from the Nass River in northern British Columbia, through the mainland to the Fraser River, and to eastern and western Vancouver Island. Minisatellite loci are segments of DNA consisting of tandomly repeated sequences 10-75 base pairs in length, and alleles consist of different numbers of these repeats. Alleles detected with one probe, *pSsa-A34*, were previously shown to follow Mendelian inheritance (Stevens et al. 1993). Band counts were binned into size classes, because it was not always possible to establish the homologies of electrophoretically similar fragments. The frequencies of these size classes were used to assess population genetic structure in the same way allozyme alleles were used to test for Hardy-Weinberg proportions or reproductive isolation among populations. Beacham et al. (1996) found strong frequency differences between northern and southern populations of chinook salmon in British Columbia, and also between Fraser River, West Vancouver Island, and East Vancouver Island populations. A neighbor-joining tree of Mahalanobis generalized distances between samples showed two major clusters consisting of samples from northern British Columbia and those from southern British Columbia and Vancouver Island. A PCA analysis, however, indicated a major genetic discontinuity between mainland populations and populations on Vancouver Island. In the PCA, samples of mainland populations fell into a linear array reflecting isolation by distance, a feature of population genetic structure that was not apparent in the neighbor-joining tree. The genetic distinction of southern mainland populations of chinook salmon (excluding the Fraser River) and eastern Vancouver Island populations was not previously detected by the analysis of allozyme variability (Utter et al. 1989).

In a study of chinook salmon in southwestern British Columbia, Heath et al. (1995), examined variability among seven populations on the eastern side of Vancouver Island and two populations in the Fraser River with the analysis of a single-locus minisatellite gene with the probe *OtSL1*. Alleles with similar allelic mobilities after electrophoresis were binned and the frequencies of the binned classes were analyzed with a PCA. The principal components were tested for significance with a one-way ANOVA, and significant components were used in a discriminant function analysis to produce estimates of population differentiation. They found a 52% overall success rate of assigning sampled fish to the locations from which they had been drawn. Populations that had received transplants tended to show the least amount of discrimination, and this was attributed to the homogenizing effects of gene flow from the transfers. These results are consistent with allozyme studies for this area in showing detectable genetic differences between populations over a restricted area. The analysis of minisatellite loci, however, may have more discriminating power than allozymes, because of the higher mutation rate for minisatellite loci.

Washington

Reisenbichler and Phelps (1987) examined chinook salmon allozyme variability in four river drainages on the north coast of Washington. Six of the 55 enzyme-encoding loci examined for genetic variability were polymorphic with frequencies of common alleles less than 0.95, and hence were useful for depicting population structure. Juveniles and adults were sampled in the lower portions of rivers, so intra-river variability could not be estimated. The variance in allelic frequencies between brood years 1981 and 1982 at four localities was used as an error term in an ANOVA of arcsine transformed common-allele frequencies. The ANOVA failed to detect significant allele-frequency heterogeneity among the four drainages for the fall-run samples; that is, the amount of allele-frequency variability among drainages along the coast was no greater than variability between years within rivers, on average. The comparison between summer- and fall-run adult chinook salmon in four rivers, however, approached significance (P=0.07). Comparisons between summer-run hatchery and summer-run wild fish, and between fall-run hatchery and fall-run wild fish, were both significant. These results show that in this relatively small area on the Washington coast a greater amount of reproductive isolation appeared between run types than between populations within run types. Significant frequency differences between hatchery and wild populations indicated minimal mixing between these groups of fish in this area.

Marshall et al. (1995) examined allele-frequency variability at 42 loci in 58 chinook salmon populations representing major spawning areas in Washington. They defined two nested levels of population units from the results of UPGMA clustering and multidimensional scaling of Cavalli-Sforza and Edwards' genetic distances between samples. The more inclusive units, major ancestral lineages (MAL), were defined by four clusters: 1) upper Columbia and Snake River (spring run) samples, 2) upper Columbia River (summer- and fall-run "brights"), mid- and lower Columbia River (spring- and fall-run "tules" and "brights"), and Snake River (fall run) samples, 3) Washington coastal and Strait of Juan de Fuca (spring and fall run) samples, and 4) Puget Sound (spring, summer, and fall run) samples. Each of these four groups were further distinguished by characteristic levels of allozyme polymorphism and by shared occurrences of rare or private alleles among populations within the clusters. Finer scale genetic diversity units (GDUs) were designated within each of the four groups by considering life history, ecological, and physiographic information in addition to allelic frequencies and genetic distances between samples.

Columbia River Basin

One of the earliest studies of chinook salmon genetics in the Columbia River was by Kristiansson and McIntyre (1976), who reported allelic frequencies for 4 polymorphic loci in samples from 10 hatcheries, 5 of which were located along the coast and 5 in the lower Columbia River Basin. Significant frequency differences for *SOD** were detected between spring- and fall-run samples collected at the Little White Salmon Hatchery on the Columbia River, but not for spring- and fall-run samples from the Trask River Hatchery along the northern coast of Oregon. Significant allele-frequency differences were also found between Columbia River samples as a group and Oregon coastal samples for *PGM** and *MDH**.

Utter et al. (1982) compared allelic frequencies at 12 polymorphic loci in samples of fall-run chinook salmon from the Priest Rapids Hatchery in the mid-Columbia River and from Ice Harbor Dam on the Snake River. These samples were taken over four years at each locality. Significant allele-frequency differences between populations were detected for 5 loci.

Schreck et al. (1986) examined allele-frequency variability at 18 polymorphic loci to infer genetic relationships among 56 Columbia River Basin chinook salmon populations. A hierarchical cluster analysis of genetic correlations between populations identified two major groups. The first contained spring-run chinook salmon east of the Cascade Mountains and summer-run fish in the Salmon River. Within this group they found three subclusters: 1) wild and hatchery spring-run chinook salmon east of the Cascade Mountains, 2) spring-run chinook salmon in Idaho, and 3) widely scattered groups of spring-run chinook salmon in the White Salmon River Hatchery, the Marion Forks Hatchery, and the Tucannon River. A second major group consisted of spring-run chinook salmon west of the Cascade Crest, summer-run fish in the upper Columbia River, and all fall-run fish. Three subclusters also appeared in this group:
1) spring- and fall-run fish in the Willamette River, 2) spring- and fall-run chinook salmon below Bonneville Dam, and 3) summer- and fall-run chinook salmon in the upper Columbia River. Schreck et al. (1986) also surveyed morphological variability among areas, and these results were reviewed in the Life History section of this status review.

Waples et al. (1991a) examined 21 polymorphic loci in samples from 44 populations of chinook salmon in the Columbia River Basin. A UPGMA tree of Nei's (1978) genetic distances between samples showed three major clusters of Columbia River Basin chinook salmon:
1) Snake River spring- and summer-run chinook salmon, and mid- and upper Columbia River spring-run chinook salmon, 2) Willamette River spring-run chinook salmon, 3) mid- and upper Columbia River fall- and summer-run chinook salmon, Snake River fall-run chinook salmon, and lower Columbia River fall- and spring-run chinook salmon. These results indicate that the timing of chinook salmon returns to natal rivers was not necessarily consistent with genetic subdivisions. For example, summer-run chinook salmon in the Snake River were genetically distinct from summer-run chinook salmon in the mid and upper Columbia River, but still had similar adult run timings. Spring-run populations in the Snake, Willamette and lower, mid, and upper Columbia Rivers were also genetically distinct from each other but had similar run timings. Conversely, some populations with similar run timings, such as lower Columbia River "tule" fall-run fish and upper Columbia River "bright" fall-run fish, were genetically distinct from one another. Juvenile outmigration also differed among some groups with similar adult run timing. For example, summer-run juveniles in the upper Columbia River exhibit ocean-type life-history characteristics, but summer-run chinook salmon in the Snake River migrate exhibit stream-type life-history characteristics.

In a status review of Snake River fall chinook salmon, Waples et al. (1991b) examined genetic relationships among fall-run chinook salmon in the Columbia and Snake Rivers (Group 3 of Waples et al. 1991a) in more detail. A UPGMA cluster analysis of Nei's unbiased genetic distance, based on 21 polymorphic loci, indicated that "bright" fall-run chinook salmon in the upper Columbia River were genetically distinct from those in the Snake River. Populations in the two groups were characterized by allele-frequency differences of about 10-20% at several loci, and these differences remained relatively constant from year to year in the late 1970s and early 1980s. However, allele-frequency shifts from 1985 to 1990 for samples of fall-run chinook salmon at Lyons Ferry Hatchery in the Snake River suggested that mixing with upper Columbia River fish had occurred. This is consistent with reports that stray hatchery fish from the upper Columbia River were inadvertently used as brood stock at the Lyons Ferry Hatchery. Samples of "bright" fall-run chinook salmon from the Deschutes River and the Marion Drain irrigation channel in the Yakima River Basin also appeared in the same cluster with samples of fall-run chinook salmon from the Snake River.

Genetic analysis of oceanic mixed-stock harvests indicated differences in ocean distributions between "bright" and "tule" fall-run chinook salmon from the Columbia River. Utter et al. (1987) estimated allelic frequencies for 17 polymorphic loci in baseline samples from 88 localities extending from southern British Columbia (except 1 sample from northern British Columbia) through Washington and Oregon to northern California. These data were pooled on the basis of contingency-table tests of allelic frequencies into 65 groups with genetically homogeneous populations. These groups were used to estimate the stock composition of fishery samples taken at ports of landing from the mouth of the Strait of Juan de Fuca to northern Oregon. Tagging returns (Table 5 in Utter et al. 1987) indicated that "tule" fish tended to be caught in the coastal waters of Washington, whereas "upriver brights" tended to be caught in the commercial harvests of Alaska and British Columbia. The results of the mixed-stock analysis for samples collected in 1982 and 1983 were consistent with tagging returns in indicating different ocean distributions of “tule” and upriver “bright” Columbia River chinook salmon.

In a study of genetic effects of hatchery supplementation on naturally spawning populations in the upper Snake River Basin, Waples et al. (1993) examined allele-frequency variability at 35 polymorphic loci in 14 wild (no hatchery supplementation), naturally spawning (some hatchery supplementation), and hatchery populations of spring- and summer-run chinook salmon. Most populations were sampled over two years. An analysis of these data indicated that 96.6% of the genetic diversity existed as genetic differences among individuals within populations. Most of the remaining 3.4% was due to differences between localities, and only a negligible amount was due to allele-frequency differences between spring- and summer-run chinook salmon. Results reveal a close genetic affinity in the upper Snake River between natural spawners that suggests either gene flow between populations or a recent common ancestry. Comparisons between hatchery and natural populations in the same river indicated that the degree of genetic similarity between them reflected the source of the brood stock in the hatchery. As expected, the genetic similarity between wild and hatchery fish, for which local wild fish were used as brood stock, was high.

In a study of upper Columbia River chinook salmon, Utter et al. (1995) examined allele-frequency variability at 36 loci in samples of 16 populations. A UPGMA tree of Nei's (1972) genetic distances between samples indicated that spring-run populations were distinct from summer- and fall-run populations. The average genetic distance between samples from the two groups was about eight times the average of genetic distances between samples within each group. Allele-frequency variability among spring-run populations was considerably greater than that among summer- and fall-run populations in the upper Columbia River. The lack of strong allele-frequency differentiation between summer- and fall-run samples indicated minimal reproductive isolation between these two groups of fish. Hatchery populations of spring-run chinook salmon were genetically distinct from wild spring-run populations, but hatchery populations of fall-run chinook salmon were not genetically distinct from wild fall-run populations.

Some studies have indicated that Snake River spring- and summer-run chinook salmon have reduced levels of genetic variability. Utter et al. (1989) estimated gene diversities with 25 polymorphic loci for 65 population units and found that gene diversities in the Snake River were lower than those in the Columbia River. Winans (1989) estimated levels of gene diversity with 33 loci for spring-, summer-, and fall-run chinook salmon at 28 localities in the Columbia River Basin. Fall-run chinook salmon tended to have significantly greater levels of gene diversity (N=12, mean H=0.081) than both spring- (N=17, H=0.065) and summer-run (N=3, mean H=0.053) chinook salmon. Spring-run fish in the Snake River had the lowest gene diversities (N=4, mean H=0.044). However, Waples et al. (1991a) found that, with a larger sample of 65 loci, gene diversities in Snake River spring-run and summer-run chinook salmon were not as low as that suggested by earlier studies.

Recent, but unpublished, data are available for chinook salmon and will be discussed in the next section. However the results of the foregoing studies of Columbia and Snake River chinook salmon permit the following generalizations:

1) Populations of chinook salmon in the Columbia and Snake Rivers are genetically discrete from populations along the coasts of Washington and Oregon.

2) Strong genetic differences exist between populations of spring-run and fall-run fish in the upper Columbia and Snake Rivers. In the lower Columbia River, however, spring-run fish are genetically more closely allied with nearby fall-run fish in the lower Columbia River than with spring-run fish in the Snake and upper Columbia Rivers.

3) Summer-run fish are genetically related to spring-run fish in some areas (e.g., Snake River), but to fall-run fish in other areas (e.g., upper Columbia River).

4) Populations of fall-run fish are subdivided into several genetically discrete geographical groups in the Columbia and Snake Rivers (these populations will be discussed in detail in the next section).

5) Hatchery populations of chinook salmon tend to be genetically similar to the respective source populations used to found or augment the hatchery populations.

California and Oregon

Bartley and Gall (1990) surveyed samples from 35 populations in the Sacramento and San Joaquin Rivers and along the coast of northern California for genetic variability at up to 53 loci. Overall, genetic variability was detected at 40% (21) of the loci with the 0.95 criterion of polymorphism, but varied from 3 (5.8%) to 17 (32%) loci among samples. Cluster analysis of Nei's (1978) unbiased genetic distances between samples revealed three major clusters roughly corresponding to 1) the Klamath and Trinity Rivers populations, 2) Eel River populations, and 3) the Sacramento and San Joaquin River populations. Samples from eight coastal populations did not cluster together, but were scattered among samples in the three major clusters. One sample from the Omagar Creek pond-rearing facility in the lower Klamath River drainage did not fall into any of the three major clusters. The average percentage of the total genetic variability contained within samples was 82.3%, and the remainder was due to differences among samples on various geographical scales. The greatest sources of geographical subdivision were among rivers within a drainage (6.1%) and among drainages within a region (5.4%), on average. Differences among samples within rivers (3.3%) and among regions (2.9%) represented smaller amounts of geographical heterogeneity. The authors did not distinguish among adult run times in their analyses.

Bartley et al. (1992) expanded the study of Bartley and Gall (1990) and surveyed up to 78 loci in samples from 37 chinook salmon populations in the Sacramento and San Joaquin Rivers, northern coastal California, the Klamath and Trinity Rivers, and rivers along southern to middle coastal Oregon. The authors detected genetic variation at 47 (60.3%) loci. They found significant departures of genotypic proportions from Hardy-Weinberg proportions in 8% of the samples overall, 5% (13 of 252 tests) in samples from wild populations, but 11% (24 of 210 tests) in samples of hatchery-spawned juveniles. They also found a larger than expected number of departures from Hardy-Weinberg proportions (13%, 13 of 97 tests) in wild and hatchery samples from the Klamath River Basin. In a large number of tests, 5% are expected to be "significant" because of Type I error, but a larger proportion of significant tests may indicate that juveniles with limited numbers of parents had been collected, or that juveniles from genetically distinct subpopulations had been included in a sample, or that the genetic model or interpreting electrophoretic banding patterns was incorrect, or that natural selection was occurring on some genotypes. Allelic frequencies estimated from some of these samples may, therefore, not represent discrete randomly mating populations.

From these data, Bartley et al. (1992) calculated Nei's (1972) genetic distances between populations and produced a UPGMA tree consisting of five clusters, each with a strong geographical component. One cluster included samples from populations in the lower Klamath and Smith Rivers of northern California and the Chetco and Rogue Rivers of southern Oregon, but also included a sample from Rock Creek Hatchery, which is located along the mid-Oregon coast. A second cluster included samples from the Eel River and from coastal rivers of northern California. A third cluster included samples from the upper Klamath and Trinity Rivers. A more distantly related cluster contained samples from the Oregon coast north of the Rogue River. The most distinct cluster included samples from the Sacramento and San Joaquin Rivers, which were not well differentiated from each other. A hierarchical gene diversity analysis, modeled a posteriori after the geographical subdivisions found in the cluster analysis of genetic identities, showed that 89.4% of the total genetic variability observed in the study was contained on average within subpopulations, 7.4% was due to differences among the 5 major groups detected in the UPGMA tree, and 3.2% was due to differences among populations within the groups on average. These results indicate that the major drainages from mid Oregon south each contain genetically distinct populations of chinook salmon.

Yip (1994) examined allozyme variability at 53 enzyme loci in 398 fish collected between September and December 1992 at the Trinity River Hatchery in the Klamath River drainage. About 40 fish returning to the hatchery were sampled each week for 11 weeks during the spawning season. Average heterozygosities in these samples ranged from 0.021 to 0.035 with a mean of 0.029. These low values were similar to the low values in Klamath River populations found by (Utter et al. 1987) and are well below the average of 0.102 for 80 populations of chinook salmon (Utter et al. 1987). The entry timing of spring- and fall-run fish into the Trinity River Hatchery was estimated from fish with coded wire tags in the years 1989-92 and 1994. Based on these returns, the weekly samples for genetic analysis were divided a priori into two groups, weeks 1-4 and weeks 5-11. Tests for allele-frequency differences were made with 5 polymorphic loci. Not all of the fish used in the genetic analysis had coded wire tags, so there may have been a some overlap between spring- and fall-run fish in the middle of the spawning season when they entered the hatchery. The sums of the G-statistics for individual tests were not significant for weekly samples within either group, but were highly significant ($P<0.01$) for the between-group comparisons. These results were interpreted to indicate that spring- and fall-run chinook salmon returning to the hatchery were genetically different. The analysis of temporal run-time differences was continued in 1994 with allele frequencies for three polymorphic loci, *GPI-B2**, *sMEP-1**, and *PGK-2**. (Yip et al. 1996). As in 1992, comparisons of allele frequencies between dates within the 1994 spring and fall runs were not significant. Comparisons between allele frequencies between 1992 and 1994 for the spring run were not significant, but there was a significant overall difference between 1992 and 1994 fall-run fish. An approximate F ratio, based on the sums of the G-tests for within-group allele-frequency heterogeneity, was used to test whether between-run heterogeneity was greater than temporal differences within runs. This test was significant and was concordant with the conclusions of the earlier study that spring- and fall-run chinook salmon were genetically discrete.

Vilkitis et al. (1994) used RFLP analysis of internal transcribed spacers of ribosomal DNA, and randomly amplified polymorphic DNA (RAPD) to measure the level of divergence between the spring and fall runs at 4 locations in the Salmon River, California. This preliminary study of samples, collected during 1992-93, found distinct genotypes in spring- and fall-run chinook salmon that indicated there were differences between locations, yet did not present any quantitative information on the actual level of divergence.

In tests for between-year differences in allele frequencies at an average of 10 polymorphic loci in samples from hatchery and wild populations in Oregon, Waples and Teel (1990) found a greater number of significant tests between years for hatchery samples than for samples from naturally spawning populations. The greater allele-frequency instability between years in the hatcheries was attributed to the use of an effective number of parents less than 50 in many hatchery propagation programs, even though the numbers of returning adults was much higher.

Populations of chinook salmon in California have also been examined for repeat length polymorphisms at microsatellite loci. Hedgecock et al. (1995) analyzed samples of fall-, late fall-, winter-, and spring-run chinook salmon populations in the Sacramento River for variability at a single locus. Winter-run samples included fish from 1) 1995 brood stock from the Coleman National Fish Hatchery (CNFH), 2) 1995 carcasses from the Sacramento River, and 3) 1991-94 CNFH brood stock. Spring-run fish were sampled at Deer Creek, and fall- and late fall-run fish were sampled from Battle Creek Hatchery stock. The authors concluded that winter-run fish were distinct from spring-, fall- and late fall-run fish but that winter-run brood stock in CNFH may have included a genetic contribution from spring-run fish, not only in 1995, but also in previous years. Banks et al. (Bodega Marine Laboratory, Bodega Bay, CA. Unpublished, 1996.) extended the study of these samples with an analysis of four additional microsatellite loci. A UPGMA tree of Nei's (1978) genetic distance showed that fall- and late fall-run fish were most similar among run types. Even so, a randomized chi-square test (Roff and Bentzen 1989) showed that allele frequencies for 1 of the 5 loci in fall- and late fall-run fish were significantly different. Spring-run fish were the next most closely related to fall- and late fall-run fish, but showed significant allele-frequency differences with fall- or late fall-run fish at 7 of the 10 possible comparisons. Winter-run chinook salmon was a distant outlier to the three other runs, and showed significant allele-frequency differences for 13 of the possible 15 comparisons with the other run types. The average F_{ST} over the 5 loci was 0.084 and represents considerable divergence among the run types. These results demonstrate significant levels of reproductive isolation between winter-run fish and the other three run types, and between spring-run fish and fall- and late fall-run fish in the Sacramento River. It is difficult, however, to evaluate the importance of these run-time differences relative to run-time differences in populations elsewhere, because of the lack of a coast-wide data base for these microsatellite loci.

Nielsen (1995) surveyed sequence variability in a 164-base-pair segment of the control region of mtDNA in California Central Valley chinook salmon from 8 rivers, 5 hatcheries, and the Guadalupe Slough. These samples included spring-, fall-, late-fall-, and winter-run fish. Ten haplotypes were defined by 7 nucleotide substitutions: 4 transversions, 2 transitions, and an 81 base-pair insertion. Although the analysis of a single locus should be used cautiously, the relatively large sample sizes in this study provided considerable power to test some hypotheses of population structure. A significant haplotypic frequency difference was found between two successive years for returning adults at one of two hatcheries. None of the tests for haplotype-frequency differences between pairs of wild fall-run samples was significant. However, frequencies in some fall-run wild samples were significantly different from frequencies in samples of fall-run hatchery populations. Haplotypic frequencies in samples from Guadalupe Slough were significantly different from each of the four run types, but were not significantly different from haplotype frequencies at the Feather and Merced River hatcheries. Significant differences appeared between each of the four run types. Nucleotide diversity, the average level of sequence divergence between haplotypes, was small, ranging from 0.001 to 0.009 between run types and averaging 0.004 in the pooled sample. Haplotype diversity (analogous to single-locus heterozygosity) ranged from 0.07 in winter-run chinook salmon to 0.64 in late fall-run chinook salmon, and averaged 0.42 over samples. A gene diversity analysis of haplotypic frequencies indicated that 84.7% of the total variability was contained, on average, within run time and 15.3% was due to differences between run times. This level of differentiation among run types is high, but is similar to differentiation between run types in some other regions based on allozyme frequencies.

Levels of Genetic Differentiation among Populations

A summary of representative estimates of gene diversity statistics appears in Table 2 for chinook salmon and other species of salmon and sea run trout. The geographical areas covered in the studies listed in the table are similar, except for the studies of coho salmon (Wehrhahn and Powell 1987, Reisenbichler and Phelps 1987), which were conducted over smaller areas. Genetic subdivision among populations within drainages or among drainages (or adult run type) was estimated with $G_{ST}=H_S/H_T$, where H_S is the average within-population gene diversity and H_T is the total gene diversity, disregarding genetic subdivision. The percentage of gene diversity contained within populations, on average over loci, ranges from about 80% to about 98% in

Table 2. Gene diversity structure (within and among populations in drainages, and among drainages or run types) for chinook salmon (*Oncorhynchus tshawytscha*) and other species of salmon.

Region	Within Pop.	Among Pop. in Drainages	Among Drainages or Run Types	Reference
Chinook Salmon (*Oncorhynchus tshawytscha)*)				
Alaska (AK)	94.1		5.9	Gharrett et al. 1987
Pacific Northwest	87.7	4.6	7.7	Utter et al. 1989
Oregon (OR)-California (CA)	82.3	3.3	14.4	Bartley and Gall 1990
OR-CA	89.4		10.6	Bartley et al. 1992
CA	84.7		15.3	Nielsen 1995
Chum Salmon (*O. keta*)				
Japan-Russia	96.2		3.8	Winans et al. 1994
SE AK-British Columbia (BC)	97.3		2.7	Kondzela et al. 1994
BC-WA	97.2	0.3	2.5	Phelps et al. 1994
Coho Salmon (*O. kisutch*)				
Southern B.C.	91.4		8.6	Wehrhahn and Powell 1987
Northern WA	95.1	9.0	4.0	Reisenbichler and Phelps 1987
Pink Salmon (*O. gorbuscha*) (Even Year)				
B.C.-WA	98.5		1.5	Hard et al. 1996
AK	96.4	1.3	2.3	Gharrett et al. 1988
Pink Salmon (Odd year)				
B.C.-WA	97.9		2.1	Hard et al. 1996
Sockeye Salmon (*O. nerka*)				
B.C.	82.8	8.0	9.2	Wood et al. 1994
WA, B.C., Idaho	84.7	15.3		Winans et al. 1996
Steelhead (*O. mykiss*)				
WA	98.2		1.8	Reisenbichler and Phelps 1987
OR-CA	98.3		1.7	Reisenbichler and Phelps 1987

species of salmon and anadromous trouts. Chinook salmon in the Pacific Northwest tend to show greater levels of genetic subdivision among populations (G_{ST} 11-18%) than do chum, coho, pink salmon (G_{ST} 2-9%), and steelhead (G_{ST} 1.7%) in many of the same areas. Like chinook salmon, sockeye salmon (*O. nerka)* tend to show a greater degree of genetic subdivision among populations (G_{ST} 18%) than do other species of salmon. Chinook salmon populations in Alaska tend to show less genetic differentiation (G_{ST} 5.9%) than do southern populations in British Columbia, Washington, Oregon, and California.

New Studies

To examine evidence for reproductively isolated populations or groups of populations, we analyzed allelic frequencies collected over 15 years by geneticists at NMFS, University of California at Davis, Washington Department of Fish and Wildlife, and the Alaska Department of Fish and Game. This set of data included both published and unpublished allelic frequencies collected with standardized laboratory procedures and compiled for use by participating fishery management agencies. Complete sets of data were available for 31 polymorphic loci: *mAAT-1**, *sAAT-1,2**, *sAAT-3**, *sAAT-4**, *ADA-1**, *ADA-2**, *mAH-4**, *sAH**, *GPI-A**, *GR**, *HAGH**, *mIDHP-2**, *sIDHP-1**, *sIDHP-2**, *LDH-B2**, *LDH-C**, *mMDH-2**, *sMDH-A1,2**, *sMDH-B1,2**, *sMEP-1**, *MPI**, *PEPA**, *PEPB-1**, *PEPD-2**, *PEPLT**, *PGDH**, *PGK-2**, *PGM-1**, *PGM-2**, *sSOD-1**, *TPI-4**. Two loci, *mAH-4** and *GR**, were not available for Alaska chinook salmon samples, so analyses including these samples were based on only 29 loci. For populations sampled more than 1 year—some as many as 3 or 4 years—allelic frequencies for each locus were combined, and the pooled frequencies were used to represent the population frequencies. In several instances, allelic frequencies for neighboring populations were also combined, if the sum of the individual G-tests of frequencies between samples, divided by the sum of the degrees of freedom was not significant. (This data set also serves as a population baseline for estimating the stock contributions of chinook salmon to mixed-population ocean or river-mouth harvests, chiefly along the coasts of Washington and Oregon.) A total of 193 populations extending from Alaska to California were included in the present analyses (Table 3 and Fig. 18). We calculated Rogers' (1972), Nei's unbiased (1978), and Cavalli-Sforza and Edwards' (1967) chord distances between samples, and searched for genetically-discrete geographical groups with multidimensional scaling in three dimensions and with the UPGMA tree algorithm.

Regional patterns of genetic variability

All 193 population units were included in the first analysis to examine large-scale geographical patterns of genetic structure among chinook salmon populations from Alaska to California. A major feature of the UPGMA tree and MDS analysis (Fig. 19) of these samples was a clear genetic separation between populations with stream-type life histories and those with ocean-type life histories. Stream-type populations extend from Alaska, through northern British

Table 3. Samples of chinook salmon used in the genetic analyses for this report. Samples are referred to in figures by the sample codes shown here. Genetic data were provided by Lisa Seeb (Alaska Department of Fish and Game; Laboratory 1), National Marine Fisheries Service (Laboratory 2), Bartley et al. (1992) (University of California at Davis; Laboratory 3), and Anne Marshall (Washington Department of Fish and Wildlife; Laboratory 4). Asterisks indicate combined temporal samples from the same location, or samples from neighboring populations that were combined in the genetic analysis for this report.

Sample No.	**Source**	**Run**	***N***	**Date**	**Laboratory**
Sacramento River Basin					
1*	Mokelumne and Nimbus Hatcheries	fall	350	1981,1984, 1988	2,3
2	Merced Hatchery	fall	100	1988	3
3	Feather Hatchery	fall	300	1981,1984, 1988	2,3
4	Feather Hatchery	spring	244	1981,1984, 1988	2,3
5	Coleman Hatchery (Battle Creek stock)	fall	200	1981,1987	2,3
6	Upper Sacramento River	winter	94	1987	3
California Coast					
7	Mattole River	fall	150	1984,1987	2,3
8	Van Duzen River	fall	100	1987	3
9	Salmon Creek	fall	96	1987	3
10	Redwood Creek (Eel River)	fall	93	1987	3
11	Benbow Creek	fall	99	1987	3
12	Hollow Tree Creek	fall	100	1987	3
13	Mid Fork Eel River	fall	95	1987	3
14	Mad River Hatchery	fall	149	1984,1987	2,3
15	North Fork Mad River	fall	61	1987	3
16	Redwood Creek	fall	195	1987	3
Klamath and Trinity River Basin					
17	Iron Gate Hatchery	fall	247	1981,1984,1987	2,3
18	Trinity Hatchery	fall	270	1981,1984,1987	2,3
19*	Salmon and Scott Rivers	fall	198	1984,1987	2,3
20*	Shasta River and Bogus Creek	fall	259	1984,1987	2,3
21	South Fork Trinity River	fall	100	1987	3
22	Blue Creek	fall	100	1987	3
23	Omagar Creek Hatchery	fall	100	1988	3
South Oregon and north California Coasts					
24	Rowdy Creek Hatchery	fall	112	1984,1987	2,3
25	Mid fork Smith River	fall	99	1987	3
26	Winchuck River	fall	170	1984,1995	2
27	Chetco River	fall	343	1981,1984, 1988,1996	2,3
28	Pistol River	fall	200	1984,1995	2
29	Hunter Creek	fall	100	1995	2
30	Cole Rivers Hatchery	spring	263	1981,1985,1995	2

Table 3 (Cont.).

Sample No.	Source	Run	*N*	Date	Laboratory
31	**Applegate River**	**fall**	**181**	**1984,1988**	**2,3**
32	**Rogue River at Gold Hill**	**fall**	**100**	**1988**	**3**
Mid- and north Oregon Coast					
33	Euchre Creek	fall	57	1996	2
34*	Elk River and Elk River Hatchery	fall	400	1981,1985, 1988,1995	2,3
35	Sixes River	fall	268	1981,1983,1995	2
36	South Fork Coquille River	fall	100	1988	3
37	Bandon Hatchery	fall	59	1995	2
38	Millicoma River	fall	100	1988	3
39	Morgan Creek Hatchery	fall	100	1988	3
40	Noble Creek Hatchery	fall	100	1995	2
41	Rock Creek Hatchery	spring	300	1981,1985,1995	2
42	Rock Creek Hatchery	fall	100	1995	2
43	Siuslaw River	fall	160	1983,1996	2
44	Alsea River	fall	181	1981,1983,1995	2
45	Fall Creek Hatchery	fall	300	1981,1985,1988	2,3
46	Trask Hatchery	fall	300	1981,1985,1987	2,4
47	Nehalem River	summer	53	1996	2
Lower Columbia River					
48	Cowlitz Hatchery	spring	152	1982,1987	2,4
49	Cowlitz Hatchery	fall	198	1981,1982,1988	2,4
50	Kalama Hatchery	spring	159	1982,1990	2,4
51	Kalama Hatchery	fall	199	1982,1988,1989	2,4
52	Lewis Hatchery	spring	135	1988	4
53	Lewis River	fall	120	1990	4
54*	Mckenzie and Dexter Hatcheries	spring	248	1982,1987,1988	2,4
55	Clackamas Hatchery	spring	100	1988	4
56	North Fork Clackamas River	spring	80	1996	2
57	Marion Forks Hatchery	spring	100	1990	4
58	Sandy River	fall	140	1990,1991,1992	4
59*	Spring Creek and Big Creek Hatcheries	fall	504	1982,1987,1990	2,4
Mid- and Upper Columbia River spring run					
60	Carson Hatchery	spring	250	1982,1989	2,4
61	Klickitat River	spring	261	1990,1991, 1992,1993	4
62*	Warm Springs Hatchery and River	spring	210	1982,1987	2
63	Round Butte Hatchery	spring	159	1982,1990	2,4
64	North Fork John Day River	spring	85	1990,1991,1992	4
65*	Yakima and Cle Elum Rivers	spring	401	1986,1989,1990	4
66	American River	spring	226	1986,1989,1990	4
67*	Naches, Little Naches, and Bumping Rivers	spring	251	1989,1990	4
68	White River	spring	137	1989,1991,1992	4
69	Nason River	spring	122	1989,1992	4

Table 3 (Cont.).

Sample No.	**Source**	**Run**	***N***	**Date**	**Labo-ratory**
70	**Chiwawa River**	**spring**	**247**	**1989,1990, 1991,1992**	**4**
71	**Methow River**	**spring**	**93**	**1993**	**4**
72	**Chewack River**	**spring**	**151**	**1992,1993**	**4**
73	**Twisp River**	**spring**	**107**	**1992,1993**	**4**
Mid- and upper Columbia River summer and fall run					
74	Klickitat River	summer	324	1991,1992, 1993,1994	4
75	Klickitat River	fall	250	1991,1992, 1993,1994	4
76	Bonneville Hatchery	fall	200	1989,1990	4
77	Little White Salmon Hatchery	fall	200	1989,1990	4
78	Deschutes River	fall	179	1982,1985,1990	2,4
79	Yakima River	fall	109	1990	4
80	Marion Drain	fall	153	1989,1990	4
81	Hanford Reach	fall	258	1982,1990	2,4
82	Priest Rapids Hatchery	fall	300	1981,1986, 1987,1990	2,4
83	Wenatchee River	summer	350	1985,1988, 1989,1990	2,4
84	Similkameen River	summer	206	1991,1992,1993	4
85	Methow River	summer	59	1992,1993	4
Snake River					
86	Lyons Ferry Hatchery	fall	399	1985,1986, 1987,1990	2,4
87	Tucannon Hatchery	spring	758	1985,1986,1987, 1988,1989,1990	2,4
88	Rapid River	spring	293	1982,1985,1990	2
89	Lookingglass Hatchery	spring	100	1991	2
90	Minam River (Grande Ronde River)	spring	100	1990	2
91	Lostine River (Grande Ronde River)	spring	297	1989,1990,1991	2
92	Catherine Creek (Grande Ronde River)	spring	100	1990	2
93	McCall Hatchery	summer	350	1982,1989, 1990,1991	2
94	Secesh River	summer	254	1989,1990,1991	2
95	Johnson Creek	summer	316	1982,1989, 1990,1991	2
96	Marsh Creek	spring	259	1989,1990,1991	2
97	Sawtooth Hatchery	spring	350	1982,1989, 1990,1991	2
98	Valley Creek	spring	279	1989,1990,1991	2
99	Upper Salmon River at Blaine Bridge	spring	60	1989	2
100	Upper Salmon River at Frenchman Creek	spring	60	1991	2
101	Upper Salmon River at Sawtooth	spring	100	1991	2

Table 3 (Cont.).

Sample No.	**Source**	**Run**	***N***	**Date**	**Labo-ratory**
102	**Imnaha River and Hatchery**	**summer**	**480**	**1989,1990, 1991**	**2**
Washington Coast					
103	Naselle Hatchery	fall	448	1987,1988, 1989,1990	4
104*	Wynoochee River and Hatchery	fall	209	1990,1993	4
105	Wishkah River	fall	96	1990,1993	4
106	East Fork Satsop River	fall	102	1993	4
107	Skookumchuck River	spring	74	1990,1991, 1992,1993	4
108	Humptulips Hatchery	fall	103	1990	4
109	Quinault Hatchery	fall	200	1981,1990	2,4
110	Queets River	fall	190	1981,1990	2,4
111	Hoh River	fall	176	1981,1982,1990	2,4
Strait of Juan de Fuca					
112	Hoko River	fall	80	1993	4
113	Elwha Hatchery	fall	200	1981,1988	2,4
114	Elwha River	fall	200	1988,1991	4
Puget Sound					
115*	North Fork Nooksack Hatchery and River	spring	255	1985,1988,1993	4
116	South Fork Nooksack River	spring	51	1993	4
117	Skagit Hatchery	spring	92	1990	4
118	Skagit Hatchery	summer	90	1988	4
119	Skagit Hatchery	fall	107	1987	4
120	Skagit River	fall	69	1986,1987	4
121	Sauk River	summer	74	1986	4
122	Suiattle River	spring	543	1985,1986,1987, 1988,1989,1990	4
123	Sauk River	spring	147	1986,1994	4
124	Cascade River	spring	84	1993,1994	4
125	Skagit River	summer	284	1986,1994	4
126	North Fork Stilliguamish River	summer	106	1987,1988	4
127	Skykomish River	summer	235	1987,1988,1989	4
128	Bridal Veil Creek	summer	87	1987,1988	4
129	Skykomish Hatchery	fall	106	1987	4
130	Wallace River	fall	82	1989	4
131	Sultan River	fall	95	1987,1988,	4
132	Snoqualmie River	fall	101	1988	4
133	Green River Hatchery	fall	398	1981,1987, 1988,1990	2,4
134	White River Hatchery	spring	400	1992,1993	4
135	South Prairie Creek	fall	86	1992,1993	4
136	Deschutes Hatchery	fall	250	1981,1987	2,4
137	Hoodsport Hatchery	fall	248	1981,1988	2,4

Sample No.	Source	Run	*N*	Date	Laboratory
Fraser River Basin					
138*	Chehalis Hatchery and Harrison River	fall	440	1988,1989,1990	4
139	Chilliwack Hatchery	fall	87	1989,1990	4
140	Coldwater River	summer	162	1982,1987	2
141	Deadman River	summer	80	1987	2
142	Spius Creek	summer	158	1987	2
143	Bonaparte River	summer	120	1987	2
144*	Salmon River and Hatchery	summer	420	1985,1987,1988	2
145*	Eagle River and Hatchery	summer	380	1985,1987,1988	2
147	Adams River	summer	80	1987	2
148*	Clearwater Hatchery and Horseshoe River	summer	302	1982,1985,1987	2
149	Finn Creek	summer	120	1987	2
150	Chilko River	summer	227	1982,1987,1988	2
151	Chilcotin River	summer	80	1987	2
152*	Quesnel Hatchery and River	spring	676	1985,1987, 1988,1990	2
153	Lower Cariboo River	spring	120	1987	2
154	Upper Cariboo River	spring	180	1985,1987	2
155	Baezaeko River	spring	260	1985,1987	2
156	Willow River	spring	256	1985,1987	2
157	Walker Creek	spring	80	1987	2
158	Morkill River	spring	80	1987	2
159	Horsey River	spring	120	1987	2
160	Swift Creek	spring	80	1987	2
161	Fraser River at Tete Jaune	spring	137	1982,1988	2,4
South British Columbia					
162	Tenderfoot Hatchery	summer	435	1985,1988, 1991,1992	2,4
163	Bute Inlet	fall	109	1991	4
164	Cowichan Hatchery	fall	484	1988,1989,1990	4
165	Nanaimo Hatchery	fall	241	1985,1988, 1989,1990	2,4
166	Nanaimo/Nanaimo Lake	summer	104	1989,1990	4
167	Big Qualicum Hatchery	fall	537	1981,1985, 1988,1989, 1990	2,4
168	Quinsam Hatchery	fall	643	1981,1985, 1988,1989, 1990	2,4
169	Robertson Creek Hatchery	fall	300	1981,1985, 1991	2
170	Kennedy River	fall	150	1991,1992	4
171*	Sucwoa and Conuma Rivers	fall	180	1985,1992	2

Table 3 (Cont.).

Sample No.	**Source**	**Run**	***N***	**Date**	**Labo-ratory**
Central British Columbia					
172	Wannock River	fall	180	1988,1991	2
173	Kitimat River	summer	190	1985,1988	2
174	Atnarko River	spring	329	1985,1990, 1991	2
Skeena River Basin					
175	Kitsumkalum River	summer	281	1988,1989,1991	2
176	Cedar River	spring	100	1991	2
177	Kitwanga River	spring	111	1991	2
178	Bulkley River	spring	192	1989,1991	2
179	Kispiox River	spring	80	1989	2
180	Babine River	spring	113	1982,1988	2
181	Bear River	spring	218	1988,1991	2
Nass River Basin					
182	Cranberry River	spring	93	1988,1989	2
183	Damdochax River	spring	75	1988	2
Stikine River Basin					
184	Iskut River	spring	73	1990	4
185	Little Tahltan River	spring	100	1990	4
Southeast Alaska					
186	Whitman Lake Hatchery	-	55	1994	1
187	Tahini River	-	69	1992	1
Kenai					
188	Crooked Creek	-	82	1992	1
Kodiak					
189	Ayakulik River	-	98	1993	1
Bristol Bay					
190	Nushagak River	-	53	1993	1
191	Togiak River	-	62	1993	1
Kuskokwim					
192	Tuluksak River	-	50	1993	1
193	Kogrukluk River	-	50	1993	1

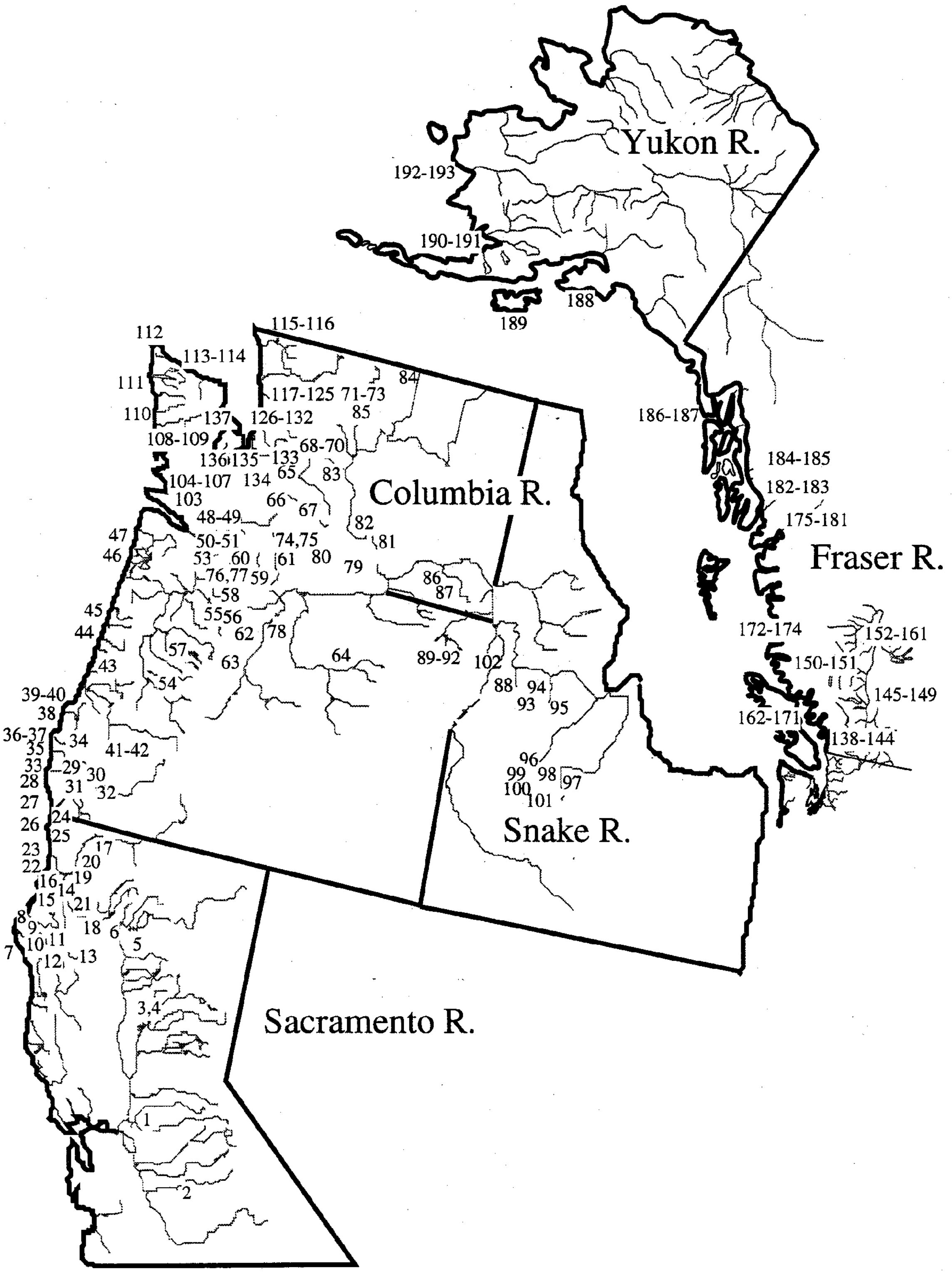


Figure 18. Locations of sample sites used in genetic analysis. Sample site numbers correspond to those in Table 3.

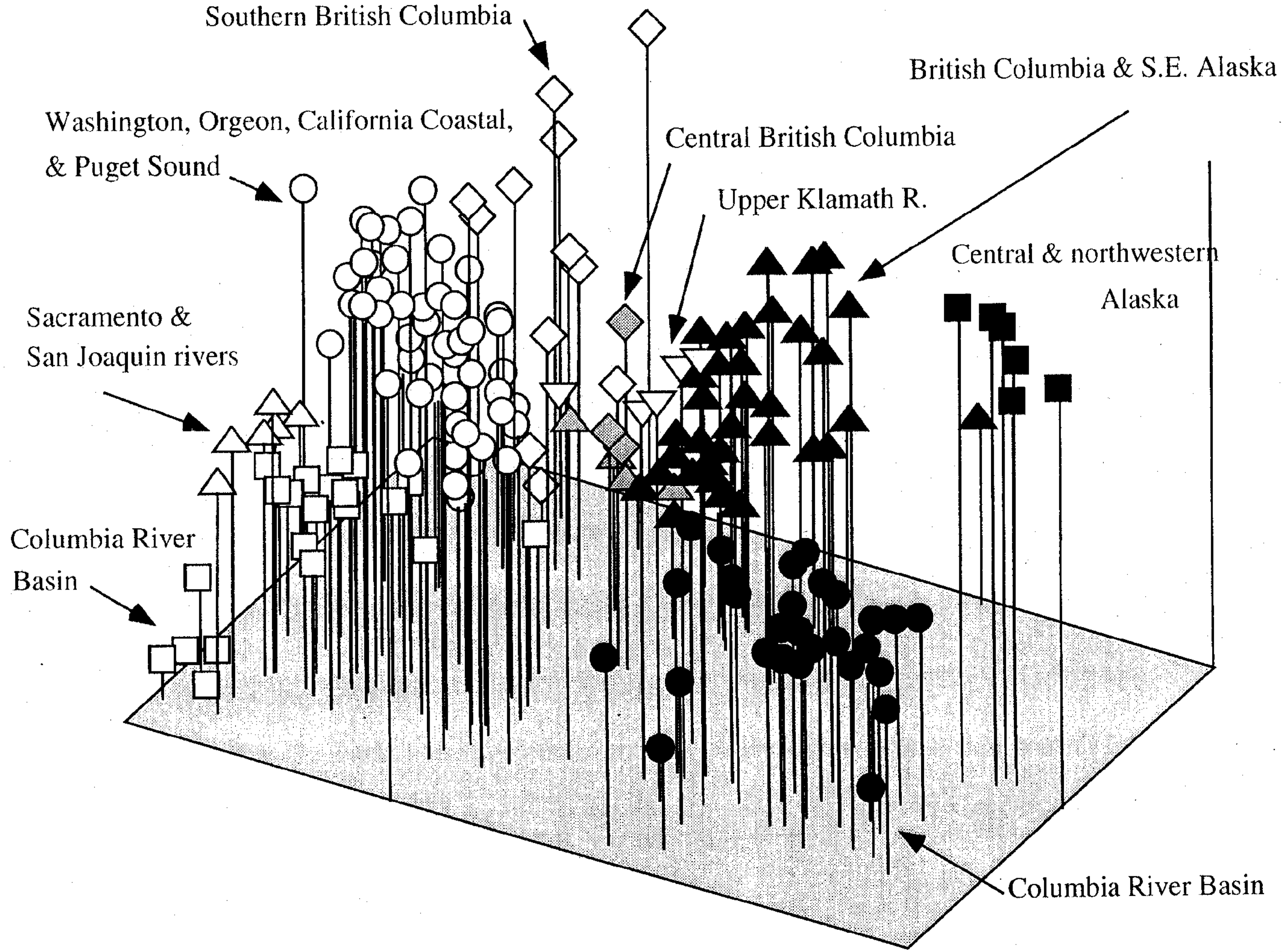


Figure 19. Multidimensional scaling plot (MDS) of Cavall-Sforza and Edwards (1967) chord distances based on 29 allozyme loci between 193 composite samples of chinook salmon from populations extending from Alaska to California. The MDS clustering of these samples had a stress of 0.245, which represents a fair fit of distances between samples in the graph to the original genetics distances. Open symbols denote ocean-type populations, filled symbols denote stream-type populations, and gray symbols denote populations of intermediate type.

Columbia, into the upper Fraser River, and into the mid- and upper Columbia River Basin. Ocean-type populations, and populations showing both ocean- and stream-type juvenile migration (mixed-type populations), extend from central British Columbia to the Sacramento-San Joaquin River drainage in California. The transition zone from ocean- and mixed-type populations in the south to only stream-type populations in the north occurs along the central coast of British Columbia. In this zone, populations such as those in the Kitimat, Atnarko, and Wannock Rivers were intermediate in the MDS diagram between the two larger clusters representing ocean- and stream-type populations. Samples from populations in the lower and South Thompson River, a Fraser River tributary, also clustered in an intermediate position.

Several subclusters appeared within stream-type chinook salmon. Six samples from south-central and northwestern Alaska were genetically distinct from all other samples. These Alaskan samples showed surprisingly little genetic differentiation from each other, even though they were collected over an area extending from Bristol Bay to south-central Alaska. The amount of genetic diversity among these populations was considerably less than that among populations extending over comparable areas in British Columbia, Washington, Oregon, and California. Two samples from southeastern Alaska clustered with samples from northern British Columbia. Geographical patterns were also apparent among the remaining stream-type samples. Stream-type populations in the Columbia River Basin were genetically distinct from stream-type populations in the upper Fraser, Skeena, Nass, and Stikine Rivers in British Columbia.

Several distinct subclusters also appeared among ocean-type samples of chinook salmon. Samples from southern British Columbia and from Puget Sound rivers fell into a large subcluster. Another subcluster contained samples from the coastal rivers of Washington, Oregon, and California. Samples from the upper Klamath River were genetically distinct from other samples of ocean-type populations and clustered near the convergence of the two life-history groups. Other distinct subclusters of ocean-type fish included samples from the Columbia River Basin and those from the Sacramento-San Joaquin River drainage. The following analyses of subsets of these samples examine these groups in more detail.

British Columbia, Washington, Oregon, and California

A subset including samples from 83 ocean-type populations in southern British Columbia, Washington, Oregon, and California was analyzed with both the UPGMA (Fig. 20) and MDS (Fig. 21) clustering methods. Since the purpose of analyzing this subset of samples was to discern relationships among coastal populations, Columbia River and upper Klamath River populations were not included because they were genetically very different from coastal populations. In the subset of 83 samples, 5 clusters of more or less genetically distinct samples appeared in both analyses. All the samples from British Columbia, including samples from the lower Fraser River, Vancouver Island, and southern British Columbia mainland clustered together in the MDS diagram. A large distinct cluster of British Columbia populations was also

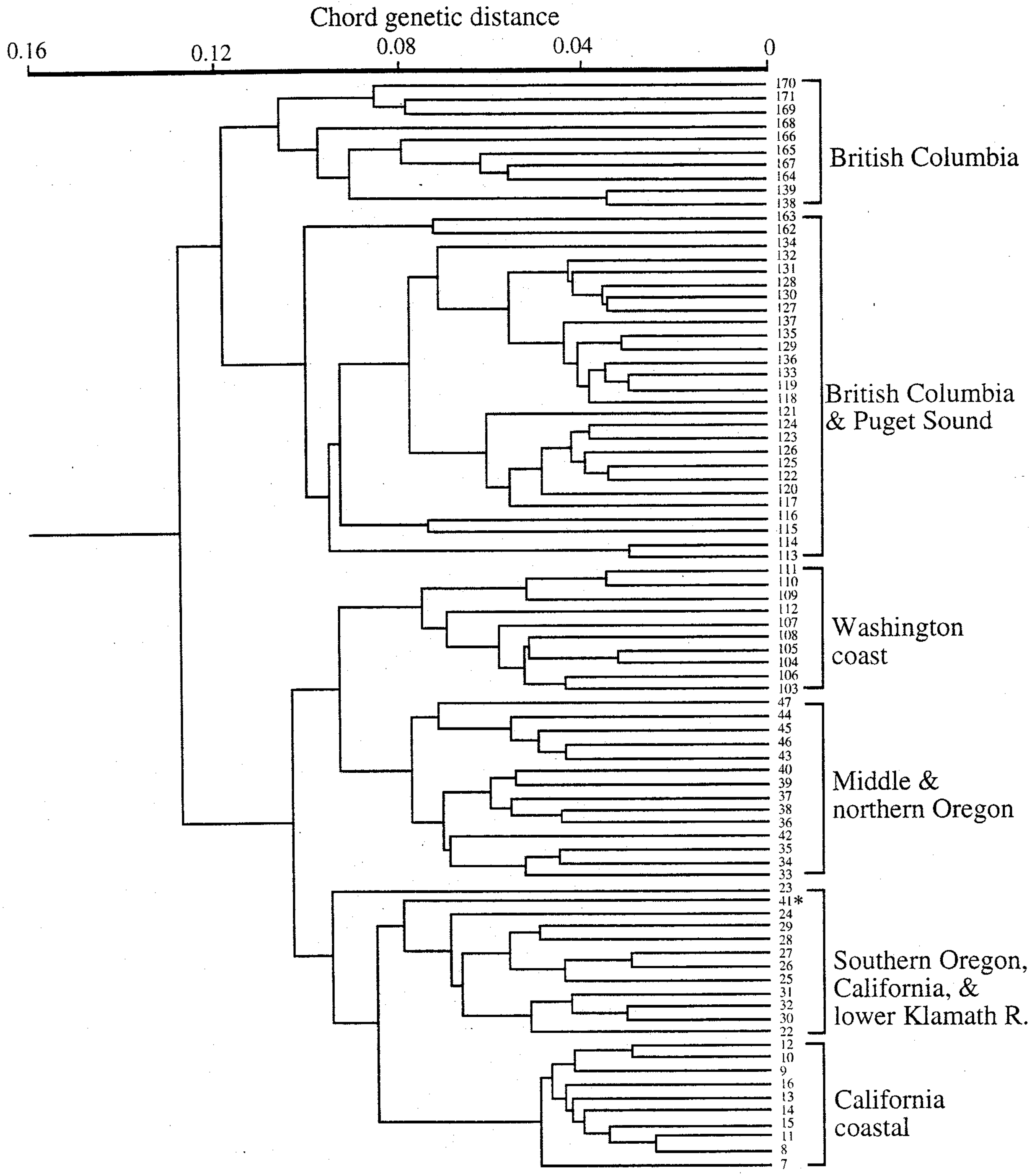


Figure 20. Unweighted pair group method with arithmetic averages (UPGMA) tree of Cavalli-Sforza and Edwards (1967) chord distances based on 31 allozyme loci between 83 composite samples of chinook salmon from coastal populations extending from British Columbia to northern California.

Sample numbers correspond to those in Table 3. Sample 41 (asterisk) is from a population located in middle Oregon which clustered with samples from southern Oregon.

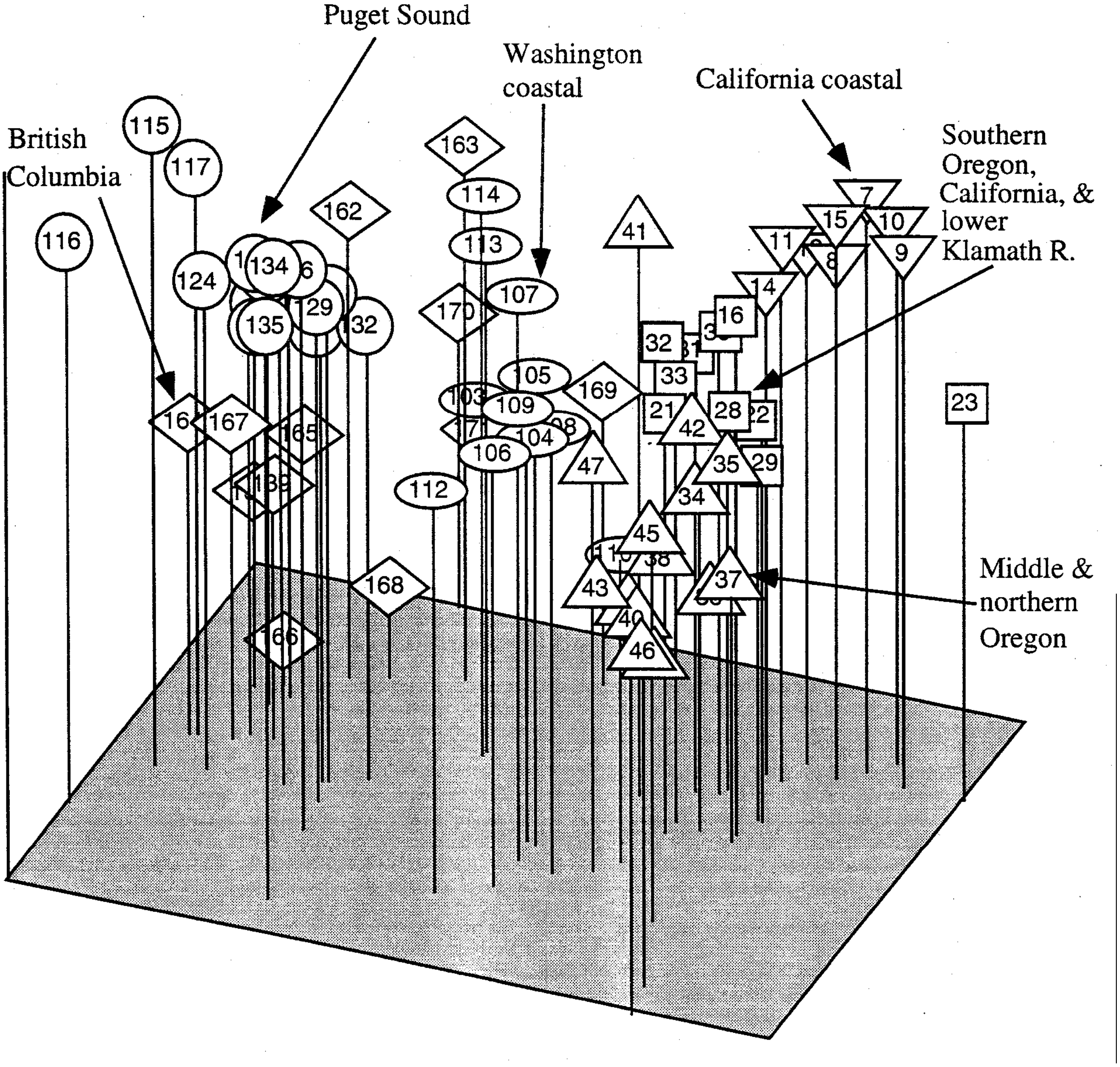


Figure 21. Multidimensional scaling (Mds) of Cavalli-Sforza and Edwards (1967) chord distances based on 31 allozyme loci between 83 composite samples of chinook salmon from coastal populations extending from British Columbia to northern California. Sample numbers correspond to those in Table 3. The MDS clustering of these samples had a stress of 0.215, which represents a fair fit of distances between samples in the graph and the original genetics distance matrix.

apparent in the UPGMA tree. However, two samples from the lower British Columbia mainland grouped separately. In both the MDS and UPGMA clustering methods, geographically nearby samples were more similar to each other than were more distantly separated samples. British Columbia samples, as a group, were most closely related to samples from populations in Puget Sound.

A second large cluster included samples from populations of chinook salmon in rivers draining into Puget Sound. Four groupings within this cluster were apparent in the UPGMA tree: 1) the Elwha River populations, 2) the Nooksack River populations, 3) populations from the Skagit and Stilliguamish Rivers, and 4) south Puget Sound populations and Skagit Hatchery fall-run and summer-run populations. In the three-dimensional MDS diagram, the samples from the Elwha River were intermediate between the Puget Sound samples and samples from the coast of Washington.

A third large UPGMA cluster included all samples from the coast of Washington. In the UPGMA tree, the cluster of samples from rivers along the Washington coast joined with a cluster of samples from north Oregon coastal rivers. In the MDS diagram, however, Washington coastal river samples were situated between Puget Sound river samples and Oregon coastal river samples. The Washington coastal clusters in both clustering methods contained a sample from the Hoko River, which drains into the Strait of Juan de Fuca west of the Elwha River. In the UPGMA tree, samples from the Quinault, Queets, and Hoh Rivers formed a subcluster separate from other samples from Washington outer-coastal rivers.

In both the MDS diagram and the UPGMA tree, a fourth cluster included samples from northern and mid-Oregon coastal rivers as far south as Euchre Creek. One exception was the sample of spring-run chinook salmon from the Rock Creek Hatchery on the Umpqua River, which was more closely related to samples from southern Oregon coastal rivers than to samples from mid-Oregon. Northern and mid-Oregon coastal river samples, as a group, appeared to be more closely related to Washington coastal river samples than to samples from rivers in southern Oregon and northern California.

A fifth cluster included samples from southern Oregon coastal rivers, the lower Klamath River, and coastal rivers in northern California. Two distinct subclusters of samples appeared within this cluster. One contained samples from populations in the lower Klamath River and coastal rivers to the north. This subcluster also contained the spring-run sample from the Rock Creek Hatchery as mentioned above. The second subcluster contained samples from coastal rivers south of the Klamath River. The sample from Omagar Creek, located in the lower Klamath River, did not appear in either of these two subclusters.

Columbia and Snake Rivers

We analyzed a set of allelic frequencies for 31 loci in 55 samples from the Columbia and Snake Rivers to depict population structure among populations in these drainages. An MDS diagram of Cavalli-Sforza and Edwards' chord genetic distance best illustrated the major features of this analysis (Fig. 22). Samples in this analysis were separated into two distinct clusters: ocean-type populations and stream-type populations; except for a sample of spring-run chinook salmon from the Klickitat River, which was genetically intermediate between the two clusters.

Additional genetic population structure was apparent within these two life-history types. Within ocean-type chinook salmon, samples of spring- and fall-run chinook salmon from the lower Columbia River were distinct from all inland samples. The lower Columbia River group included naturally spawning fish from the Lewis and Sandy Rivers and from hatchery brood stock derived from populations west of the Cascade Mountain Range. Four samples, three from Willamette River hatcheries and one from the North Fork Clackamas River, were genetically distinct from other ocean-type chinook salmon in the Columbia River drainage.

Samples of ocean-type fish from localities east of the Cascade Crest included fish from both "bright" fall- and summer-run populations, including fall-run populations at the Bonneville and Little White Salmon hatcheries and in the Klickitat River. Although these populations are located on the west side of the Cascade Crest, brood stocks used in the hatchery programs in these rivers were derived from upriver populations of ocean-type chinook salmon. The Klickitat River summer-run population, which was introduced from upriver sources, appeared in the MDS diagram in an intermediate position between inland and lower Columbia River ocean-type populations.

The arrangement of samples of stream-type chinook salmon in the MDS diagram (Fig. 22) is largely consistent with geographical relationships among populations, except for a few notable samples. Samples of ocean-type fish (lefthand side of Figure) were clearly separated from stream type fish (righthand side of Figure). A genetically diverse group of samples of stream-type fish (squares) from the Klickitat, John Day, Deschutes, and Yakima Rivers of the mid Columbia River were positioned between the extremes of ocean-type and stream-type fish. A second group of stream-type fish (inverted triangles plus samples 90 and 91) were positioned between mid-Columbia River spring-run fish and fish from spring- and summer-run populations in the Snake River. This group included geographically diverse samples from the Wenatchee and Methow Rivers in the upper Columbia River, as well as two samples (90, 91) from the Grande Ronde River, a tributary of the Snake River. The inclusion of samples from the Wenatchee, Methow, and Grand Ronde River tributaries in this group may be due to a long history of introducing Carson Hatchery fish, or fish derived from Carson Hatchery fish, into upper Columbia River tributaries. Carson Hatchery was initially stocked with fish from the Snake River, and introductions followed by hybridization may have produced the similarity of upper Columbia River spring-run fish to Snake River fish. The third cluster of stream-type

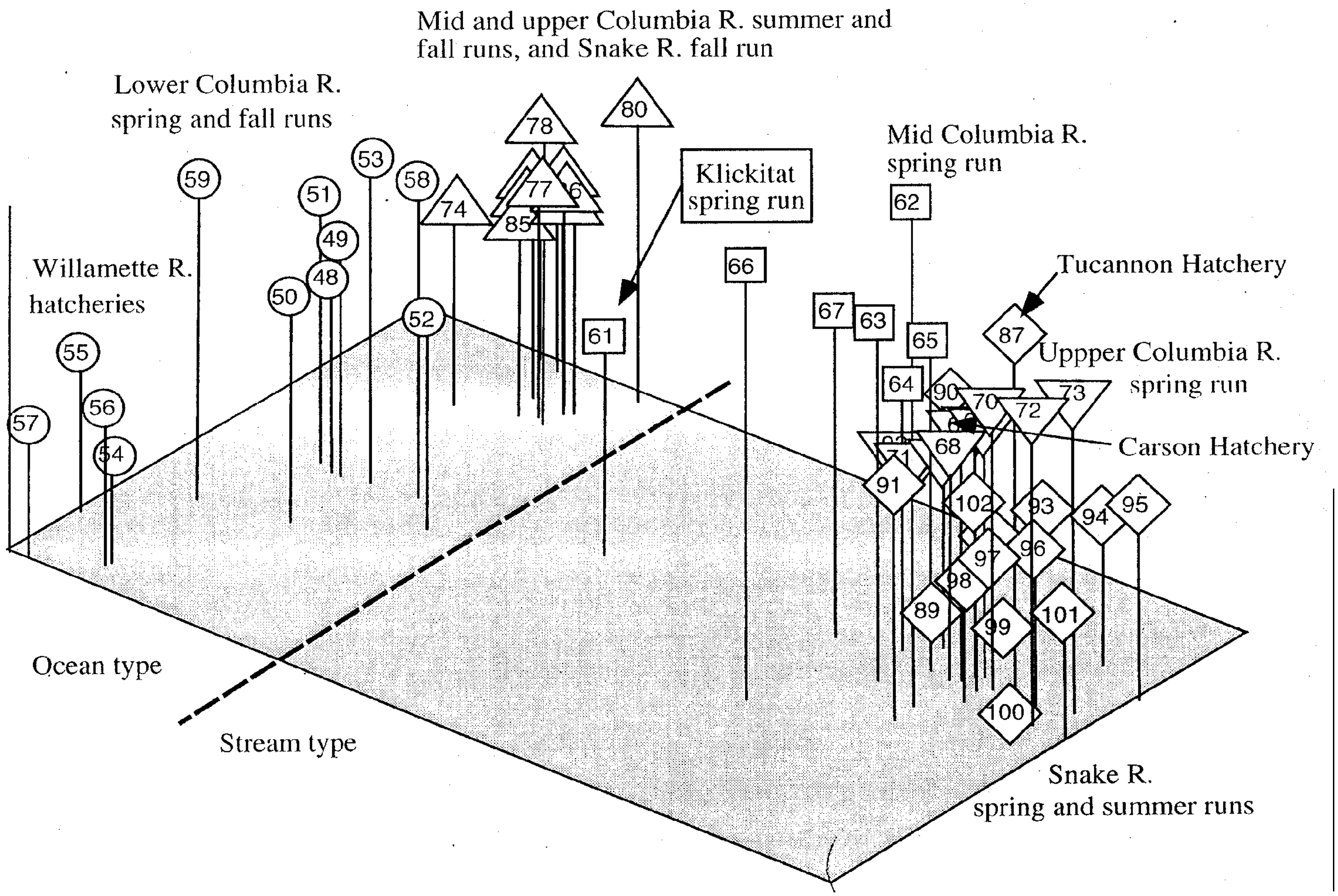


Figure 22. Multidimensional scaling (MDS) of Cavalli-Sforza and Edwards (1967) chord distances based on 31 allozyme loci between 55 composite samples of chinook salmon from populations in the Columbia River drainage. Sample numbers correspond to those in Table 3. The MDS clustering of these samples had a stress of 0.078, which represents a good fit of distances between samples in the graph and the original genetics distances between the samples.

chinook salmon was most distantly related to ocean-type chinook salmon and included samples from Snake River populations in the Salmon and Imnaha Rivers, and Rapid River, and Lookingglass Hatcheries.

Summary

The genetic groupings of chinook salmon appearing in our analyses of the coast-wide set of allelic frequencies were largely consistent with those described in previous studies of chinook salmon. Our results for populations in Alaska agreed with those of Gharrett et al. (1987), who also found that chinook salmon populations in south-central and northwestern Alaska showed less inter-population genetic diversity than did populations in other regions, and that south-central and northwestern Alaska populations were genetically distinct from populations in southeastern Alaska. Populations in southeastern Alaska appear to be genetically most similar to stream-type populations in northern British Columbia. Our analysis and that of Utter et al. (1989) indicated that stream-type populations in the upper Fraser River were closely allied with stream-type populations in northern British Columbia.

Ocean-type chinook salmon populations in Vancouver Island rivers, in the lower Fraser River, and in rivers in southern British Columbia form a genetically distinct, though diverse, group of populations. Utter et al. (1989) proposed a similar grouping of populations, but placed a single sample from west Vancouver Island with coastal populations to the south. Puget Sound populations of chinook salmon appear to constitute a genetically distinct group, a conclusion that is consistent with the results of Utter et al. (1989) and Marshall et al. (1995). In our analyses, Washington coastal populations appeared to form a genetically distinct group that was most similar to, but still distinct from, Oregon coastal populations. The Washington coastal group included the Hoko River population in the western part of the Strait of Juan de Fuca. Chinook salmon in the Elwha River, which also drains into the Strait of Juan de Fuca, were genetically intermediate between Puget Sound and Washington coastal populations. Marshall et al. (1995) grouped this and other Strait of Juan de Fuca populations with Washington coastal populations.

Chinook salmon populations in the Columbia and Snake Rivers appear to be separated into two large genetic groups: those producing ocean-type juvenile outmigrants and those producing stream-type outmigrants. The subdivision of Columbia River Basin populations into two major genetic units is consistent with Waples et al. (1991a) and Marshall et al. (1995). The first group includes populations in lower Columbia River tributaries, with both spring-run and fall-run "tule" life histories. These ocean-type populations exhibit a range of juvenile life-history patterns that appear to depend on local environmental conditions. The Willamette River hatchery populations form a distinct subgroup within the lower Columbia River group. Ocean-type chinook salmon populations east of the Cascade Range Crest include both summer- and fall-run "bright" populations, and are genetically distinct from lower Columbia River ocean-type populations. Fall-run populations in the Snake River, Deschutes River, and Marion Drain

(Yakima River) form a distinct subgroup. These genetic groupings are also consistent with the analyses of Waples et al. (1991a) and Marshall et al. (1995).

The second major group of chinook salmon in the Columbia and Snake River drainage consists of spring- or summer-run fish. Three relatively distinct subgroups appeared within these stream-type populations. One subgroup includes populations in the Klickitat, John Day, Deschutes, and Yakima Rivers of the mid Columbia River. A second subgroup includes upper Columbia River spring-run chinook salmon in the Wenatchee and Methow Rivers, but also spring-run fish in the Grande Ronde River and Carson Hatchery. A third subgroup consists of Snake River spring- and summer-run populations in the Imnaha and Salmon Rivers, and in the Rapid River and Lookingglass Hatcheries. These groupings are consistent with those found by Waples et al. (1991a). However, Marshall et al. (1995), who examined only populations in Washington State for genetic variability, identified three groups of stream-type chinook salmon 1) Yakima River, 2) Wenatchee and Methow Rivers, and 3) a Snake River spring-run population (Tucannon River). The Klickitat River spring-run population appears to be genetically intermediate between upper and lower Columbia River groups, a conclusion consistent with that of Marshall et al. (1995).

All populations of chinook salmon south of the Columbia River drainage appear to consist of ocean-type fish. Populations along the north coast of Oregon form a genetically distinct group, consisting of populations north of and including the Elk River, except for the Rock Creek Hatchery spring-run population, which shows greater genetic affinity to southern Oregon coastal populations. A southern coastal group includes populations south of the Elk River to and including populations in the lower Klamath River in northern California. However, Euchre Creek, located near the Rogue River, has been stocked extensively with Elk River stock and clustered with populations north of Cape Blanco. A California coastal group consists of populations south of the Klamath River. These genetic groups are consistent with Bartley et al. (1992). Upper Klamath River populations of chinook salmon are genetically distinct from other northern California populations. The results of Bartley and Gall (1990) and Bartley et al. (1992) are consistent with these groupings of northern California and southern Oregon populations.

Sacramento and San Joaquin River populations are genetically distinct from northern California coastal and Klamath River populations. Previous studies grouped populations in the Sacramento River and with those in the San Joaquin River (Utter et al. 1989, Bartley and Gall 1990, Bartley et al. 1992). However, Hedgecock et al. (1995), Banks (1996), and Nielsen (1995, 1997) surveyed DNA markers and these results indicate that the winter, spring, fall, and late-fall runs are genetically distinct from one another.

Discussion and Conclusions on ESU Determinations

Most of the ESUs described below include multiple spawning populations of chinook salmon, and most also extend over a considerable geographic area. This result is consistent with NMFS' species definition paper, which states that, in general, "ESUs should correspond to more comprehensive units unless there is clear evidence that evolutionarily important differences exist between smaller population segments" (Waples 1991b, p. 20). However, considerable diversity in genetic or life-history traits or habitat features exists within most ESUs, and maintaining this diversity is critical to their overall health. The descriptions below briefly summarize some of the notable types of diversity within each ESU, and this diversity is considered in the next section in evaluating risk to the ESU as a whole.

According to NMFS policy, populations of Pacific salmon will be considered "distinct" (and hence "species" as defined by the ESA) if they represent evolutionarily significant units of the biological species. A variety of factors are considered in evaluating the two criteria for salmon populations or groups of populations to be considered ESUs: reproductive isolation and substantial contribution to ecological/genetic diversity of the species as a whole.

Previous status reviews conducted by NMFS have identified three ESUs of chinook salmon in the Columbia River: Snake River fall (Waples et al. 1991b), Snake River spring and summer (Matthews and Waples 1991), and mid-Columbia River summer-run chinook salmon (Waknitz et al. 1995). In addition, prior to development of the ESU policy, NMFS recognized Sacramento River winter chinook salmon as a "distinct population segment" under the ESA (NMFS 1987). In reviewing the biological and ecological information concerning west coast chinook salmon, the Biological Review Team identified 11 additional ESUs for chinook salmon from Washington, Oregon, and California. Genetic data (from protein electrophoresis and DNA analysis) and tagging information were key factors considered for the reproductive isolation criterion, supplemented by inferences about barriers to migration created by natural features. A number of factors were considered to be important in evaluations of ecological/genetic diversity. Data on life-history characteristics (especially age at smoltification, ocean distribution, time of freshwater entry, and age at maturation) and geographic, hydrological, and environmental characteristics were the most informative.

Evolutionary Significance of Life-History Forms

The predominant differentiation in chinook salmon life-history types is between ocean- and stream-type chinook salmon. Gilbert (1912) initially defined ocean- and stream-type life-history types to discriminate between fish that emigrated to saltwater as subyearlings (ocean-type) and those that emigrated at one or more years of age (stream-type). Healey (1983, 1991) utilized a number of additional life-history traits to expand this process to describe two races of chinook salmon. In Healey's scheme, ocean-type populations typically migrate to seawater in their first year of life and spend most of their oceanic life in coastal waters, whereas stream-type populations migrate to sea as yearlings and often make extensive oceanic migrations. Stream-type fish spawn in the upper Fraser River and Columbia River Basins, as well as coastal areas north of about latitude 55°N (Healey 1983). Ocean-type chinook salmon spawn in the Sacramento River and the mainstem and lower tributaries of the Columbia, Snake, and Fraser River Basins, and throughout western North American coastal drainages to approximately 55°N. In this review, we have followed Healey's scheme, which focuses on populations rather than individual fish, and focuses on a suite of genetic and life-history traits rather than just age at juvenile outmigration.

In some areas within the Columbia River Basin, stream- and ocean-type chinook salmon stocks spawn in relatively close proximity to one another but are separated by run timing. Stream-type chinook salmon include spring-run populations in the Columbia River and its tributaries east of the Cascade Crest, and spring- and summer-run fish in the Snake River and its tributaries; ocean-type chinook salmon include fall-run chinook salmon in both the Columbia and Snake River Basins, summer-run chinook salmon from the Columbia River, and spring-run fish from the lower Columbia River. Although it has also been known for some time that there are substantial genetic differences between stream- and ocean-type chinook salmon in both the Fraser and Columbia River Basins, the genetic analyses in this status review show clearly for the first time that the two life-history forms represent two major (and presumably monophyletic) evolutionary lineages. Genetic differences between the two forms, as measured by variation in allozymes, are of the same order of magnitude as the differences found between the inland and coastal subspecies of steelhead (*O. mykiss*) and between even- and odd-year pink salmon (*O. gorbuscha)*.

Adult run time has also long been used to identify different temporal “races” of chinook salmon. In cases where the run-time differences correspond to differences between stream- and ocean-type fish (e.g. in the Columbia and Fraser River Basins), relatively large genetic differences (as well as ecological and life-history differences) can be found between the different runs. In most coastal areas, however, life-history and genetic differences between the runs are relatively modest. Although many populations have some fraction of yearling migrants, all the coastal populations are part of the ocean-type lineage, and spring- and fall-run fish are very similar in ocean distribution patterns and genetic characteristics.

Among basins supporting only ocean-type chinook salmon, the Sacramento River system is somewhat unusual in that its large size and ecological diversity historically allowed for substantial spatial as well as temporal separation of different runs. Genetic and life-history data both suggest that considerable differentiation among the runs has occurred in this basin. The Klamath River Basin shares some features of coastal rivers but historically also provided an opportunity for substantial spatial separation of different temporal runs. As discussed below, the BRT found that the diversity in run timing made identifying ESUs difficult in the Klamath and Sacramento River Basins.

The ecological importance and underlying genetic basis of specific life-history traits has been discussed in a previous section. The BRT considered differences in life-history traits as a possible indicator of adaptation to different environmental regimes and resource partitioning within those regimes.

Major Chinook Salmon Groups

Based on preliminary information indicating substantial ecological, geographic, and genetic differences among chinook salmon from the Columbia and Sacramento Rivers and coastal drainages, the BRT considered the following three geographic areas separately in making ESU determinations: California Central Valley, coastal basins and Puget Sound, and Columbia River. Some of the factors considered important in defining ESUs within each area are briefly discussed here, followed by more detailed descriptions of each of the proposed ESUs.

California Central Valley

The Sacramento River winter chinook salmon was designated as a distinct population segment (NMFS 1987) almost entirely on its unique life-history features. No genetic data for the population were available at the time of the listing determination, and the NMFS species policy had not been formulated. Recent DNA data show substantial differences between the winter run and all other runs in the basin. The BRT concluded that the life-history and genetic data collectively support designation of the winter run as an ESU. The DNA data also show significant differences between spring-run fish and the fall and late-fall runs. Ecological data show strong evidence for historic spatial and temporal isolation of the spring run, and the BRT also concluded that this run represents an ESU. The majority of the BRT felt that differences between fall and late-fall runs were consistent with diversity within a single ESU and did not warrant the creation of separate ESUs for these runs.

Coastal basins and Puget Sound

All populations of chinook salmon in Puget Sound and coastal drainages of Washington, Oregon, and California are considered ocean type. In these areas, life-history differences exist between spring- and fall-run fish, but not to the same extent as is observed in larger inland basins, and genetic data indicate the two run types are polyphyletic in coastal drainages. Utter et al. (1989) identified three genetic groups of chinook salmon in this geographic region: Puget Sound, upper Klamath River Basin, and other coastal streams from the Olympic Peninsula to northern California. Recent genetic data indicate the presence of more geographically clustered groups along the coast. Based primarily on genetic data, geographic and environmental features, and life-history traits, the BRT identified five ESUs in this area: Puget Sound, Washington Coast, Oregon Coast, Southern Oregon and California Coast, and Upper Klamath and Trinity Rivers. A minority of the BRT proposed that the Southern Oregon and California Coast ESU should be split into two ESUs, with a boundary south of the Klamath River.

Columbia River

As noted above, a major phylogenetic break occurs between stream- and ocean-type chinook salmon in the Columbia River. Populations from both types were included in ESUs defined in previous status reviews. Groups whose ESU status had not been determined previously include ocean-type fish below McNary Dam, stream-type fish from outside the Snake River Basin, and spring-run chinook salmon in the upper Willamette River. Willamette River spring-run fish are isolated from, and genetically quite distinct from, all other Columbia River chinook salmon, and the BRT agreed that they represent an ESU. The BRT also concluded that ocean-type fish spawning below the Cascade Crest, including both spring and fall chinook salmon, were part of a single ESU. This ESU includes the "tule" fall runs, which return in an advanced stage of maturation and exhibit distinct secondary maturation characteristics: darkened skin, resorbed scales, and pronounced kype. These are distinguishable from "upriver brights", which return to spawning sites above the Cascade Crest and enter freshwater at a less advanced stage of maturation.

Four geographic/genetic groups of stream-type chinook salmon can be identified in the Columbia River: Snake River, Columbia River tributaries from Bonneville Dam to the Snake River, Yakima River Basin, and upper Columbia River (tributaries upstream of the Yakima River). The latter group includes all populations affected by the Grand Coulee Fish Maintenance Project. The majority of the BRT concluded that there are three ESUs in this area: Snake River, upper Columbia River, and mid-Columbia River (Bonneville Dam to Yakima River, inclusive). Scenarios favored by minorities of the BRT included a single ESU encompassing all stream-type chinook salmon, two ESUs (Snake River and Columbia River), and four ESUs (each of the abovementioned groups).

The BRT also considered several populations of "upriver bright" ocean-type chinook salmon whose ESU status had not been resolved in previous status reviews. Excluded from discussion were several upriver bright chinook salmon populations in the Wind, White and Little White Salmon, and Klickitat Rivers; historical records (e.g., Fulton 1968) do not document native populations in these areas, and current populations are believed to be the result of stock transfers. Native fall-run populations in the John Day, Umatilla, and Walla Walla Rivers have been extirpated (Kostow 1995), and populations that are presently found in these systems are also considered to be the result of introductions. Of particular interest are populations in the Deschutes River and Marion Drain in the Yakima River drainage that have shown a genetic affinity with Snake River fall chinook salmon (Waples et al. 1991b, WDF et al. 1993). A minority of the BRT felt that the Marion Drain population should be considered part of the Snake River ESU, but the majority felt that the origin of this population is too uncertain to determine its ESU status. A majority of the BRT concluded that the Deschutes River population should be considered part of the Snake River ESU, whereas a minority felt that this population was historically part of a separate ESU that included populations from the John Day, Umatilla, and Walla Walla Rivers. All members felt it was important to develop more definitive information about the Deschutes River population and its possible link to Snake River fish.

ESU Descriptions

Most of the ESUs described below include multiple spawning populations of chinook salmon, and most also extend over a considerable geographic area (Figs. 23 and 24). This result is consistent with NMFS' species definition paper, which states that, in general, "ESUs should correspond to more comprehensive units unless there is clear evidence that evolutionarily important differences exist between smaller population segments" (Waples 1991b, p. 20). However, considerable diversity in genetic or life-history traits or habitat features exists within most ESUs, and maintaining this diversity is critical to their overall health. The descriptions below briefly summarize some of the notable types of diversity within each ESU, and this diversity is considered in the next section in evaluating risk to the ESUs as a whole.

1) Sacramento River Winter-Run ESU

This run was determined to be a distinct population segment by NMFS in 1987, prior to development of the NMFS species policy. The BRT concluded that this run meets the criteria to be considered an ESU. It includes chinook salmon entering the Sacramento River from November to June and spawning from late-April to mid-August, with a peak from May to June. No other chinook salmon populations have a similar life-history pattern. In general, winter-run chinook salmon exhibit an ocean-type life-history strategy, with smolts emigrating to the ocean after five to nine months of freshwater residence (Johnson et al. 1992b) and remaining near the coasts of California and Oregon. Winter-run chinook salmon also mature at a relatively young age (2-3 years old). DNA analysis indicates substantial genetic differences between winter-run and other chinook salmon in the Sacramento River.

Historically, winter-run populations existed in the Upper Sacramento, Pit, McCloud, and Calaveras Rivers. The spawning habitat for these stocks was primarily located in the Sierra Nevada Ecoregion (Omernik 1987). Construction of dams on these rivers in the 1940s led to the extirpation of populations in the San Joaquin River Basin and displaced the Sacramento River population to areas below Shasta Dam.

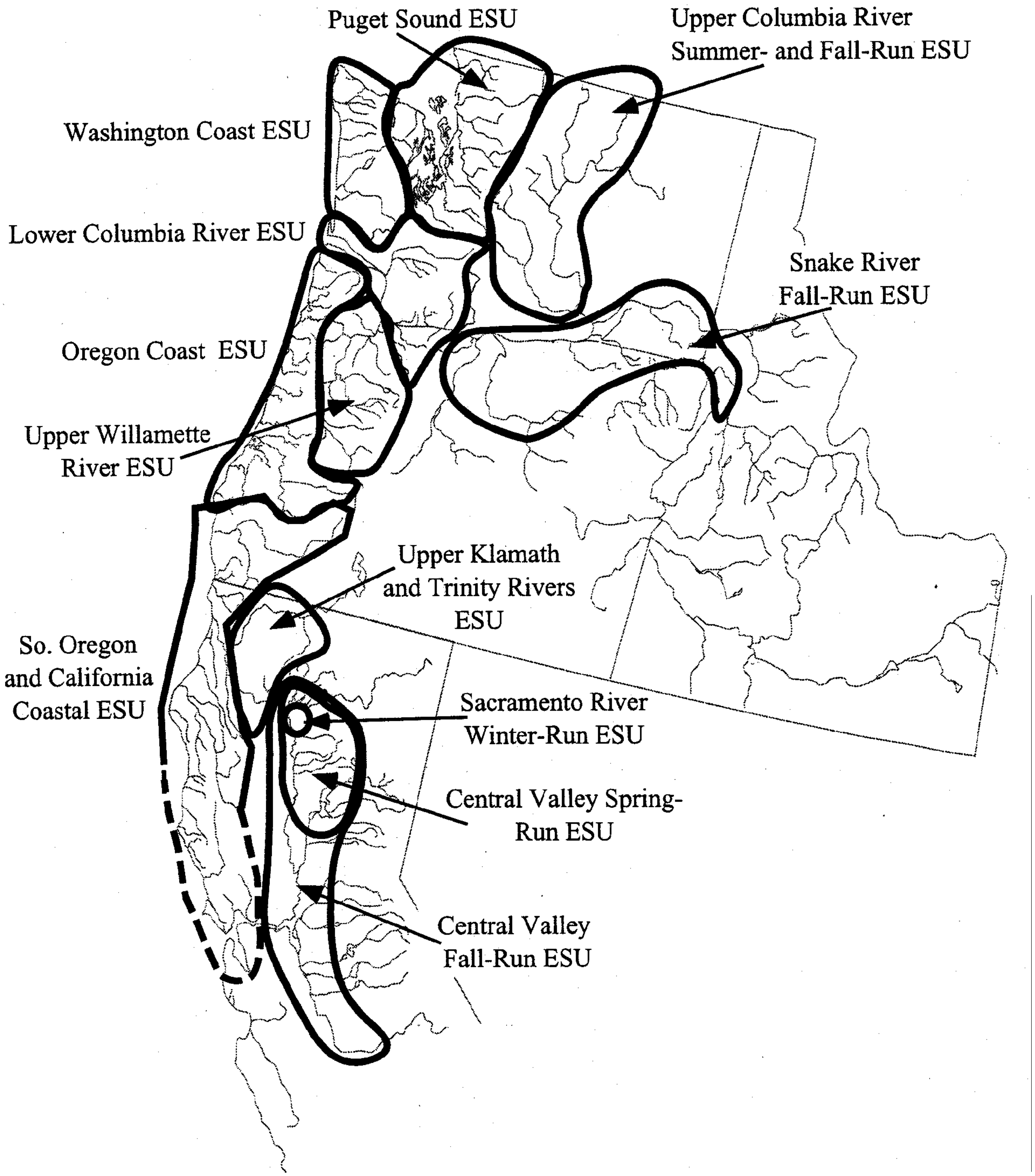


Figure 23. Map of the approximate geographic ranges of proposed evolutionarily significant units (ESUs) for west coast ocean-type chinook salmon.

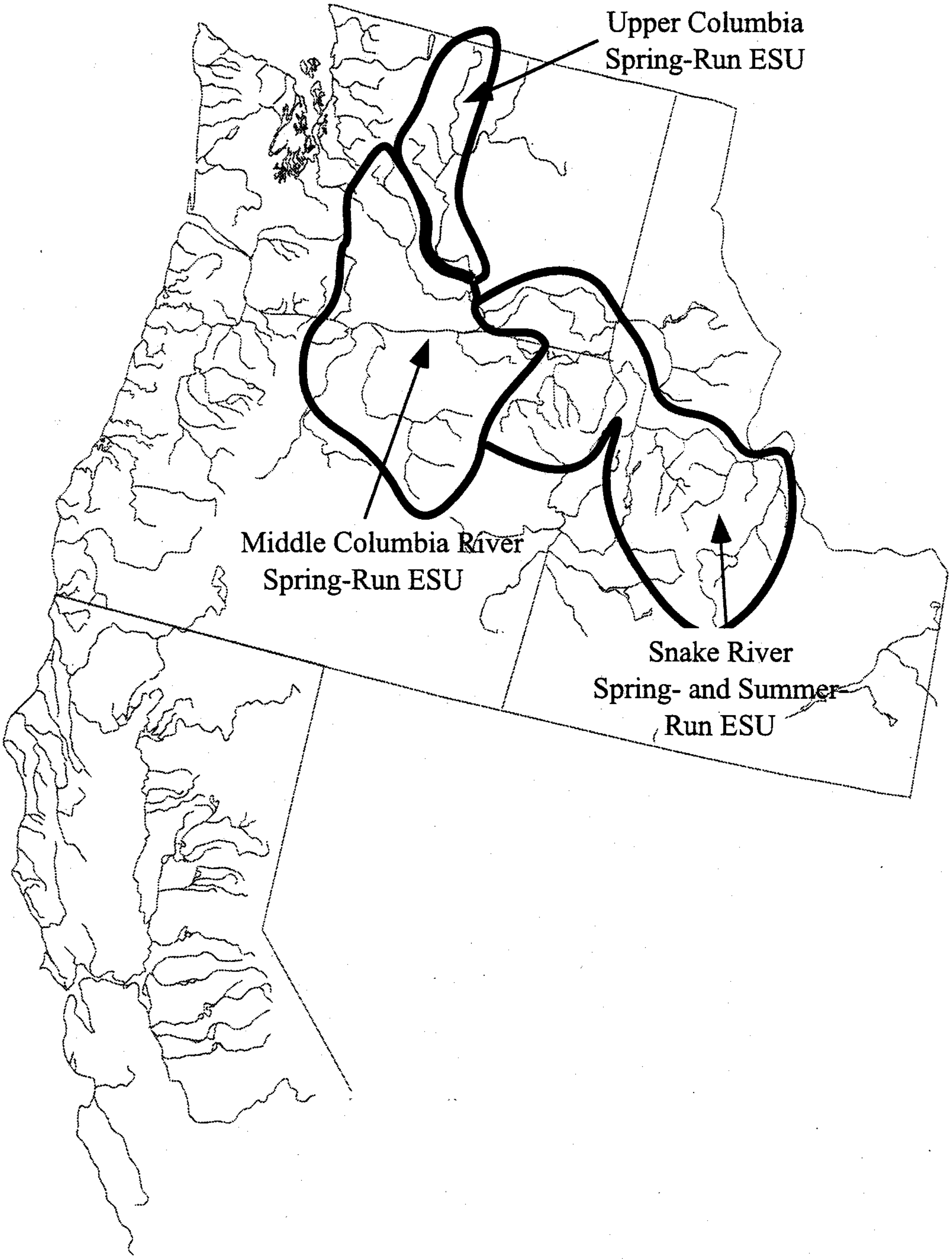


Figure 24. Map of the approximate geographic ranges of proposed evolutionarily significant units (ESUs) for west coast stream-type chinook salmon.

2) Central Valley Spring-Run ESU

Extant populations in this ESU spawn in the Sacramento River and its tributaries. Historically, spring-run chinook salmon were the dominant run in the Sacramento and San Joaquin River Basins (Clark 1929), but native populations in the San Joaquin River have apparently all been extirpated (Campbell and Moyle 1990). This ESU includes chinook salmon entering the Sacramento River from March to July and spawning from late August through early October, with a peak in September. Spring-run fish in the Sacramento River exhibit an ocean-type life history, emigrating as fry, subyearlings, and yearlings. Coded-wire-tag (CWT) recoveries are primarily from ocean fisheries off the California and Oregon coast. There were minimal differences in the ocean distribution of fall- and spring-run fish from the Feather River Hatchery (as determined by CWT analysis); however, due to hybridization in the hatchery between these two runs, this similarity in ocean migration may not be representative of wild runs. The BRT noted substantial ecological differences in the historical spawning habitat for spring-run vs. fall- and late-fall-run fish. The spring chinook salmon run timing was suited to gaining access to the upper reaches of river systems (up to 1,500 m elevation) prior to the onset of prohibitively high water temperatures and low flows that inhibit access to these areas during the fall. Differences in adult size, fecundity, and smolt size are also observed between spring- and fall-run chinook salmon in the Sacramento River.

No allozyme data are available for naturally spawning Sacramento River spring-run chinook salmon. A sample from Feather River Hatchery spring-run fish, which may have undergone substantial hybridization with fall chinook salmon, shows modest (but statistically significant) differences from fall-run hatchery populations. DNA data show moderate genetic differences between the spring and fall/late-fall runs in the Sacramento River; however, these data are difficult to interpret in the context of this broad status review because comparable data are not available for other geographic regions.

There were lengthy discussions by the BRT concerning the disposition of spring runs in the Sacramento River, and a number of different scenarios were considered. The majority of the BRT felt that the spring-run chinook salmon in the Sacramento River represented a separate ESU. A minority felt that the spring-run fish are part of a larger ESU that also includes the fall and late-fall runs. Based largely on environmental factors, the BRT also considered the possibility that spring-run fish from the San Joaquin River were historically part of a separate ESU, but little life-history and genetic information was available to evaluate this hypothesis. The BRT felt that it was important to develop additional genetic information to elucidate the status of the remnant spring-run populations in Butte, Deer, and Mill Creeks and their relationship to spring-run fish from the mainstem Sacramento and Feather Rivers.

3) Central Valley Fall-Run ESU

This ESU includes fall and late-fall chinook salmon spawning in the Sacramento and San Joaquin Rivers and their tributaries. These populations enter the Sacramento and San Joaquin Rivers from July through April and spawn from October through February. Both runs are ocean-type chinook salmon, emigrating predominantly as fry and subyearlings and remaining off the California coast during their ocean migration. All chinook salmon in the Sacramento/San Joaquin Basin are genetically and physically distinguishable from coastal forms (Clark 1929, Snyder 1931). Ecologically, the Central Valley also differs in many important ways from coastal areas.

There were a number of life-history differences noted between Sacramento and San Joaquin River Basin fall-run populations. In general, San Joaquin River populations tend to mature at an earlier age and spawn later in the year than Sacramento River populations. These differences could have been phenotypic responses to the generally warmer temperature and lower flow conditions found in the San Joaquin River Basin relative to the Sacramento River Basin. There was no apparent difference in the distribution of marine CWT recoveries from Sacramento and San Joaquin River hatchery populations, nor were there genetic differences between Sacramento and San Joaquin River fall-run populations (based on DNA and allozyme analysis) of a similar magnitude to that used in distinguishing other ESUs. This apparent lack of distinguishing life-history and genetic characteristics may be due, in part, to large-scale transfers of Sacramento River fall-run chinook salmon into the San Joaquin River Basin. There was some concern expressed by the BRT that the information available may not be representative of fish historically occupying the San Joaquin River Basin.

A majority of the BRT felt that fall and late-fall chinook salmon in the Sacramento River represented a single ESU. Contrasting minority viewpoints were that: 1) Spring-run fish are part of the same ESU that includes the fall and late-fall runs; 2) fall and late-fall runs constituted separate ESUs; and 3) fall-run fish in the San Joaquin River Basin constituted their own ESU.

4) Southern Oregon and California Coastal ESU

All coastal spring and fall chinook salmon spawning from Cape Blanco (south of the Elk River) to the southern extent of the current range comprise this ESU. The Cape Blanco region is a major biogeographic boundary for numerous species. The Southern Oregon and California Coastal ESU extends to the southern limit of the Coastal Range Ecoregion. Populations from the Central Valley and Klamath River Basin upstream from the Trinity River confluence are in separate ESUs. Chinook salmon in this ESU exhibit an ocean-type life-history; ocean distribution (based on marine CWT recoveries) is predominantly off the California and Oregon coasts. Life-history information on smaller populations, especially in the southern portion of the ESU, is extremely limited. Additionally, there was anecdotal or incomplete information on the existence of several spring-run populations, including the Chetco, Winchuck, Smith, Mad, and Eel Rivers. Allozyme data indicate that this ESU is genetically distinguishable from the Oregon Coast, Upper Klamath and Trinity River, and Central Valley ESUs.

Ecologically, the majority of the river systems in this ESU are relatively small and heavily influenced by a maritime climate. Low summer flows and high temperatures in many rivers result in seasonal, physical, and thermal barrier bars that block movement by anadromous fish. The Rogue River is the largest river basin in this ESU and extends inland, into the Sierra Nevada and Cascades Ecoregions.

A minority of the BRT felt that coastal chinook salmon from south of the Klamath River should be considered a separate ESU. Allozyme data, which show some level of genetic divergence between coastal chinook salmon populations north and south of the Klamath River, support this argument, as do the establishment of ESU boundaries for steelhead south of the Klamath River and for coho salmon south of Punta Gorda. A nearly total lack of biological information for chinook salmon south of the Eel River makes this issue difficult to resolve.

The BRT also considered arguments for the creation of separate fall- and spring-run ESUs in this and other coastal regions, but the consensus of the BRT was that this was not warranted.

5) Upper Klamath and Trinity Rivers ESU

Included in this ESU are all Klamath River Basin populations from the Trinity River and the Klamath River upstream from the confluence of the Trinity River. These populations include both spring- and fall-run fish that enter the Upper Klamath River Basin from March through July and July through October and spawn from late August through September and September through early January, respectively. Body morphology (vertebral counts, lateral-line scale counts, and fin-ray counts) and reproductive traits (egg size and number) for populations from the Upper Klamath River differ from those of populations in the Sacramento River Basin. Genetic analysis indicated that populations from the Upper Klamath River Basin form a unique group that is quite distinctive compared to neighboring ESUs. The Upper Klamath River crosses the Coastal Range, Sierra Nevada, and Eastern Cascades Ecoregions, although dams prevent access to the upper river headwaters of the Klamath River in the Eastern Cascades Ecoregion.

Within the Upper Klamath River Basin, there are statistically significant, but fairly modest, genetic differences between the fall and spring runs. The majority of spring- and fall-run fish emigrate to the marine environment primarily as subyearlings, but have a significant proportion of yearling smolts. Recoveries of CWTs indicate that both runs have a coastal distribution off the California and Oregon coasts. There was no apparent difference in the marine distribution of CWT recoveries from fall-run (Iron Gate and Trinity River Hatcheries) and spring-run populations (Trinity River Hatchery). The BRT discussed at some length the proposition that spring- and fall-run populations should be in separate ESUs based on differences in run timing and habitat utilization and reproductive isolation. The majority of the BRT concluded that both run types should be considered part of the same ESU; a minority felt that separation into two ESUs was warranted; and some BRT members were undecided on this issue. The BRT was concerned that the only estimate of the genetic relationship between spring and fall runs in this ESU is from a comparison of hatchery stocks that may have undergone some introgression during hatchery spawning operations. The BRT acknowledged that the ESU determination should be revisited if substantial new information from natural spring-run populations becomes available.

6) Oregon Coast ESU

This ESU contains coastal populations of spring- and fall-run chinook salmon from the Elk River north to the mouth of the Columbia River. These populations exhibit an ocean-type life history and mature at ages 3, 4, and 5. In contrast to the more southerly ocean distribution pattern shown by populations from the lower Columbia River and farther south, CWT recoveries from populations within this ESU are predominantly from British Columbia and Alaska coastal fisheries. There is a strong genetic separation between Oregon Coast ESU populations and neighboring ESU populations. This ESU falls within the Coastal Ecoregion and is characterized by a strong maritime influence, with moderate temperatures and high precipitation levels.

A minority of the BRT felt that, because of similarities in life-history traits and environmental features, populations from the Oregon and Washington coasts were part of a single ESU. A separate minority felt that, based primarily on genetic information, the Oregon Coast ESU should be divided into two units, with populations north of the Umpqua River being in separate ESUs.

7) Washington Coast ESU

Coastal populations spawning north of the Columbia River and west of the Elwha River are included in this ESU. These populations can be distinguished from those in Puget Sound by their older age at maturity and more northerly ocean distribution. Allozyme data also indicates geographical differences between populations from this area and those in Puget Sound, the Columbia River, and the Oregon coast ESUs. Populations within this ESU are ocean-type chinook salmon and generally mature at ages 3, 4, and 5. Ocean distribution for these fish is more northerly than that for the Puget Sound and Lower Columbia River ESUs. The boundaries of this ESU lie within the Coastal Ecoregion, which is strongly influenced by the marine environment: high precipitation, moderate temperatures, and easy migration access. As noted above, a minority of the BRT felt that this ESU should be combined with chinook salmon from the Oregon coast.

8) Puget Sound ESU

This ESU encompasses all runs of chinook salmon in the Puget Sound region from the North Fork Nooksack River to the Elwha River on the Olympic Peninsula. Chinook salmon in this area all exhibit an ocean-type life history. Although some spring-run chinook salmon populations in the Puget Sound ESU have a high proportion of yearling smolt emigrants, the proportion varies substantially from year to year and appears to be environmentally mediated rather than genetically determined. Puget Sound stocks all tend to mature at ages 3 and 4 and exhibit similar, coastally-oriented, ocean migration patterns. There are substantial ocean distribution differences between Puget Sound and Washington coast stocks, with CWTs from Washington Coast fish being recovered in much larger proportions from Alaskan waters. The marine distribution of Elwha River chinook salmon most closely resembled other Puget Sound stocks, rather than Washington coast stocks. The BRT concluded that, on the basis of substantial genetic separation, the Puget Sound ESU does not include Canadian populations of chinook salmon. Allozyme analysis of North Fork and South Fork Nooksack River spring-run chinook salmon identified them as outliers, but most closely allied with other Puget Sound samples. DNA analysis identified a number of markers that appear to be restricted to either the Puget Sound or Washington coastal stocks. Some allozyme markers suggested an affinity of the Elwha River population with the Washington coastal stocks, while others suggested an affinity with Puget Sound stocks.

The boundaries of the Puget Sound ESU correspond generally with the boundaries of the Puget Lowland Ecoregion. Despite being in the rainshadow of the Olympic Mountains, the river systems in this area maintain high flow rates due to the melting snowpack in the surrounding mountains. Temperatures tend to be moderated by the marine environment. The Elwha River, which is in the Coastal Ecoregion, is the only system in this ESU which lies outside the Puget Sound Ecoregion. Furthermore, the boundary between the Washington Coast and Puget Sound ESUs (which includes the Elwha River in the Puget Sound ESU) corresponds with ESU boundaries for steelhead and coho salmon. In life history and genetic attributes, the Elwha River chinook salmon appear to be transitional between populations from Puget Sound and the Washington Coast ESU.

A majority of the BRT considered that Elwha River chinook salmon were part of the Puget Sound ESU. A minority of the BRT felt that the Elwha River chinook salmon belonged in the Washington Coast ESU, and a further minority was undecided.

9) Lower Columbia River ESU

This ESU includes all native populations from the mouth of the Columbia River to the crest of the Cascade Range, excluding populations above Willamette Falls. Celilo Falls, which corresponds to the edge of the drier Columbia Basin Ecosystem and historically may have presented a migrational barrier to chinook salmon at certain times of the year, is the eastern boundary for this ESU. Not included in this ESU are “stream-type” spring-run chinook salmon found in the Klickitat River (which are considered part of the Mid-Columbia River Spring-Run ESU) or the introduced Carson spring-chinook salmon strain. “Tule” fall chinook salmon in the Wind and Little White Salmon Rivers are included in this ESU, but not introduced “upriver bright” fall-chinook salmon populations in the Wind, White Salmon, and Klickitat Rivers. Available information suggests that spring-run chinook salmon presently in the Clackamas and Sandy Rivers are predominantly the result of introductions from the Willamette River ESU and are thus probably not representative of spring-run chinook salmon historically found in these two rivers.

In addition to the geographic features mentioned above, genetic and life-history data were important factors in defining this ESU. Populations in this ESU are considered ocean type. Some spring-run populations have a large proportion of yearling migrants, but this trend may be biased by yearling hatchery releases. Subyearling migrants were found to contribute to the escapement. CWT recoveries for Lower Columbia River ESU populations indicate a northerly migration route, but with little contribution to the Alaskan fishery. Populations in this ESU also tend to mature at ages 3 and 4, somewhat younger than populations from the coastal, upriver, and Willamette ESUs. Ecologically, the Lower Columbia River ESU crosses several ecoregions: Coastal, Willamette Valley, Cascades and East Cascades.

10) Upper Willamette River ESU

This ESU includes native spring-run populations above Willamette Falls. Fall chinook salmon above the Willamette Falls were introduced and are not considered part of this ESU. Populations in this ESU have an unusual life history that shares features of both the stream and ocean types. Scale analysis of returning fish indicate a predominantly yearling smolt life-history and maturity at 4 years of age, but these data are primarily from hatchery fish and may not accurately reflect patterns for the natural fish. Young-of-year smolts have been found to contribute to the returning 3-year-old year class. The ocean distribution is consistent with an ocean-type life history, and CWT recoveries occur in considerable numbers in the Alaskan and British Columbian coastal fisheries. Intrabasin transfers have contributed to the homogenization of Willamette River spring-run chinook salmon stocks; however, Willamette River spring-run chinook salmon remain one of the most genetically distinctive groups of chinook salmon in the Columbia River Basin.

The geography and ecology of the Willamette Valley is considerably different from surrounding areas (see discussion of the Willamette Valley Ecoregion). Historically, the Willamette Falls offered a narrow temporal window for upriver migration, which may have promoted isolation from other Columbia River stocks.

11) Mid-Columbia River Spring-Run ESU

Included in this ESU are stream-type chinook salmon spawning in the Klickitat, Deschutes, John Day, and Yakima Rivers. Historically, spring-run populations from the Hood, Walla Walla, and Umatilla Rivers may have also belonged in this ESU, but these populations are now considered extinct. Chinook salmon from this ESU emigrate to the ocean as yearlings and apparently migrate far off-shore, as they do not appear in appreciable numbers in any ocean fisheries. The majority of adults spawn as 4-year-olds, with the exception of fish returning to the upper tributaries of the Yakima River, which return predominantly at age 5. Populations in this

ESU are genetically distinguishable from other stream-type chinook salmon in the Columbia and Snake Rivers. Streams in this region drain desert areas east of the Cascades (Columbia Basin Ecoregion) and are ecologically differentiated from the colder, less productive, glacial streams of the upper Columbia River Spring-Run ESU and from the generally higher elevation streams of the Snake River.

There were two different minority BRT opinions regarding fish from this area. Some BRT members felt that all stream-type chinook salmon populations from the Columbia River Basin (or all populations outside the Snake River) are part of a single ESU. A separate minority felt that the Yakima River populations should be considered a separate ESU from spring-run populations downstream from the Snake River.

12) Upper-Columbia River Summer- and Fall-Run ESU

(Formerly known as the Mid-Columbia River Summer/Fall Chinook salmon ESU.)

Waknitz et al. (1995) and NMFS (1994a) identified an ESU that included all ocean-type chinook salmon spawning in areas between McNary Dam and Chief Joseph Dam. The BRT for the current status review concluded that the boundaries of this ESU do not extend downstream from the Snake River. In particular, the BRT concluded that Deschutes River fall chinook salmon are not part of this ESU. The ESU status of the Marion Drain population from the Yakima River is still unresolved. The BRT also identified the importance of obtaining more definitive genetic and life-history information for naturally spawning fall chinook salmon elsewhere in the Yakima River drainage.

Fish from this ESU primarily emigrate to the ocean as subyearlings but mature at an older age than ocean-type chinook salmon in the Lower Columbia and Snake Rivers. Furthermore, a greater proportion of CWT recoveries for this ESU occur in the Alaskan coastal fishery than is the case for Snake River fish. The status review for Snake River fall chinook salmon (Waples et al. 1991b, NMFS 1992) also identified genetic and environmental differences between the Columbia and Snake Rivers. Substantial life-history and genetic differences distinguish fish in this ESU from stream-type spring-run chinook salmon from the mid- and upper-Columbia Rivers.

This ESU falls within part of the Columbia Basin Ecoregion. The area is generally dry and relies on Cascade Range snowmelt for peak spring flows. Historically, this ESU may have extended farther upstream; spawning habitat was compressed down-river following construction of Grand Coulee Dam.

13) Upper Columbia River Spring-Run ESU

This ESU includes stream-type chinook salmon spawning above Rock Island Dam—that is, those in the Wenatchee, Entiat, and Methow Rivers. All chinook salmon in the Okanogan

River are apparently ocean-type and are considered part of the Upper Columbia River Summer- and Fall-Run ESU. These upper Columbia River populations exhibit classical stream-type life-history strategies: yearling smolt emigration with only rare CWT recoveries in coastal fisheries. These populations are genetically and ecologically well separated from the summer- and fall-run populations that exist in the lower parts of many of the same river systems. Morphological differences and meristic traits also distinguish stream and ocean types in the Columbia and Snake River Basins (Schreck et al. 1986).

Rivers in this ESU drain the east slopes of the Cascade Range and are fed primarily by snowmelt. The waters tend to be cooler and less turbid than the Snake and Yakima Rivers to the south. Although these fish appear to be closely related genetically to stream-type chinook salmon in the Snake River, the BRT recognized substantial ecological differences between the Snake and Columbia Rivers, particularly in the upper tributaries favored by stream-type chinook salmon. Allozyme data demonstrate even larger differences between spring-run chinook salmon populations from the mid- and upper Columbia River.

Artificial propagation programs have had a considerable influence on this ESU. During the Grand Coulee Fish-Maintenance Project (GCFMP 1939-43), all spring-run chinook salmon reaching Rock Island Dam, including those destined for areas above Grand Coulee Dam, were collected, and they or their progeny were dispersed into streams in this ESU (Fish and Hanavan 1948). Some ocean-type fish were undoubtedly also incorporated into this program. Spring-run escapements to the Wenatchee, Entiat, and Methow Rivers were severely depressed prior to the GCFMP but increased considerably in subsequent years, suggesting that the effects of the program may have been substantial. Subsequently, widespread transplants of Carson stock spring-run chinook salmon (derived from a mixture of Columbia River and Snake River stream-type chinook salmon) have also contributed to erosion of the genetic integrity of this ESU. Nevertheless, the majority of the BRT felt that, in spite of considerable homogenization, this ESU still represents an important genetic resource, in part because it presumably contains the last remnants of the gene pools for populations from the headwaters of the Columbia River. A minority of the BRT felt that chinook salmon in this area should be considered part of a larger ESU that includes other Columbia River (and perhaps Snake River) populations of stream-type chinook salmon.

14) Snake River Fall-Run ESU

This ESU, which includes ocean-type fish, was identified in an earlier status review (Waples et al. 1991b, NMFS 1992) based on genetic, life history, and ecological differences between Columbia and Snake River populations. In that status review and in a later review of mid-Columbia River summer-run chinook salmon (Waknitz et al. 1995), the ESU status of populations from Marion Drain and the Deschutes River was not resolved, so these issues were considered in the current review. Both populations show a greater genetic affinity to Snake River fall chinook salmon than to other ocean-type Columbia River populations.

As the origin of both of these populations is uncertain, the BRT considered several possible alternative hypotheses. The Marion Drain is an irrigation channel dug early in this century that is used to return irrigation water to the Yakima River. Perhaps because of the relative inhospitability of the mainstem Yakima River, the channel appears to be favored by spawning chinook salmon and other species. Obviously, the current population is not native to this artificial channel, but it may represent a native population that at one time inhabited the mainstem Yakima River or other nearby areas. Under this scenario, the fish in Marion Drain might better reflect the historical Yakima River fall chinook salmon than do fish currently spawning in the mainstem, which is heavily stocked with fish from the Priest Rapids/Bonneville Hatchery upriver "bright" stock. The genetic affinity between the Marion Drain and Snake River fish thus might reflect a historical link between areas that share some ecological similarities (e.g., relatively high summer water temperatures). Alternatively, the current population might have colonized Marion Drain from the Snake River more recently, perhaps as Snake River fish were displaced from their historic spawning areas by the series of impassable dams in Hells Canyon or by flooding of habitat by the four dams on the lower Snake River. Finally, the current Marion Drain population might be the result of stock transfers during the past several decades. Several possible scenarios involving stock transfers have been hypothesized, but the BRT found no direct evidence to substantiate them. In either of these latter two scenarios, the Marion Drain fish would be considered an introduced population and therefore not an ESA issue, except perhaps as a reserve source of genetic material for the listed Snake River population.

After considerable discussion, the majority of the BRT concluded that chinook salmon spawning in the Marion Drain could not with any certainty be assigned to any historic or current ESU.

The Deschutes River historically supported a population of fall chinook salmon, as evidenced by counts of fish at Sherars Falls in the 1940s. Genetic and life-history data for the current population indicate a closer affinity to fall chinook salmon in the Snake River than to those in the Columbia River. Similarities were observed in the distribution of CWT ocean recoveries for Snake River and Deschutes River fall-run chinook salmon; however, information on Deschutes River fish was based on a limited number of releases over a relatively short time frame. One hypothesis is that these similarities reflect a historic relationship between populations in the Deschutes and Snake Rivers. Another hypothesis is that displacement of Snake River fish by construction of John Day Dam and/or the lower Snake River dams led to colonization of the Deschutes River by Snake River fish and interbreeding with, or replacement of, the native fish. There was a considerable increase in the run-size of fall chinook salmon in the Deschutes River following the construction of John Day Dam, although it has been suggested that these fish may have been local mainstem spawners whose spawning areas were inundated (Nehlsen 1995). Coded-wire-tag data indicate that straying by non-native chinook salmon into the Deschutes River is very low and does not appear to be disproportionately influenced by Snake River fall-run chinook salmon (Hymer et al. 1992b).

After considerable discussion, a plurality of the BRT concluded that the Deschutes River population should be considered part of the Snake River Fall-Run ESU. Separate minorities favored two other scenarios: 1) The Deschutes River population is part of a separate ESU that historically also included ocean-type fish in the Umatilla, John Day, and Walla Walla Rivers. Populations in the later three rivers are considered to be extinct (Kostow 1995). 2) All ocean-type chinook salmon upstream of the historical site of Celilo Falls (approximately the location of the Dalles Dam) belonged to one ESU. A further minority was undecided on the ESU status of these populations. All of the BRT members were concerned about the lack of definitive information for the Deschutes River population(s).

15) Snake River Spring- and Summer-Run ESU

This ESU, which includes populations of spring- and summer-run chinook salmon from the Snake River Basin (excluding the Clearwater River), was identified in a previous status review (Waples 1991, NMFS 1992). These populations show modest genetic differences, but substantial ecological differences, in comparison with Columbia River stream-type populations. Populations from this ESU emigrate to the ocean as yearlings, mature at ages 4 and 5, and are rarely taken in ocean fisheries. The majority of the spawning habitat occurs in the Northern Rockies and Blue Mountains ecoregions. A minority of the BRT felt this ESU should be combined with stream-type spring-run chinook salmon from the Columbia River.

Relationship to State Conservation Management Units

Marshall et al. (1995) identified Major Ancestral Lineages (MALs) and Genetic Diversity Units (GDUs=subsets of MALs) for chinook salmon in Washington State. This effort, which seeks to identify the existing amount and patterns of genetic diversity within the state, supports the goals of the Wild Salmonid Policy under development by state and tribal fishery managers and is intended to facilitate its implementation. The terminology (GDUs and MALs) differs somewhat from that of previous documents prepared by WDW and WDFW (Leider et al. 1995). According to Busack and Marshall (1995), GDU designations were based on a combination of genetic, life history/ecological, and physiographic/ecoregion data.

ODFW has designated Gene Conservation Groups (GCGs) for salmonid and non-salmonid fishes (Kostow 1995). These designations are part of the implementation of the Oregon Wild Fish Management Policy and Wild Fish Gene Resource Conservation Policy. The definition of the GCG is roughly equivalent to WDFW’s GDU and considers similar criteria: genetic, meristic, geographic, and life-history differences. In addition, ODFW has presented NMFS with specific recommendations for ESU boundaries (ODFW 1995).

Comparison of proposed ESUs with state conservation management groups is complicated in some cases by the restricted scope of the state evaluations. For example, ESUs

can extend across state (or even international) borders, but Washington and Oregon generally only considered populations within their respective state boundaries. Nevertheless, comparison of proposed ESUs for chinook salmon with Washington's GDUs and MALs supports the prediction by Marshall et al. (1995) that individual ESUs would often include multiple GDUs but would be unlikely to include multiple MALs. The Puget Sound ESU and Washington Coast ESU generally correspond to the WDFW Puget Sound Chinook salmon MAL and Coastal and Strait of Juan de Fuca Chinook salmon MAL, with the exception of the Elwha and Dungeness River populations, which WDFW placed in the Coastal and Strait of Juan de Fuca MAL
(Table 4).

The boundaries for ESUs on the Oregon coast correspond with one of the scenarios recommended by ODFW. The Oregon Coast ESU includes five GCGs from the Elk River to the Nehalem River and Elk Creek. The Oregon portion of the Southern Oregon and California Coastal ESU is composed of a single GCG (Table 5).

The Lower Columbia River ESU incorporates several GCGs and generally agrees with the ODFW recommendation for an ESU. The Willamette River ESU also corresponds to an ESU suggested by ODFW; however, whereas ODFW considers spring-run chinook salmon in the Clackamas and Sandy Rivers to be part of this ESU, the BRT considered these to be introduced populations.

The Mid-Columbia Spring-Run ESU contains portions of the Upper Columbia and Snake Spring Chinook Salmon MAL and Upper Columbia Summer and Fall, Snake Fall, and Mid & Lower Columbia MAL. The Klickitat River was determined by WDFW to belong to a separate Lower and Mid-Columbia MAL relative to the other rivers in this ESU, in contrast to ODFW’s recommendation to group the Klickitat, Deschutes, and John Day Rivers into one ESU. ODFW grouped the Deschutes River and John Day River spring-run chinook salmon into the Mid-Columbia Spring GCG, which historically would have also included the now extinct Hood, Umatilla, and Walla Walla River spring chinook salmon runs. It is not clear whether ODFW considered the Yakima River in their evaluations. The Upper Columbia Spring-Run ESU

Table 4. How the Washington Department of Fish and Wildlife's genetic diversity units (GDUs) and major ancestral lineages (MALs) correspond to ESUs (Marshall et al. 1995).

MAL/GDU	ESU
I. Upper Columbia and Snake Spring Chinook MAL	
1. Snake River Spring GDU	15
2. Upper Columbia River Spring GDU	13
3. Yakima River Spring GDU	11
II. Upper Columbia Summer + Fall, Snake Fall, and Mid & Lower Columbia Chinook MAL	
4. Upper Columbia River Summer GDU	12
5. Upper Columbia River Fall GDU	12
6. Mid-Columbia and Snake River Fall GDU	12,14
7. Mid- & Lower Columbia River Spring GDU	9,11
8. Mid-Columbia River "Tule" Fall GDU	9
9. Lower Columbia River "Bright" Fall GDU	9
10. Lower Columbia River "Tule" Fall GDU	9
III. Coastal and Strait of Juan de Fuca Chinook MAL	
11. South Coast Fall GDU	7
12. Chehalis River Spring GDU	7
13. North Coast Fall GDU	7
14. North Coast Spring GDU	7
15. Western Strait GDU	7
16. Eastern Strait GDU	8
IV. Puget Sound Chinook MAL	
17. South Puget Sound, Hood Canal, & Snohomish River Summer + Fall GDU	8
18. South Puget Sound Spring GDU	8
19. Stillaguamish & Skagit GDU	8
20. South Fork Nooksack Spring GDU	8
21. North Fork Nooksack Spring GDU	8

Table 5. How ESUs and the Oregon Department of Fish and Wildlife's genetic conservation groups (GCG) correspond (Kostow 1995).

ESU	**GCG**
4) So. Oregon and California Coast	South Coast: Euchre Creek to Oregon/California
6) Oregon Coast	Nehalem/Ecola River North-Mid Coast: Tillamook Bay to Siuslaw River Umpqua River Basin Mid-South Coast: Coos Bay to Elk River
9) Lower Columbia River	Lower Columbia Fall Sandy River Fall
10) Willamette River Spring	Willamette River Spring*
11) Middle Columbia River Spring Run	Mid-Columbia River Spring
14) Snake River Fall Run	Deschutes River Fall
15) Snake River Spring and Summer Run	Snake Spring/Summer

* GCG includes Sandy and Clackamas spring run; however, these populations were not included in the ESU.

corresponds with the Upper Columbia Spring Genetic Diversity Unit (GDU), which is a subunit of the larger Upper Columbia and Snake Spring Chinook salmon MAL designated by WDFW.

The Upper Columbia Summer- and Fall-Run ESU boundaries incorporate two GDUs designated by WDFW within the Upper Columbia Summer and Fall, Snake Fall, and Mid & Lower Columbia MAL. The WDFW GDUs include introduced “upriver bright” fall chinook salmon in the Klickitat, White Salmon, and Wind Rivers that were not considered by the BRT.

The Snake River Fall-Run ESU is geographically a component of the Mid-Columbia and Snake Fall Chinook salmon GDU designated by WDFW. This GDU includes upriver “brights” from the Hanford Reach, lower Yakima River, and Marion Drain, in addition to the Snake River fall-run chinook salmon. ODFW has designated separate GCGs for Deschutes and Snake River fall chinook salmon, and recommend that the Deschutes River fall chinook salmon constitutes its own ESU.

The Snake River Spring- and Summer-Run ESU includes the WDFW Snake River Spring GDU, ODFW Snake Spring/Summer GCG, and other populations in Idaho.

Relationship to ESU Boundaries for other Anadromous Pacific Salmonids

The historic distribution and life history of chinook salmon most closely resembles those of coho salmon and steelhead. Ocean-type chinook salmon prefer to spawn in mainstem rivers and larger tributaries with relatively low gradients and generally have a shorter freshwater residence time than do coho salmon and steelhead in the same geographic area. In comparing coastal ESU boundaries, because of their preference for smaller systems to spawn in and extended freshwater rearing period, steelhead and coho salmon probably exhibit a finer scale of ecological adaptation than do ocean-type chinook salmon. Conversely, in inland regions stream-type chinook salmon and steelhead express similar life-history strategies and there is a greater similarity in ESU boundaries. Differences in ESU boundaries among these species may also be related to artificial propagation practices and anthropogenic changes in habitat quality or access.

The boundaries for the Central Valley Fall-Run ESU correspond to those for the Central Valley Steelhead ESU. Chinook and coho salmon (Weitkamp et al. 1995) and steelhead (Busby et al. 1996) ESU designations for coastal California and southern Oregon are quite different, except that all three share a common boundary at Cape Blanco, on the Oregon Coast (Fig. 25). Cape Blanco is a recognized biogeographical transition zone for aquatic organisms. In the steelhead and coho salmon ESU determinations, the Klamath River Basin was incorporated with coastal systems, whereas it is proposed as a separate ESU for chinook salmon. In other coastal areas the Oregon Coast and Puget Sound ESUs were generally the same for all three species.

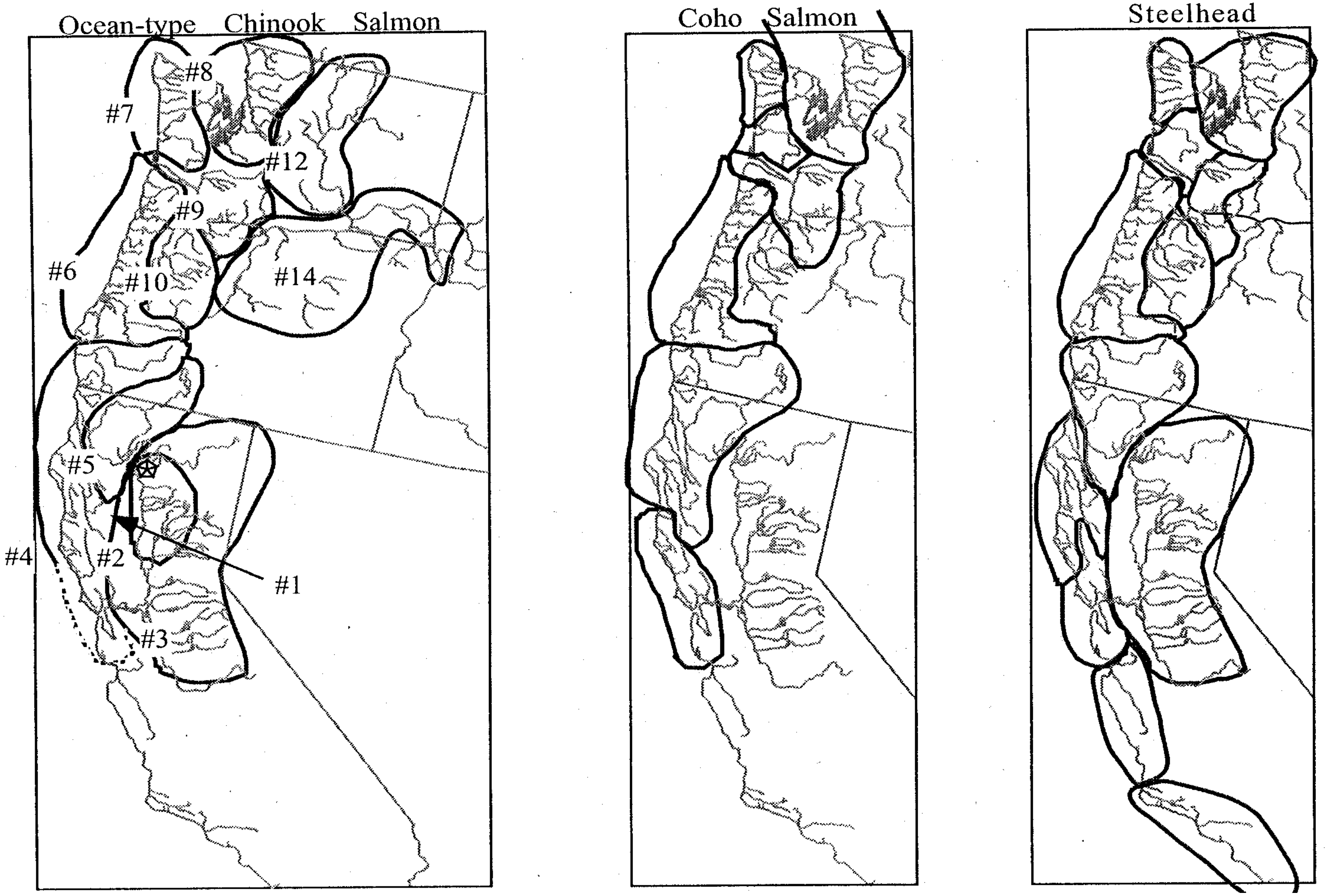


Figure 25. Comparisons between proposed ESU boundaries for ocean-type chinook salmon and ESU boundaries of coho salmon (Weitkamp et al. 1995) and steelhead (Busby et al. 1996) for coastal populations in Washington, Oregon, California, the Sacramento, Klamath, and Columbia river basins.

The ESU boundaries for the chinook salmon Washington Coast ESU encompasses the steelhead Olympic Peninsula ESU and a portion of the Southwest Washington ESU, as well as the coho salmon Olympic Peninsula and Southwest Washington Coast ESUs.

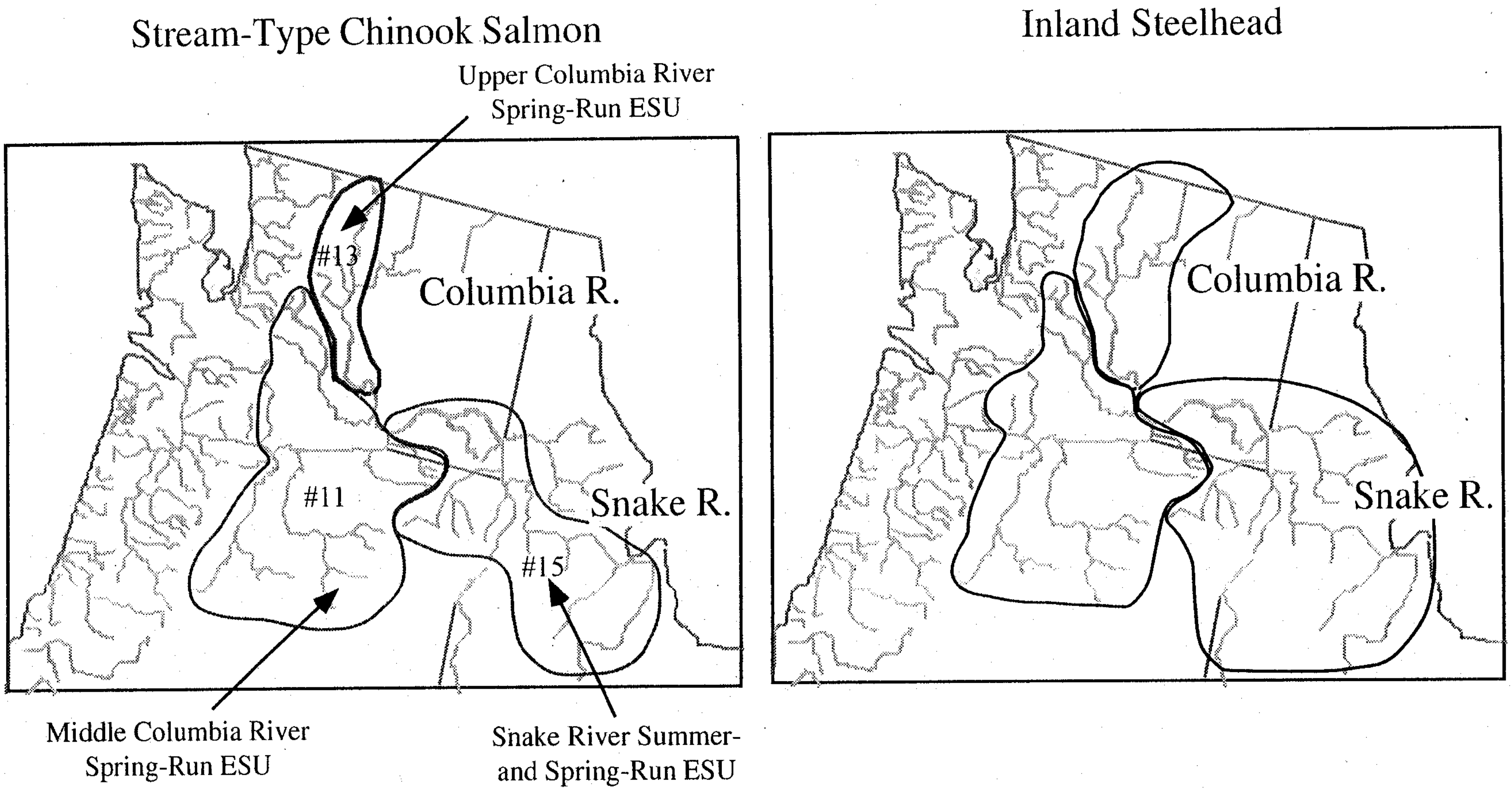
The Lower Columbia River ESU incorporates portions of ESUs designated for coho salmon and steelhead, but most notably shares similar geographic boundaries at the Willamette Falls, the Oregon Coast, and the Cascade Crest. The Willamette River, above Willamette Falls, forms a geographically defined area that contains separate chinook salmon and steelhead ESUs.

Beyond the Cascade Crest, native coho salmon populations have been extirpated. The three stream-type chinook salmon ESUs east of the Cascades correspond almost exactly with those for steelhead (Fig. 26). The ESUs for ocean-type chinook salmon east of the Cascades have no analogue in steelhead ESU designations.

Artificial Propagation

NMFS policy (Hard et al. 1992; NMFS 1993) stipulates that in determining 1) whether a population is distinct for purposes of the ESA, and 2) whether an ESA species is threatened or endangered, attention should focus on "natural" fish, which are defined as the progeny of naturally spawning fish (Waples 1991a). This approach directs attention to fish that spend their entire life cycle in natural habitat and is consistent with the mandate of the ESA to conserve threatened and endangered species in their native ecosystems. Implicit in this approach is the recognition that fish hatcheries are not a substitute for natural ecosystems.

Nevertheless, artificial propagation is important to consider in ESA evaluations of anadromous Pacific salmonids for several reasons. First, although natural fish are the focus of ESU determinations, possible effects of artificial propagation on natural populations must also be evaluated. For example, stock transfers might change the genetic bases or phenotypic expression of life-history characteristics in a natural population in such a way that the population might seem either less or more distinctive than it was historically. Artificial propagation can also alter life-history characteristics such as smolt age and migration and spawn timing (e.g., Crawford 1979, NRC 1996). Second, artificial propagation poses a number of risks to natural populations that may affect their risk of extinction or endangerment. These risks are discussed below in the "Assessment of Extinction Risk" section, p. 177. Finally, if any natural populations are listed under the ESA, then it will be necessary to determine the ESA status of all associated hatchery populations. This latter determination would be made following a proposed listing and is not considered further in this document. The remainder of this section is intended to provide a summary of the nature and scope of artificial propagation activities for west coast chinook salmon and to identify influences of artificial propagation on natural populations.


Stream-Type Chinook Salmon

Inland Steelhead

Figure 26. Comparison between proposed ESU boundaries for stream-type chinook salmon and ESU boundaries for inland steelhead (Busby et al. 1996) for populations in the Upper Columbia River Basin (upstream from the Cascade Crest).

Overview of Artificial Propagation

The focus of the Artificial Propagation section concerns the culture of chinook salmon in individual ESUs. To provide some perspective with respect to the magnitude of propagation efforts along the West Coast, a brief review of chinook salmon culture in areas outside the continental United States will be given here. In addition, we will provide a short review of important events in the history of artificial propagation of chinook salmon in the Columbia River Basin will be presented, as 7 of the 15 chinook salmon ESUs are located in this large river system.

Asia and Oceania

Japan—Although spawning chinook salmon have been observed in Japanese streams (Healey 1991), there appear to have been few, if any, large-scale chinook salmon programs in Japanese hatcheries, although experimental releases of Washington State chinook salmon have occurred (McNeil 1977).

Russia—Spawning populations of chinook salmon are found in large rivers of eastern Russia; however, the overwhelming majority of effort regarding artificial propagation has been devoted to sockeye and chum salmon (Atkinson 1960, Konovalov 1980). Experiments to investigate the effects of hatchery culture on chinook salmon biology have been conducted (Pisarevsky 1978, Smirnov et al. 1994) with the goal of developing hatchery chinook salmon for harvest (Smirnov et al. 1994).

New Zealand—Attempts to introduce chinook salmon to New Zealand waters in the 1870s were not successful; however, transplants of Sacramento River chinook salmon in 1901 successfully established self-sustaining anadromous and landlocked populations, as well as providing broodstock for subsequent artificial propagation programs (McDowall 1994). By 1925, the naturalized chinook salmon had produced 1.5 million eggs for distribution in New Zealand streams (Lever 1996). Artificial propagation of chinook salmon in New Zealand remains an important component of management of the species (Unwin 1997).

North America

Alaska—Hatcheries in Alaska have been used to mitigate overharvest and to provide harvest opportunities, whereas hatcheries in the lower 48 States have usually been operated to mitigate for destruction and blockage of habitat. In the early days of the Alaskan salmon fishery, hatcheries were used as a means of assurance against the adverse effects of commercial fishing (Roppel 1982). The first federal hatchery in Alaska was built on a lake at Yes Bay in Southeast Alaska in 1905, and a second federal facility was built on Afognak Island in 1908 (Roppel 1982). During this period, legislation in Alaska required canneries to operate hatcheries, although few companies complied. Nonetheless, by 1920 there were at least four private hatcheries in the state, as well as several federal facilities inovlved in the propagation of Pacific salmon (Heard 1985, Heard et al. 1995). Hatchery efforts were directed primarily at the premier commercial species in Alaska, sockeye salmon; other salmon species, including chinook salmon, were reared on an experimental basis.

Occasional attempts to establish runs of non-native chinook salmon were made in Alaska. Between 1923 and 1926, chinook salmon originating from the Columbia River and unspecified locations in Washington State were released into lakes and rivers near Cordova, (571,000 “Washington” chinook salmon), Seward (1,387,000 “Washington” chinook salmon) and near Ketchican (1,952,000 Kalama River, 972,500 “lower Columbia River,” and 1,819,000 “Washington” chinook salmon) (Roppel 1982). Not long afterward, Alaska abandoned the concept of using hatcheries to augment natural production, as hatchery releases had not resulted in increases in fish abundance. This may have been related to the poor hatchery practices of that era and general large-scale increases in harvest (Roppel 1982). After a hiatus of two decades, chinook salmon production was resumed at several hatcheries in 1955 in Southeast Alaska and near Anchorage (Wahle and Smith 1979), although production numbers for the state have been relatively low until recently. For example, between 1975 and 1982, a total of 4.7 million fish, or about 597,000 chinook salmon juveniles annually, were released in Alaskan waters. Since 1983, total hatchery production has increased to 73 million fish, or about 7.3 million fish per year (Fig. 27). Much of the increased production has resulted from legislation permitting the operation of private, non-profit hatcheries (McNair 1996). As of 1992, seven private, three state, and one federal hatchery accounted for almost all chinook salmon hatchery production in Alaska (NRC 1996). In Alaska, the majority of chinook salmon stocks exhibit a stream-type life-history, therefore the majority of hatchery fish are released as yearling smolts (NRC 1996).

British Columbia—The first British Columbia salmon hatchery was constructed in 1884 near Westminster, on the Fraser River. Although sockeye salmon were the principal focus of this and other early hatcheries in this province, a few chinook salmon were released as well (Wahle and Smith 1979). Between 1903 and 1927, 72 million chinook salmon were released into British Columbian waters, three-quarters of these into the Fraser River Basin (Cobb 1930). Production during this period peaked in 1908 with the release of 7.5 million chinook salmon (Cobb 1930). However, as in Alaska, there was no apparent increase in the abundance of sockeye salmon, and it became apparent that the artificial propagation of sockeye salmon in British Columbia did not result in a significant increase in efficiency over natural production in areas where there was a reasonable expectation of successful natural propagation (Foerster 1968). By 1930, salmon hatcheries were no longer operating in British Columbia (Foerster 1968, Wahle and Smith 1979). Economic restrictions resulting from the Great Depression and World War II further constrained the ability of the provincial government to initiate hatchery programs. Hatchery production of salmonids was not reestablished in British Columbia until 1967 with the construction of the Big Qualicum Hatchery on Vancouver Island (Wahle and Smith 1979). Artificial propagation efforts

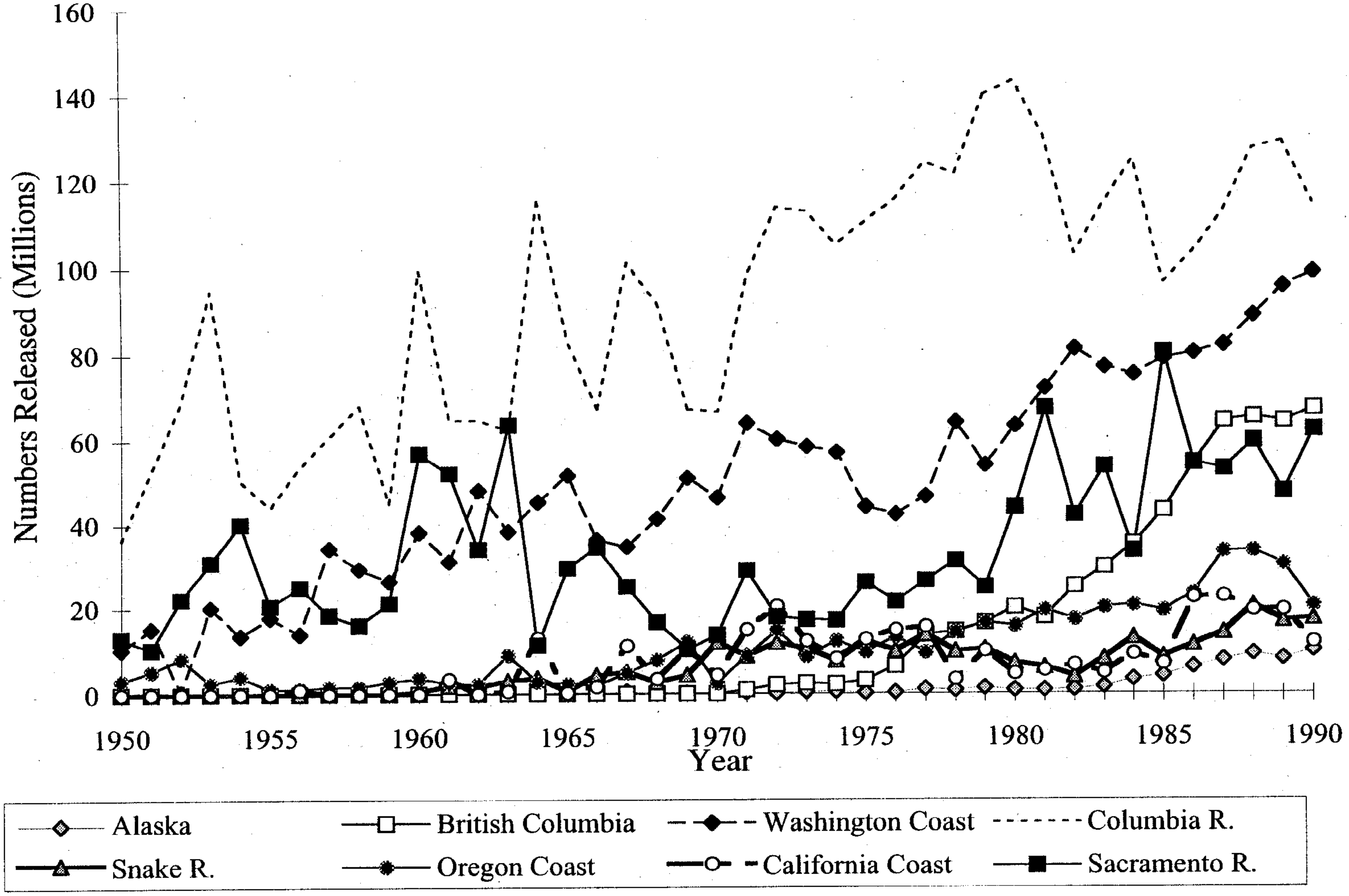


Figure 27. Annual releases

of juvenile chinook salmon from artificial propag ation facilities in different North American regi ons from 1950-90 (from Mahnken et al. 1997).

accelerated after the launching of the Salmonid Enhancement Program (SEP) in 1977, which was designed to double harvest levels and preserve, rehabilitate, and enhance natural salmonid stocks (Winton and Hilborn 1994). Since that time, the total chinook salmon hatchery effort in British Columbia has expanded to include 50 major (>40,000 juvenile fish released annually) and about 20 minor (<40,000 juvenile fish released annually) fish rearing facilities (NRC 1996). Total chinook salmon production for the period 1975 to 1982 was about 94.7 million juveniles for an average of just under 12 million fish per year. However, to meet expanding harvest demands, hatchery production between 1983 and 1992 increased to 562 million fish, about 56 million fish annually. New propagation/release strategies are being employed to rebuild or enhance British Columbia chinook salmon stocks, especially in lower Georgia Strait streams. These new methods include rearing juveniles to smolt in net-pens in lakes, extended rearing of smolts in sea pens, and maintaining captive broodstocks in sea pens to increase egg availability (Cross et al. 1991). Unlike many chinook salmon hatcheries in the United States (see below), British Columbia hatchery broodstocks have been established using local stocks, although, in some cases, centralized hatcheries are used for the enhancement of many different river-specific stocks within a region (Cross et al. 1991). The contribution from SEP hatcheries varied between 5.3% and 18.6% of the total British Columbia chinook salmon catch from 1978 through 1989 (Winton and Hilborn 1994).

Columbia River Basin—Artificial propagation in the Columbia River basin initially developed following the expansion of the commercial fishery, with the first Columbia River hatchery built in 1876 on the Clackamas River and operated by a cannery interest (CBFWA 1990b). State and federal hatchery operations to enhance commercial fisheries began soon afterward, and by the 1890s, many hatcheries and egg-taking stations were in operation between the Chinook River at the mouth of the Columbia River and the Little Spokane River in the upper basin (CBFWA 1990b). By 1905, about 62 million fry were released annually; however, due to poor returns to these hatcheries, support for Columbia River hatcheries waned shortly thereafter (CBFWA 1996). After the late 1930s, the negative effects of agricultural development, timber activities and other land use practices, and the initial development of the Columbia River dam complex, resulted in an increased need to mitigate for reduced natural production (CBFWA 1990b). Between 1957 and 1975, eleven new mainstream dams were constructed on the Columbia and Snake Rivers, resulting in further loss of habitat and increased migrational mortality. Although fish passage facilities were generally successful at low dams, their efficacy was not great at high dams, which constituted most of the dams built during this later period (CBFWA 1990b). Therefore, artificial production appeared to be the only means available to fish managers to compensate for fish losses and the resulting decline in fish available for harvest. Several of these mitigation programs will be briefly discussed here.

Grand Coulee Fish Maintenance Project—After the construction of the Grand Coulee Dam (RKm 959) in 1939, which completely eliminated passage of anadromous salmon above that point, the federal government initiated the Grand Coulee Fish Maintenance Project (GCFMP), which lasted from 1939 to 1943. The GCFMP sought to maintain fish runs in the Columbia River above Rock Island Dam (RKm 730) by two means: 1) improving salmonid habitat, and 2) establishing hatcheries (Fish and Hanavan 1948).

Adult chinook salmon passing Rock Island Dam from 1939 to 1943 were taken either to USFWS hatcheries on the Wenatchee or Methow Rivers for artificial spawning or to fenced reaches of the Wenatchee or Entiat Rivers for natural spawning. Juveniles derived from adults passing over Rock Island Dam were reared at USFWS hatcheries and transplanted into the Wenatchee, Methow, and Entiat Rivers.

Fish trapping operations began in May 1939, and continued through late fall each year until 1943. A total of five brood years were affected. Early-run fish (stream type) were treated separately from late-run fish (ocean type), but few distinctions were made regarding either the so-called "summer" or "fall" components of the late run, as all late-run fish were captured. The GCFMP continued for five years and intercepted all chinook salmon passing Rock Island Dam, including those destined for now inaccessible spawning areas in British Columbia. As a result, all present day chinook salmon above Rock Island Dam are the progeny of the mixture of chinook salmon collected at Rock Island Dam from 1939 to 1943 (Waknitz et al. 1995).

Chinook salmon spawning channels—Artificial spawning channels for ocean-type chinook salmon were operated during the 1960s and 1970s near Priest Rapids (1963-71), Turtle Rock (1961-69), and Wells Dam (1967-77), but were discontinued in favor of more traditional hatchery methods due to high pre-spawning mortality in adult fish and poor egg survival in the artificial spawning beds (CBFWA 1990b, Chapman et al. 1994).

Mitchell Act—In 1938, in response to the construction of Bonneville and Grand Coulee Dams, Congress passed the Mitchell Act, which required the construction of hatcheries to compensate for fish losses caused by these dams and by logging and pollution (Mighetto and Ebel 1994). An amendment to the Mitchell Act in 1946 led to the development of the Lower Columbia River Fishery Development Plan (CRFDP) in 1948, which initiated the major phase of hatchery construction in the Columbia River Basin (CBFWA 1990b). In 1956, the CRFDP was expanded to include the upper Columbia River and Snake River Basins. Although the majority of lost natural salmonid production to be mitigated by the Mitchell Act was located in the upper Columbia River and Snake River basins, only 4 of the 39 facilities eventually authorized by this Act were constructed above Dalles Dam on the lower Columbia River, partly due to concerns regarding the ability of fish to bypass dams in the upper basin, and partly because the primary goal was to provide fish for harvest in the ocean and lower river (CBFWA 1990b, 1996).

Lower Snake River Fish and Wildlife Compensation Plan—The Lower Snake River Fish and Wildlife Compensation Plan (LSRCP) was authorized by Congress in 1976 to replace lost salmonid production caused by fish passage problems at four U.S. Army Corps of Engineer (COE) dams in the lower Snake River (CBFWA 1990b). To date, 22 facilities have been constructed under the LSRCP, including hatcheries and acclimation ponds. In general, LSRCP facilities have had more success in increasing the abundance of steelhead than chinook salmon (Mighetto and Ebel 1994).

U.S. Army Corps of Engineers—The Corps of Engineers (COE) has funded the construction or expansion of 19 hatcheries as mitigation for fish losses caused by COE hydroelectric programs throughout the entire Columbia River basin, including the building of 12 dams in the Willamette River basin between 1941 and 1968 (CBFWA 1990b). Many hatcheries constructed under the Mitchell Act were funded by COE.

Public and private power generators—These non-governmental entities have funded the construction and/or operation of 16 artificial propagation facilities in the Columbia River basin as compensation for lost fish production due to their water-use projects. Utilities and companies participating in Columbia River fish culture operations include Chelan, Douglas and Grant County PUDs in Washington (ESUs 12 and 13), Idaho Power Company (ESUs 14 and 15), Portland General Electric (ESUs 9 and 11), Tacoma City Light (ESU 9), and Pacific Power and Light (ESU 9) (CBFWA 1990b).

Scale of Hatchery Production

West Coast hatchery production of chinook salmon is summarized in Table 6, with data taken from a database developed under contract to NMFS (NRC 1996). Some release information presented here dates back to the turn of the century, but any data prior to 1950—when hatchery records became more reliable—should be considered incomplete.

The ratio of hatchery- to naturally-produced chinook salmon on the West Coast varies from region to region, as well as from watershed to watershed, within a particular ESU, with chinook salmon populations dominated by hatchery production in some areas and maintained by natural production in others (Howell et al. 1985, WDF et al. 1993, Kostow 1995). Large hatchery programs have produced substantial numbers of fish relative to natural production in many West Coast regions, especially in areas where hatcheries have been used to create or enhance harvest opportunities. These areas include many locations in Puget Sound, the majority of watersheds in the Columbia River Basin, several Oregon coastal streams, the Klamath River Basin, and the Sacramento River Basin (Howell et al. 1985; WDF et al. 1993; PFMC 1994,1997; Kostow 1995). A list of the larger chinook salmon artificial propagation facilities operating on the West Coast is provided in Table 7.

Table 6. Summary of hatchery releases of juvenile chinook salmon by ESU during selected years. Releases are broken down into those originating from within or outside the geographic boundaries of the ESU. For reasons explained in the text, these figures may underestimate the percentage of fish introduced from outside the ESU. Data for years before 1960 may not be complete. The full data series is presented in Appendix D.

ESU	Years	Within ESU (1,000s)	Outside ESU (1,000s)	% of Total (Outside ESU)
1) Sacramento River Winter Run	1962-95	347	0	0
2) Sacramento River Spring Run	1943-93	39,180	0	0
3) Central Valley Fall Run	1944-93	1,683,325	876	>1
4) Southern Oregon and California Coast	1953-93	55,623	16,371	23
5) Upper Klamath and Trinity Rivers	1964-94	286,246	43	>1
6) Oregon Coast	1907-93	303,076	94,172	24
7) Washington Coast	1952-93	256,651	61,794	19
8) Puget Sound	1953-93	1,757,915	13,047	1
9) Lower Columbia River	1910-94	3,364,477	233,432	6
10) Upper Willamette River	1902-94	498,670	208,202	29
11) Mid-Columbia River Spring Run	1919-93	57,954	62,746	52
12) Upper Columbia River Summer and Fall Run	1941-93	177,548	14,497	8
13) Upper Columbia River Spring Run	1941-94	63,827	18,808	23
14) Snake River Fall Run	1945-93	27,245	1,595	6
15) Snake River Spring and Summer Run	1914-94	211,197	15,939	7

Table 7. Summary of major west coast chinook salmon artificial propagation facilities. Agency designations: California Fisheries Commission (CFC), California Department of Fish and Game (CDFG), facilities cooperatively operated by state agencies and citizen's groups (COOP), Hoopa Valley Tribe (HVT), Idaho Department of Fish and Game (IDFG), National Marine Fisheries Service (NMFS), Oregon Fisheries Commission (OFC), Oregon Department of Fish and Wildlife (ODFW), private commercial concerns (PRIV), Shoshone-Bannock Tribes of Ft. Hood (ShoBan), U.S. Fisheries Commission (USFC), U.S. Fish and Wildlife Service (USFWS), University of Washington (UW), Washington Department of Fisheries (WDF), Washington Department of Fish and Wildlife (WDFW).

Facility	**Agency**	**Years**	**Location**
1) Sacramento River Winter-Run ESU			
Coleman NFH	USFWS	1962-present	Sacramento River
2) Central Valley Spring-Run ESU			
Coleman NFH	USFWS	1943 to 1952	Sacramento River
Feather River Hatchery	CDFG	1983-present	Feather River
3) Central Valley Fall-Run ESU			
Baird Hatchery	USFC	1872-1936	McCloud River
Sisson (Mt. Shasta) Hatchery	CFC	1888-present	McCloud River
Hat Creek Hatchery	CFC	1885-1888	Pitt River
Battle Creek Hatchery	CFC	1895-1943	Battle Creek
Coleman NFH	USFWS	1943-present	Sacramento River
Tehama-Colusa Hatchery	CDFG	1972-present	Sacramento River
Mill Creek Hatchery	USFC	1902-1945	Mill Creek
Feather River Hatchery	CDFG	1968-present	Feather River
Nimbus Hatchery	CDFG	1957-present	American River
Mokelumne Hatchery	CDFG	1964-present	San Joaquin River
La Grange Hatchery	CDFG	1991-present	San Joaquin River
Tuolumne Hatchery	CDFG	1990-present	Tuolumne River
Merced River Hatchery	CDFG	1971-present	San Joaquin River
4) Southern Oregon and California Coastal ESU			
Cole Rivers Hatchery	ODFW	1975-present	Rogue River
Butte Falls Hatchery	ODFW	1954-1990	Rogue River
Indian Creek Pond	COOP	1969-present	Rogue River
Pistol River Hatchery	ODFW	1989, 1990	Pistol River
Jack Creek Hatchery	ODFW	1989-1991	Chetco River
Winchuck River Hatchery	ODFW	1989, 1990	Winchuck River
Pacific Salmon Ranch	PRIV	1984-1990	Burnt Hill Creek
Rowdy Creek Hatchery	CDFG	1985-present	Smith River
Cappel Creek Hatchery	USFWS	1987-present	Klamath River
High Prairie Creek	USFWS	1991-present	Klamath River
Redwood Creek	CFC	1893-1897	Redwood Creek

Table 7 (Cont.).

L Pond	CDFG	1986-1992	Little River
Korbel	CFC	1893-1897	Mad River
Mad River Hatchery	CDFG	1971-present	Mad River
Price Creek	CFC	1897-1916	Eel River
Copper Mill Creek	COOP	1988-present	Eel River
Van Arsdale Hatchery	CDFG	1972-1984	Eel River
Fort Seward	CFC	1916-1943	Eel River
Redwood Creek Pond	CDFG	1985-present	Eel River
Hollow Tree Creek Ponds	COOP	1980-present	Eel River
CA Coop	COOP	1980-present	Eel River
Sprowel Creek Ponds	COOP	1984-1988	Eel River
Warm Springs Hatchery	CDFG	1982-present	Russian River
Tiburon	NMFS	1978-1980	San Francisco Bay
Silverking Farms	PRIV	1980-1985	Davenport Landing
5) Upper Klamath and Trinity Rivers Spring- and Fall-Run ESU			
Fall Creek	CFC	1919-1948	Klamath River
Iron Gate	CDFG	1966-present	Klamath River
Klamathon	CFC	1910-1940	Klamath River
Spruce Creek	USFWS	1991, 1992	Klamath River
Indian Creek	CDFG	1981-present	Klamath River
Elk Creek	CDFG	1989-1991	Klamath River
Bluff Creek	CDFG	1989-present	Klamath River
Sawmill Ponds	COOP	1987, 1988	Trinity River
Mill Creek	COOP	1986-1988	Trinity River
Supply Creek	CDFG/HVT	1985-present	Trinity River
Horse Linto Creek	CDFG	1986-present	Trinity River
Trinity Hatchery	CDFG	1961-present	Trinity River
6) Oregon Coast ESU			
Nehalem Hatchery	ODFW	1921-1982	Nehalem River
Trask Hatchery	ODFW	1907-present	Trask River
Tuffy Creek Hatchery	ODFW	1989-present	Trask River
Cedar Creek Hatchery	ODFW	1959-present	Nestucca River
Salmon River Hatchery	ODFW	1977-present	Salmon River
Siletz Hatchery	ODFW	1948-1974	Siletz River
Ore-Aqua Yaquina	PRIV	1975-1989	Yaquina Bay
Fall Creek Hatchery	ODFW	1975-present	Alsea River
Alsea River Hatchery	ODFW	1902-1980	Alsea River
Rock Creek Hatchery	ODFW	1956-present	North Umpqua River
Umpqua River	ODFW	1988-present	South Umpqua River
Coos River	ODFW	1901-1958	Coos River
Noble Creek	ODFW	1990-present	Coos River
Anadromous Inc.	PRIV	1978-1989	Coos Bay
Bandon Hatchery	ODFW	1956-present	Coquille River
Elk River	ODFW	1969-present	Elk River

7) Washington Coast ESU			
Hoko Pond	Makah Tribe	1984-present	Hoko River
Makah NFH	USFWS	1982-present	Sooes River
Bear Springs Hatchery	WDFW	1980-present	Sol Duc River
Solduc Hatchery	WDFW	1971-present	Sol Duc River
Lonesome Creek Hatchery	Quillayute Tribe	1988-present	Quillayute River
Chalaat Creek Hatchery	Hoh Tribe	1977-1985	Hoh River
Salmon River Pond	Quinault Tribe	1989, 1990	Queets River
Quinault Lake	Quinault Tribe	1975-present	Quinault River
Quinault NFH	USFWS	1969-present	Quinault River
Humptulips Hatchery	WDFW	1977-present	Humptulips River
Simpson Hatchery	WDFW	1950-present	Chehalis River
Satsop Springs Pond	WDFW	1980-1989	Chehalis River
Elama Game Association Hatchery	COOP	1990-present	Chehalis River
Lower Chehalis Pond	WDFW	1987-present	Chehalis River
Long Live The Kings Hatchery	WDFW/COOP	1990, 1991	Wishkah River
Wishkah Ponds	COOP	1988-1992	Wishkah River
Pacific Trollers	COOP	1983-1989	Chehalis River
North River Protection Association	COOP	1992-present	North River
Willapa Hatchery	WDFW	1948-present	Willapa River
NWSSC	COOP	1988-1990	Willapa River
Bay Center	COOP	1973-present	Willapa Bay
Willapa Bay Gillnetters	COOP	1977-present	Willapa Bay
Willapa Bay	COOP	1992-present	Willapa Bay
Nemah Hatchery	WDFW	1954-present	Nemah River
Naselle Hatchery	WDFW	1948-present	Naselle River

8) Puget Sound ESU			
Nooksack Hatchery	WDFW	1899-present	Nooksack River
Skookum Creek Hatchery	Lummi Tribe	1974-present	Nooksack River
Mamoya Ponds	Lummi Tribe	1990-present	Nooksack River
NWSSC (Whatcom Co)	COOP	1978-1989	Nooksack River
Glenwood Springs Hatchery	COOP	1984-present	San Juan Island
San Juan Island Net Pens	COOP	1988-1992	San Juan Island
Lummi Sea Ponds	Lummi Tribe	1977-present	North Puget Sound
Whatcom Creek Hatchery	COOP	1982-present	East Puget Sound
Bowmans Bay Hatchery	WDFW	1948-1964	North Puget Sound
Samish Hatchery	WDFW	1899-present	Samish River
Skagit Hatchery	WDFW	1945-present	Skagit River
Oak Harbor Net Pens	COOP	1984-present	North Puget Sound
Puget Sound Anglers	COOP	1991-present	North Puget Sound
Stillaguamish Tribal Hatchery	Stillaguamish T.	1981-present	Stillaguamish River
Skykomish Hatchery	WDFW	1907-present	Skykomish River
Tulalip Hatchery	Tulalip Tribe	1974-present	East Puget Sound

Table 7 (Cont.).

NWSSC (Mukilteo)	COOP	1989-present	East Puget Sound
Laebugten Wharf	COOP	1987-1991	East Puget Sound
Issaquah Hatchery	WDFW	1933-present	Lake Washington
Classroom Community	COOP	1981-1990	Lake Washington
UW College Of Fisheries	UW	1950-present	Lake Washington
Shilshole Bay	COOP	1990, 1991	East Puget Sound
Icy Creek Pond	WDFW	1977-present	Green River
Keta Creek Hatchery	Muckleshoot T.	1979-present	Green River
Lake Youngs School	COOP	1989-1991	Green River
Crisp Creek Hatchery	Muckleshoot T.	1981-1991	Green River
Green River Hatchery	WDFW	1905-present	Green River
Elliot Bay Seapens	COOP	1974-present	Elliot Bay
Seattle Aquarium	COOP	1977-1991	Elliot Bay
NWSSC (Des Moines)	COOP	1984-present	East Puget Sound
White River Hatchery	Muckleshoot T.	1990-present	Puyallup River
Puyallup Hatchery	WDFW	1917-present	Puyallup River
Puyallup Tribal Hatchery	Puyallup Tribe	1980-present	Puyallup River
Narrows Marina Net Pens	COOP	1974-1990	South Puget Sound
NWSSC (Pt Defiance)	COOP	1989, 1990	South Puget Sound
Garrison Springs Hatchery	WDFW	1972-present	Chambers Creek
Schorno Springs Hatchery	WDFW	1977-1989	Nisqually River
Kalama Creek Hatchery	Nisqually Tribe	1980-present	Nisqually River
Clear Creek Hatchery	Nisqually Tribe	1991-present	Nisqually River
Mcallister Creek Hatchery	WDFW	1982-present	Nisqually River
Agate	COOP	1991-present	South Puget Sound
Allison Springs Hatchery	WDFW	1978-1992	South Puget Sound
Zittels Marina Net Pens	COOP	1984-1992	South Puget Sound
Deschutes Facility	WDFW	1971-present	Deschutes River
South Sound Net Pens	COOP	1974-present	South Puget Sound
Squaxin Island Net Pens	WDFW/Squaxin T.	1972-1987	South Puget Sound
Fox Island Net Pens	WDFW	1977-present	South Puget Sound
Coulter Creek Hatchery	WDFW	1979-present	West Puget Sound
Minter Creek Hatchery	WDFW	1936-present	West Puget Sound
Hupp Springs Hatchery	WDFW	1981-present	West Puget Sound
Gorst Creek Rearing Pond	WDFW/Suquamish T.	1972-present	West Puget Sound
Clear Creek Pond	Suquamish T.	1988-present	West Puget Sound
Websters	Suquamish T.	1985-present	West Puget Sound
Grovers Creek Hatchery	Suquamish T.	1979-present	West Puget Sound
Big Beef Creek Hatchery	UW	1972-1985	East Hood Canal
George Adams Hatchery	WDFW	1962-present	Skokomish River
Mckernan Hatchery	WDFW	1980-present	Skokomish River
Skokomish Tribal Hatchery	Skokomish Tribe	1981-present	Skokomish River
Hood Canal Hatchery	WDFW	1953-present	West Hood Canal
Hood Canal Marina	COOP	1991-present	West Hood Canal
Hoodsport Marina	COOP	1992-present	West Hood Canal

Table 7 (Cont.).

Pleasant Harbor Net Pens	COOP	1992, 1993	West Hood Canal
Glenn Ayr Net Pens	COOP	1991-present	West Hood Canal
Hood Canal Net Pens	COOP	1991-present	West Hood Canal
Quilcene NFH	USFWS	1960-present	Quilcene River
Dungeness Hatchery	WDFW	1948-1979	Dungeness River
Elwha Hatchery	WDFW	1976-present	Elwha River
Lower Elwha Hatchery	Elwha Tribe	1983-present	Elwha River
Hurd Creek Hatchery	WDFW	1981-present	Elwha River
Peninsula College	COOP	1972-present	Elwha River
9) Lower Columbia River ESU			
Sea Resource Net Pens	COOP	1972-present	Chinook River
Youngs Bay Net Pens	ODFW	1990-present	Youngs Bay
CEDC	ODFW	1987-present	Youngs Bay
Grays River Hatchery	WDFW	1962-present	Grays River
Weyco Pond	WDFW	1976-1986	Grays River
Grays River Pond	WDFW	1982-present	Grays River
Big Creek Hatchery	ODFW	1941-present	Big Creek
Gnat Creek Hatchery	ODFW	1960-1987	Lower Columbia River
Klaskanine Hatchery	ODFW	1912-1990	Klaskanine River
Klaskanine Pond	ODFW	1981-present	Klaskanine River
Elokomin Hatchery	WDFW	1955-present	Elokomin River
Abernathy NFH	USFWS	1960-present	Abernathy Creek
Cowlitz Hatchery	WDFW	1967-present	Cowlitz River
Olequa Creek. Pond	COOP	1990, 1991	Cowlitz River
Toutle Hatchery	WDFW	1952-present	Toutle River
Speelyai Hatchery	WDFW	1959-present	Lewis River
Lewis Hatchery	WDFW	1909-present	Lewis River
Kalama Falls Hatchery	WDFW	1960-present	Kalama River
Gobar Pond	WDFW	1975-present	Kalama River
Lower Kalama Hatchery	WDFW	1895-present	Kalama River
Sandy Hatchery	ODFW	1901-1977	Sandy River
Clackamas Hatchery	ODFW	1979-present	Clackamas River
Eagle Creek NFH	USFWS	1926-present	Clackamas River
Washougal Hatchery	WDFW	1958-present	Washougal River
Bonneville Hatchery	ODFW	1910-present	Lower Columbia River
Cascade Hatchery	ODFW	1960-1980	Lower Columbia River
Oxbow Hatchery	ODFW	1915-1991	Lower Columbia River
Carson NFH	USFWS	1955-present	Wind River
Lower Wind R	WDF	1899-1938	Wind River
Little White Salmon NFH	USFWS	1898-present	Little White Salmon River
Willard NFH	USFWS	1953-present	Little White Salmon River
Spring Creek NFH	USFWS	1901-1986	Lower Columbia River
Big White Salmon Pond	USFWS	1961-present	Big White Salmon River

Table 7 (Cont.).

Klickitat Hatchery	WDFW	1951-present	Klickitat River
10) Upper Willamette River ESU			
Aumsville Pond	ODFW	1971-1977	North Santiam River
Marion Forks Hatchery	ODFW	1921-present	North Santiam River
Stayton Pond	ODFW	1969-present	North Santiam River
South Santiam Hatchery	ODFW	1930-present	South Santiam River
Leaburg Hatchery	ODFW	1968-present	McKenzie River
Mckenzie River Hatchery	ODFW	1902-present	McKenzie River
Dexter Ponds	ODFW	1970-present	Middle Fk. Willamette River
Willamette River Hatchery	ODFW	1920-present	Middle Fk Willamette River
11) Middle Columbia River Spring-Run ESU			
Metolius Hatchery	OSFC	1948-1973	Deschutes River
Oak Springs Hatchery	ODFW	1967-1982	Deschutes River
Round Butte Hatchery	ODFW	1969-present	Deschutes River
Warm Springs NFH	USFWS	1980-present	Deschutes River
Nile Springs Ponds	WDFW/Yakima T.	1964-1982	Naches River
Bonifer Pond	ODFW	1985-1990	Umatilla River
Umatilla Hatchery	ODFW	1992-present	Umatilla River
Minthorn Pond	Umatilla Tribe	1986-present	Umatilla River
12) Upper Columbia River Summer- and Fall-Run ESU			
Similkameen Pond	WDFW	1991-present	Okanogan River
Carlton Rearing Pond	WDFW	1992-present	Methow River
Wells Dam Hatchery	WDFW	1971-present	Columbia River
Entiat NFH	USFWS	1942-present	Entiat River
East Bank Hatchery	WDFW	1991-present	Columbia River
Leavenworth NFH	USFWS	1965-present	Wenatchee River
Dryden Dam	WDFW	1993-present	Wenatchee River
Rocky Reach Hatchery	WDFW	1993-present	Columbia River
Turtle Rock Pond	WDFW	1975-1990	Columbia River
Priest Rapids Hatchery	WDFW	1971-present	Columbia River
Ringold Pond	WDFW	1966-present	Columbia River
Yakima Net Pens	USFWS	1988-1991	Yakima River
13) Upper Columbia River Spring-Run ESU			
Winthrop NFH	USFWS	1976-present	Methow River
Methow Hatchery	WDFW	1992-present	Methow River
Entiat NFH	USFWS	1942-present	Entiat River
Chiwawa Rearing Pond	WDFW	1991-present	Wenatchee River
Leavenworth NFH	USFWS	1942-present	Wenatchee River

Table 7 (Cont.).

14) Snake River Fall-Run ESU

Hagerman Hatchery	IDFG	1955-1985	Snake River
MaCay Hatchery	IDFG	1983-present	Salmon River
Mullan Hatchery	IDFG	1947-1986	Clearwater River
Irrigon Hatchery	ODFW	1986-present	Grande Ronde River
Lyons Ferry Hatchery	WDFW	1985-present	Snake River

15) Snake River Spring- and Summer-Run ESU

McCall Hatchery	IDFG	1976-present	Payette River
Rapid River Hatchery	IDFG	1966-present	Little Salmon River
Pahsimeroi Hatchery	IDFG	1970-present	Salmon River
Sawtooth Hatchery	IDFG	1983-present	Salmon River
Yankee Fork Ponds	ShoBan Tribe	1988-1991	Salmon River
Lookingglass Hatchery	ODFW	1983-present	Grande Ronde River
Imnaha Pond	ODFW	1990-present	Grande Ronde River
Big Canyon Trap	ODFW	1988-1990	Grande Ronde River
Powell Hatchery	IDFG	1989-present	Clearwater River
Red River Hatchery	IDFG	1978-present	Clearwater River
Crooked River Pond	IDFG	1991-present	Clearwater River
Clearwater Hatchery	IDFG	1993-present	Clearwater River
Kooskia NFH	USFWS	1970-present	Clearwater River
Dworshak NFH	USFWS	1981-present	Clearwater River
Tucannon Hatchery	WDFW	1988-present	Tucannon River

Introduction of Non-Native Chinook Salmon into Hatcheries

Chinook salmon have often been transferred among watersheds, regions, states, and countries, either to initiate or maintain hatchery populations or naturally spawning population in other watersheds. The transfer of non-native fish into some areas has shifted the genetic profiles of some hatchery and natural populations so that the affected population is genetically more similar to distant hatchery populations than to local populations (Kostow 1995, Howell et al. 1985, Marshall et al. 1995).

It is often difficult to determine the proportion of native and non-native hatchery fish released into a given watershed. Table 6 shows estimates of the proportion of non-native fish introduced into each ESU, but in many cases they will be underestimates for two reasons. First, hatchery or outplanted fish that were designated as "origin unknown" in the database (NRC 1996) were counted as native fish, even though in some cases they were probably not native. Second, transplanted hatchery fish routinely acquire the name of the river system into which they have been transferred. For example, spring-run chinook salmon released from the Leavenworth NFH are primarily the descendants of the Carson NFH stock (Marshall et al. 1995), but are designated as Leavenworth stock when released or transferred (NRC 1996). These fish were counted as native fish in this review. Sol Duc River (Washington Coast ESU) spring chinook salmon were derived from a hybrid of two out-of-ESU stocks (WDF et al. 1993), but were identified as Sol Duc stock when released from the Sol Duc Hatchery or when transferred to other ESUs, such as Hood Canal (Puget Sound ESU) (WDF et al. 1993, NRC 1996). Similarly, the Russian River (So. Oregon and Coastal California ESU) receives fall chinook salmon from a number of different hatcheries in other ESUs, which are correctly identified by hatchery of origin at release, but become “Russian River” stock when they return and are propagated for release in subsequent generations at the Warm Springs Hatchery (NRC 1996).

Until recently, the transfer of hatchery chinook salmon stocks between distant watersheds and facilities was a common management strategy (Matthews and Waples 1991, WDF et al. 1993, Kostow 1995). Agencies have instituted policies to reduce the exchange of non-indigenous genetic material among watersheds. In 1991, chinook salmon co-managers in Washington adopted a statewide plan to reduce the number of out-of-basin hatchery-to-hatchery transfers of salmon. This included genetic guidelines specifying which transfers between areas were acceptable. However, these policies applied only to transfers between hatcheries and did not explicitly prohibit introductions of non-native salmonids into natural populations (WDF 1991). At present, co-managers in Washington State are developing guidelines for transfers of hatchery chinook salmon into natural populations (WDFW 1994). In 1992, the Oregon Coastal Chinook Salmon Management Plan was implemented, which provides guidelines for stock transfers (Kostow 1995).

West Coast Artificial Propagation Activities

1) Sacramento River Winter-Run ESU

Between 1962 and 1990, Sacramento River winter-run chinook salmon were occasionally reared at Coleman National Fish Hatchery (NFH). In 1988, the Ten-Point Winter-Run Restoration Plan, which called for the artificial propagation of winter-run chinook salmon, was developed by NMFS, USFWS, CDFG, and U.S. Bureau of Reclamation (USBR) (NMFS 1988). The next year, Sacramento River winter-run chinook salmon were listed as an endangered species under the ESA. As part of an artificial propagation program intended to help avoid extinction and speed recovery, winter-run adults have been collected primarily at Red Bluff Diversion Dam (RKm 391) and Keswick Dam (RKm 486) in the mainstem Sacramento River and then transported to the Coleman NFH, where they are held until maturity. Attempts to hold winter-run adults in 1989 and 1990 at the Coleman NFH facilities were generally unsuccessful due to epizootic disease and fungal infections (Forbes 1992). The 1991 brood year effectively marked the beginning of the program. Changes in husbandry techniques and the construction of new holding facilities at the Coleman NFH greatly improved adult survival and spawning success in 1991 (Forbes 1992); however, the presence of infectious hemopoietic necrosis virus (IHNV), *Ceratomyxa shasta*, and other pathogens, may limit the effectiveness of the program.

Although releases of as many as 1.5 million winter-run chinook salmon smolts per year have been proposed, only about 100,000 fish have been released during the current recovery effort (NRC 1996). The primary constraint to increased production is the low number of adults available for spawning, as the broodstock collection permit for the program under the ESA allows for a maximum of 20 adults to be taken if less than 1,500 adults are expected to pass Red Bluff Dam (Forbes 1992). In January 1992, the first 11,582 juvenile winter-run chinook salmon that were reared at Coleman NFH were released directly into the upper Sacramento River. It was hoped that the fish would imprint on, and return to, their release site rather than to the Coleman NFH or Battle Creek, which has low flow and high temperature conditions during the time of the adult return migration. However, it appears that all of the adults recovered from these releases in 1995 returned to the hatchery site rather than the upper Sacramento River, which contains suitable natural spawning habitat (USFWS 1996b).

Winter-run adults at Keswick and Red Bluff Dams are selected according to return migration timing, and presumptive winter-run adults are further distinguished from spring-run fish by their spawning time. Natural variability in spawning time, in combination with the use of hormones to induce ovulation and spermiation, may result in the misclassification of fish. Based on DNA analysis, Hedgecock et al. (1995) concluded that several spring-run adults had been accidentally incorporated into the winter-run broodstock program.

In addition to the supplementation program, a portion of the juveniles derived from adults collected as broodstock are kept at the hatchery as part of a captive broodstock program, which provides for full-term rearing to the adult stage (Hedrick et al. 1995, Flagg et al. 1995a). The captive broodstock program was also initiated in 1991. The primary goals of the Sacramento River winter-run chinook salmon captive broodstock initiative are to provide a reserve of genetic material, should the natural run collapse, and to provide an additional source of eggs for the Coleman NFH program until conditions in the Sacramento River improve (CDFG 1995). To maximize future recovery options and to mitigate against the risk of mechanical failure, about 1,000 juveniles are transferred each year to the Bodega Bay Marine Laboratory (University of California at Davis) or the California Academy of Science's Steinhart Aquarium. The goal is for captive broodstock technology to provide about 200 mature adults per year to be spawned at Coleman NFH (CDFG 1995). Based on results obtained to date, adult growth, survival, and gamete quality appear to be lower under captive culture than in the anadromous program (USFWS 1996a).

2) Central Valley Spring-Run ESU

The propagation of Sacramento River spring-run chinook salmon began in 1872 with the construction of the U.S. Fisheries Commission Baird NFH on the McCloud River, a tributary of the Sacramento River. Livingston Stone, the first manager of the station, noted that the spring run of chinook salmon on the Sacramento River were already "much depleted," and that artificial propagation efforts were needed to revitalize the fishery (Stone 1874). The Baird NFH collected eggs from returning spring- and fall-run chinook salmon. During the first decade of operation the majority of the eggs were shipped to the East Coast in an effort to establish runs there (Shebley 1922). Operations were suspended from 1884-1888 due to low numbers of returning adults. Although millions of eggs were collected, generally only one-quarter of the eggs were reared on site, with the surplus transferred to other stations—primarily the CDFG Mt. Shasta Hatchery (Shebley 1922). In 1902, the Baird NFH collected 7,375,520 eggs from the spring run; some two-thirds were transferred to the Eel River and the Mt. Shasta Hatchery (Titcomb 1905). Until 1911, it was hatchery policy to release chinook salmon shortly after yolk sac resorption (Clark 1929), and the success of these releases was probably limited. As a result of egg transfers, hatchery practices, and irrigation diversions on the Sacramento River, the spring run of chinook salmon returning to the McCloud River had dramatically dwindled by 1914 (Titcomb 1917, Clark 1929). During the 1920s, the spring run egg-take at the Baird NFH rarely exceeded one million eggs, and there were several years when no eggs were obtained (Leach 1924, 1928, 1932). The hatchery was abandoned in 1936 (Leach 1941), and the site was submerged under Lake Shasta following the completion of Shasta Dam in 1943.

In an effort resembling the GCFMP, from 1941 to 1946 chinook salmon attempting to migrate to areas above Keswick and Shasta Dams were trapped and transported to Deer Creek to spawn naturally (spring-run only) or to the Coleman NFH on Battle Creek for artificial propagation (Moffett 1949). The transportation program for spring-run chinook salmon to Deer Creek met with limited success (Moffett 1949). From 1943 to 1949 approximately 6,853,310 spring-run chinook salmon were released from the Coleman NFH (Cope and Slater 1957). Analysis of marked spring- and fall-run fish released from the hatchery suggested that 16% of the fish returning during the "spring run" (based on a September 25 cut-off date) were the progeny of fall-run parents, and 19% of the fish returning during the “fall run” were the progeny of spring-run parents (Cope and Slater 1957). Releases from the Coleman NFH ceased in 1953 (Appendix D). Following termination of the Coleman NFH spring-run chinook salmon program, there was no artificial propagation of spring-run chinook salmon until 1967 when the California Fish and Game hatchery on the Feather River began operation. The founding stock was derived from a run of fish returning to the Feather River. Since that time over 32 million spring-run chinook salmon have been propagated at the Feather River Hatchery, and about 80% of those have been released outside of the Feather River Basin (Appendix D). Furthermore, half of all spring-run releases for the entire Central Valley have been off-station and these fish may not show the homing fidelity of fish released from their home stream. Current release practices increase the potential for hatchery fish to interbreed with fish from naturally spawning populations.

3) Central Valley Fall-Run ESU

The United States Fisheries Commission Baird NFH collected both spring- and fall-run chinook salmon for broodstock. Over the years of its operation, 1872-1936, the proportion of fall-run chinook salmon relative to fish from the spring run collected at the Baird NFH increased each year. Over the course of the next two decades, several other hatcheries were established on various tributaries of the upper Sacramento River, collectively taking as many as 100 million eggs annually from fall-run and late-fall run chinook salmon (Shebley 1922). In total, 317 million eggs (spring- and fall-run chinook salmon) were collected at the Baird NFH from 1872 to 1924, and 801 million eggs (fall-run chinook salmon) were collected at the Battle Creek and Mill Creek fish hatcheries from 1895 to 1924 (Clark 1929). Of these eggs, nearly 100 million were sent overseas and to the eastern seaboard of the U.S., and 61 million eggs and fry were sent to the Eel River (Clark 1929). Although large numbers of eggs were incubated during these early years, hatchery practices severely limited the survival of released fish (this was especially true from 1895 to 1910 when it was hatchery policy to release unfed fry) (Clark 1929).

In the San Joaquin River Basin, the artificial propagation of chinook salmon developed much later than in the Sacramento River. An experimental fall-run chinook salmon hatchery was located in Fresno County during the 1920s (Taft 1941); however, it was not until 1964 and 1971 that the Mokelumne and Merced Hatcheries began operations, respectively (NRC 1996). Most of the hatchery stocks of fall-run chinook salmon used in the San Joaquin River Basin have been imported from Sacramento River hatcheries (Appendix D).

From 1943 to 1946, fall-run chinook salmon attempting to migrate to areas above Keswick and Shasta Dams were trapped and transported to the Coleman NFH on Battle Creek for artificial propagation (Moffett 1949). Some 10,566 transported female fall-run chinook salmon were spawned at the Coleman NFH between 1943 and 1946 (Moffett 1949). Several thousand additional fall-run chinook salmon were left in the Sacramento River to spawn, or transported and released into Battle Creek (Moffett 1949).

From the late 1940s to the present, about 1.7 billion hatchery-produced fall-run and late-fall-run chinook salmon have been released into Central Valley streams (Table 6). Almost half of these were produced at Coleman National Fish Hatchery (which replaced the Battle Creek Hatchery station in 1944), the other half originated primarily from Feather River and Nimbus Hatcheries (NRC 1996). Since the early 1980s tens of millions of fall-run chinook salmon have been released into the extreme lower Sacramento River and in estuarine areas (NRC 1996) to avoid mortality associated with juvenile migration past irrigation diversions and other hazards.

Artificial propagation programs in the Central Valley have used primarily Sacramento River stocks; less than 1% of the fall-run chinook salmon released here have been from non-Sacramento River stocks. However, because of the large area occupied by this ESU, an intra-ESU transfer could involve transporting and releasing fish as far as 600 kilometers away from their hatchery of origin.

4) Southern Oregon and California Coast ESU

The artificial propagation of fall-run chinook salmon began in southern Oregon on the Rogue River in the late 1880s with hatcheries operated by canneries, most notably canneries owned by R.D. Hume (Cobb 1930, Kostow 1995). The U.S. Fisheries Commission began operating the Rogue River substation in 1900 as an egg collection and rearing site for spring-run chinook salmon (Titcomb 1904). Several million surplus eggs from the Rogue River substation were sent to a private hatchery at Wedderburn, Oregon on the Rogue River (Titcomb 1904). Additional egg collecting stations were operated intermittently during subsequent years in the Rogue River Basin on the Applegate River, Illinois River, Elk Creek, and Butte Creek. With the construction of the Oregon Game Commission Butte Falls Hatchery in 1916, salmon propagation on the Rogue River was increasingly dominated by state programs. By 1928, 85 million chinook salmon had been released into the Rogue River from state, federal, and private hatcheries (Cobb 1930).

Although the spring-run chinook salmon hatchery efforts in the Rogue River Basin did not begin in earnest until the mid 1970s, it is today one of the largest spring-run chinook salmon hatchery programs on the west coast of North America (Kostow 1995), with about 23 million hatchery-produced spring-run chinook salmon released into the Rogue River since the completion of the Cole Rivers Hatchery in 1974 (Appendix D). In 1993, nearly 1.5 million spring-run chinook salmon were released from the Cole Rivers Hatchery alone (Kostow 1995).

Compared to many of the other ESUs, the influence of fall-run chinook salmon artificial propagation in southern Oregon has been relatively minor. One exception, the Chetco River, has been stocked with almost 9 million fish since 1974, although these have been primarily of Chetco River stock (Appendix D). The other southern Oregon streams have received a total of about 5 million fall-run chinook salmon during the same period (Appendix D). The Rogue River, for example, is primarily a spring-run chinook salmon stream and not heavily stocked with fall-run chinook salmon; hatchery fall-run chinook salmon comprised only about 7% of the total adult run in 1987 (Cramer 1987).

Fall-run chinook salmon hatchery supplementation programs in some southern Oregon tributaries (Indian Creek, Rogue River Basin, Hunter Creek, and Pistol River) were intended to increase natural production; however, the results have been disappointing with a decrease in the effective population size for each river over the course of these programs (Kostow 1995). Furthermore, there has been an increase in the incidence of hatchery-derived strays between rivers in the region (Kostow 1995). Similar programs have been conducted in the Winchuck and Chetco Rivers, but hatchery-to-wild ratios are unknown in these rivers. The Winchuck River hatchery program was recently terminated. Hatchery fall-run fish released into Hunter Creek and the Pistol River are now being marked with coded-wire tags to more fully evaluate the impact of these programs (Kostow 1995). In December of 1992, the ODFW Coastal Chinook Salmon Management Plan was implemented to provide guidelines for stock transfers and to identify streams where stocking of hatchery fish should be excluded (Kostow 1995).

California coastal hatcheries and egg collecting stations began operating on several coastal streams in the early 1890s, but the first permanent facility was not established until 1910, with the construction of the Snow Mountain Station (currently known as Van Arsdale Fisheries Station) on the Eel River (Shebley 1922). Facilities on the Eel and Mad Rivers were constructed to rehabilitate depressed north coast populations (Kelly et al. 1990). A total of 95 million chinook salmon fry were released into California coastal rivers from 1875 to 1919, the majority (84 million) into the Eel River (Cobb 1930). Hatchery releases of fall-run chinook salmon since the 1970s have been relatively small, especially when compared to the large programs in the adjacent Sacramento River Basin (Appendix D). For example, the Smith River has received about 133,000 fall-run chinook salmon per year (NRC 1996), a fraction of the number of fish released into Sacramento River tributaries of similar size. The majority of the current coastal California fall-run chinook hatchery programs tend to use stock developed within basin, although these stocks may not be wholly native due to the long history of interbasin transfers that were common in earlier decades (CDNR 1931). The Russian River is a notable exception to this rule, having received artificially propagated fall-run chinook salmon from a variety of sources, most commonly Sacramento River stocks and the Great Lakes (which were stocked with a myriad of populations from Washington, Oregon, and California) (Appendix D). In the absence of existing permanent native runs of chinook salmon, local enhancement efforts south of San Francisco Bay in this area have generally used Sacramento River fall-run chinook salmon, although stocks from Washington, Oregon and the Great Lakes have been released there as well (NRC 1996). Spring-run chinook salmon artificial propagation has been very limited in the coastal river basins of California, with the exception of the Klamath River Basin (see ESU #5).

5) Upper Klamath and Trinity Rivers ESU

Early artificial propagation efforts in the Upper Klamath and Trinity Rivers began at the turn of the century. In 1896, over a million chinook salmon fry were introduced into the Klamath

River from the Sacramento River (Snyder 1931). In 1890, a fish hatchery at Fort Gaston on Minor Creek, a tributary to the Trinity River, was established (Kirk 1994). During the operation of this hatchery (1890-98) eggs were collected from the Trinity and Sacramento (Baird NFH) Rivers and Redwood Creek, and the majority of the 2 million fry produced from this facility were released into the Trinity River and Redwood Creek (Snyder 1931). Several canneries near the mouth of the Klamath River also operated small hatcheries on an intermittent basis. The U.S. Fisheries Commission Hornbrook Hatchery (later known as the Klamathon Racks) on Cottonwood Creek (a tributary of the Klamath River) initially trapped rainbow trout and coho salmon, but in 1914 trapping operations were relocated on the Klamath River to intercept chinook salmon (Snyder 1931). On average, several million eggs were collected at this site annually. By 1916, nearly 17 million chinook salmon fry had been released into the Klamath River Basin (Cobb 1930). Surplus eggs were normally transferred to the CDFG hatchery at Sisson, California (later named the Mt. Shasta Hatchery) for incubation and rearing (Snyder 1931).

To mitigate the loss of spawning habitat caused by the construction of COPCO Dam (RKm 320) on the Klamath River in 1917, a CDFG hatchery was constructed on Fall Creek (RKm 316) and supplied with eggs from the Klamathon egg collection site (Shebley 1922). From 1916 to 1928, over 118 million chinook salmon eggs had been collected from the Klamath River (Snyder 1931). Although a substantial proportion of the fry and fingerlings produced from these eggs were returned to the Klamath River Basin, millions of eggs and fry were transferred to the Sacramento, Eel, and Mad Rivers (Shebley 1915 1922; Snyder 1931). The disposition of many millions of additional eggs is unclear. The Fall Creek Hatchery was closed in 1948, and although egg collections continued, no rearing facilities existed on the Klamath until 1966 (KRBFTF 1991).

The construction of Iron Gate Dam on the Klamath River (1962) resulted in the construction of the Iron Gate Hatchery (1965). Eggs for the Iron Gate Hatchery have primarily been collected from adults returning to the hatchery, although the hatchery has occasionally relied on spawners captured in the nearby Bogus Creek. Similarly the impact of the completion of the Lewiston Dam (RKm 249) on the Trinity River (1964) was mitigated by the construction of the Trinity River Hatchery (RKm 247) in 1963. Prior to the completion of the hatchery (1958-62), returning adult chinook salmon had been trapped downstream from the dam construction site, spawned, and their eggs incubated at Mt. Shasta Hatchery.

Iron Gate Hatchery has released primarily fall-run chinook salmon. Attempts to maintain a spring run from adults returning to the hatchery were intermittent and eventually abandoned. The Trinity River Hatchery has successfully maintained both fall and spring runs of chinook salmon. Both hatcheries have relied on returning adults to maintained their runs. Since 1965, the upper Klamath River has received about 7.3 million fall-run chinook salmon juveniles per year; almost all have been Klamath River stock (Appendix D). Since 1964, about 2.6 million fall-run chinook salmon and 1.5 million spring-run chinook salmon have been released in the Trinity River each year (Appendix D), all of which have been of Trinity or Klamath River origin.

Pathogens, specifically infectious hematopoietic necrosis virus (IHNV) and bacterial kidney disease (BKD), which are caused by *Renibacterium salmoninarum*, have been detected in juvenile and returning adult spring-run chinook salmon from the Trinity River Hatchery (PFMC 1994). These pathogens may have significantly limited the success of hatchery programs in the Klamath River Basin; for example, IHNV was associated with the loss of 20% of the spring-run chinook juveniles held at the Trinity River Hatchery (PFMC 1994). Another consequence of artificial propagation in this ESU has been the inadvertent hybridization of chinook and coho salmon at the Iron Gate Hatchery (Bartley et al. 1990). However, because this interspecies hybrid is sterile (Johnson 1988a), the long-term genetic effects of this hybridization are minimal while ecological effects would depend on the hybridization rate.

6) Oregon Coast ESU

Artificial propagation efforts for chinook salmon in this ESU began in the late 1890s. By the early 1900s, there were hatcheries or egg-taking stations on most of the larger streams along the Oregon coast, especially the Yaquina, Alsea, Siuslaw, Umpqua, Coos, and Coquille Rivers (Cobb 1930, Wahle and Smith 1979). Before 1960, a substantial portion of the chinook salmon introduced into river basins in this ESU came from lower Columbia River (LCR) fall- and spring-run chinook salmon stocks—mostly from the Bonneville and Clackamas Hatcheries (Appendix D).

Chinook salmon populations in this ESU were considered to be mostly wild prior to 1960, based on the relatively low number of hatchery fish contributing to naturally spawning populations (Kaczynski and Palmisano 1993). However, the contribution of hatchery-reared fish relative to naturally spawning fish in this ESU has apparently increased since that time (ODFW 1995). Declining numbers of wild salmon prompted an increase in artificial propagation efforts. Improvements in hatchery rearing and release practices, feed formulation, and disease treatment have allowed hatcheries to produce fish that are larger, more fully-smolted, and healthier than fish produced before the mid-1960s (McGie 1980). Releases of larger smolts, in turn, have yielded a higher survival to adulthood than previous releases of fry and parr-stage fish (CBFWA 1990a). Furthermore, legislation enacted in the mid-1970s allowed the establishment of privately operated, for-profit hatcheries in Oregon (Wahle and Smith 1979). Private facilities operated in the Coos River and Yaquina River Basins until 1988 and 1989, respectively (NRC 1996). These salmon ranching operations released millions of smolts produced from spring- and fall-run broodstock primarily obtained from Oregon coastal rivers, such as the Rogue, Trask, and Yaquina (NRC 1996). In addition, a number of smaller cooperative hatcheries, built to restore depleted populations, are responsible for a substantial proportion of the current hatchery production (Appendix D).

Currently, most of the fall-run chinook salmon populations in this ESU are thought to have been minimally influenced by hatchery fish, which made up less than 10% of the spawning population (Kostow 1995). However, hatchery fish are thought to comprise up to 50% or more of the naturally spawning fish in the Salmon and Elk Rivers (ODFW 1995); Kaczynski and

Palmisano (1993) estimated that 78% of natural spawners in the Elk River were of hatchery origin. Although fall-run chinook salmon hatchery programs are currently in operation in a number of basins, ODFW (1995) concluded “hatchery fish are not thought to be sustaining natural production,” or “are not needed to sustain natural production” in most streams in this region. The influence of stray hatchery fish between basins may be significant; strays constituted some 20% of the “naturally spawning” run in the Sixes River (Kaczynski and Palmisano 1993).

Hatchery programs for spring-run chinook salmon have a significant impact on populations in the Trask and Umpqua River Basins. Hatchery contributions constituted between 40 and 60% of the total run in the North Umpqua River (ODFW 1995). Furthermore, the broodstock initially collected for the Rock Creek Hatchery (1955) on the North Fork Umpqua River may have been influenced by introductions of Rogue River spring-run chinook salmon in 1951. Low returns of adult spring-run chinook salmon over Winchester Dam (RKm 116) from 1946-48 (average, 2,404) prompted the release of 35,524 and 3,270 yearling spring-run chinook salmon from the Rogue and Imnaha Rivers, respectively (ODFW 1954). Although the number of fish released was small during this period, the hatchery fish released into the Rogue River contributed 20.9 and 12.6% of the total adult run in 1953 and 1954, respectively, due to their large size at release (ODFW 1954). In addition, the abundance of the fall-run chinook salmon in the North Fork Umpqua River increased from 12 in 1952 to 684 in 1955, largely related to introductions of fall-run chinook salmon from hatcheries on the Columbia River (ODFW 1954). Hatchery-derived spring-run chinook salmon in the Wilson, Nestucca, and South Umpqua Rivers are thought to now be abundant enough that they “may mask [abundance] trends in wild populations” (ODFW 1995).

Naturally produced fish account for the majority of chinook salmon in this ESU; however, in 1993, artificial propagation efforts were still substantial, with releases of 3,700,000 fall-run and 840,000 juvenile spring-run chinook salmon (Kostow 1995). Efforts by ODFW to utilize locally derived stocks in artificial propagation programs may reduce deleterious wild-hatchery fish interactions provided that local stocks have not been genetically altered by previous non-native introductions.

7) Washington Coast ESU

In response to declining numbers of chinook salmon in Grays Harbor drainages, the State of Washington constructed a hatchery on the lower Chehalis River in 1897. However, the facility was poorly sited and soon relocated to the Satsop River (WDFG 1902, Moore et al. 1960). In 1899, a hatchery (which still exists) was built on the Willapa River, and by 1917 additional hatcheries were operating on the Humptulips, North, and Naselle Rivers (WDFG 1920, 1921). On average, several million fall-run chinook salmon were released annually from state hatcheries from 1917 to 1941. The early years of artificial propagation in the Washington Coast ESU were marked by widespread importations of non-native stocks to fill hatcheries to capacity (WDFG 1916) due to the depressed size of local populations, primarily from overharvest (WDFG 1921). Initially, the Quinault National Fish Hatchery (1914) was operated primarily as a sockeye salmon facility (Titcomb 1917), although releases of chinook salmon increased steadily through the years. Most of the effort regarding artificial propagation in ESU 7 has focused on fall-run chinook salmon. Hatcheries on the Washington coast tend to be located near areas of commercial harvest, with two facilities in operation on the Quinault River, two on major tributaries entering Grays Harbor, and three on tributaries to Willapa Bay. In general, non-native fall-run chinook salmon stocks, primarily Green River hatchery-derived stocks, were used in ESU 7 watersheds prior to 1975. Since 1980 there has been a shift to the use of locally returning stocks (Appendix D).

Hatchery-reared spring-run chinook salmon have been released in only a few watersheds: the Sol Duc, Hoh, Quinault, and Wynoochee Rivers (NRC 1996). The impact of artificial propagation on spring-run chinook salmon populations has been modest, and with the exception of the Sol Duc River (which has received more than 9 million hatchery spring-run chinook salmon since 1972), no watershed has received more than 500,000 spring-run chinook salmon during the period covered by our database (Appendix D). The Sol Duc River spring-run chinook salmon stock was originally established from Cowlitz River x Umpqua River hybrids, with subsequent introductions of Dungeness River spring-run chinook salmon for a number of years between 1973 and 1988 (Appendix D). Although the Sol Duc River is managed for hatchery production only, it apparently has influenced nearby naturally spawning populations. In both the Sol Duc and Quillayute Rivers, similarities in run timing and a substantial incidence of natural spawning by stray Sol Duc Hatchery spring-run chinook salmon may have resulted in significant genetic exchange between the hatchery spring-run chinook salmon and natural summer-run chinook salmon populations (WDF et al. 1993). The draft scoping document for a proposed wild salmonid policy for the Washington Department of Fish and Wildlife (WDFW et al. 1994) explains the value of the Sol Duc River spring-run chinook salmon stock as follows (p. V-31):

> There are a number of unique hatchery stocks that have developed over time, out of a variety of parent stocks. Spring-run chinook at the Sol Duc Hatchery, Deschutes River (Washington) chinook, several of the stocks at the Quinault National Fish Hatchery and others represent unique genetic units that deserve some protection in the same way that we want to maintain unique wild stocks as a resource for future needs.

In general, watersheds that enter the Strait of Juan de Fuca portion of this ESU have not been stocked with hatchery fall-run chinook salmon since 1981. However, the Hoko River, which was stocked with Puget Sound and Hood Canal fall-run chinook salmon stocks from 1950 through the mid-1970s, has been stocked since 1984 with juveniles produced from adults returning to the Hoko River and reared at the Makah NFH (Appendix D).

The impact of artificial propagation on coastal systems has not been fully evaluated. There appears to be some confusion regarding stock origin and the influence of hatchery fish in some populations in this ESU, especially in tributaries of Grays Harbor. For example, the current Humptulips River Hatchery stock of fall-run chinook salmon, which was derived from both wild spawners and hatchery returns (the hatchery was founded from a variety of local and non-ESU sources (WDF et al. 1993)) has been designated as being of “native” stock origin (Ashbrook and Fuss 1996), while naturally spawning fall-run chinook salmon in the Humptulips River have been designated as of “mixed” stock origin, due to mixing with non-local stocks (WDF et al. 1993), although no non-native fall-run chinook salmon have been introduced to the system since 1981 (Appendix D). In addition, a recent study of genetic stock diversity of Washington chinook salmon populations states: “All of the spawning populations in Grays Harbor [six were identified] are considered native chinook with few impacts from hatchery releases or releases from outside the basin” (Marshall et al. 1995, p. D-31). Another recent study, based in part on genetic diversity and life-history characteristics, determined that three of these six naturally spawning Grays Harbor populations were of mixed stock origin (WDF et al. 1993), suggesting that releases from outside the basin have had some impact on them. It appears that solid data regarding the influence of artificial propagation has not yet been compiled for at least some naturally spawning populations in this ESU.

8) Puget Sound ESU

The artificial propagation of chinook salmon in the Columbia River was quickly followed by the establishment of hatcheries on Puget Sound tributaries, with state-run facilities operating in the Nooksack, Skagit, and Samish River Basins before the end of the last century. James Crawford, then Commissioner of the Washington State Fish Commission (WSFC), wrote (Crawford 1894):

> That the salmon industry is in great danger, by reason of the decrease in the supply of salmon, cannot be successfully denied, and unless some steps are immediately taken to repair by artificial
>
> propagation the ravages annually made by the different fishing appliances on our salmon supply, this industry ... will pass into history .

By 1902, eight state-run and two federally-run chinook salmon hatcheries were operating in this ESU, and new facilities were being constructed every few years (Moore et al. 1960). There are currently about 46 state, tribal, and federal facilities that regularly release chinook salmon juveniles into Puget Sound tributaries and over 50 cooperative state/public facilities that occasionally produce chinook salmon (Appendix D). Transfers of chinook salmon eggs to Puget Sound from other geographic regions, primarily the lower Columbia River, were commonplace in the early history of artificial propagation in this region. For example, by 1914, Columbia River chinook salmon had been released in many watersheds throughout Puget Sound. Increases in the commercial salmon catch subsequent to these stock transfers were assumed to be directly related to artificial propagation efforts: “The most convincing results are apparent from the practice of transplanting surplus eggs from one hatchery to another,” and the increased abundance of Puget Sound chinook salmon at that time was seen as “the direct result of the transferring of the surplus chinook salmon egg take of the Columbia River to Puget Sound and other districts.” (WDFG 1914, p. 17). The perceived benefits of inter-watershed stock transfers had a long-term impact on hatchery policies in Puget Sound and elsewhere. In 1924 state-operated hatcheries in Puget Sound collected 11,460,600 eggs from returning adults; however, an additional 6,000,000 eggs were transferred to Puget Sound from outside the region (Mayhall 1925). By 1928, almost 290 million chinook salmon fry, fingerlings, and yearlings had been released into Puget Sound tributaries (Cobb 1930). The emphasis on producing fish for harvest during the early part of this century resulted in widespread movements of chinook salmon between watersheds in this ESU (NRC 1996) (Appendix D). However, stock integrity and genetic diversity have recently become important management objectives as well, and policy revisions restricting some stock transfers have been initiated to reduce the impact of hatchery fish on natural populations (WDF 1991, WDF et al. 1993, Ashbrook and Fuss 1996).

The Green River fall-run chinook salmon stock has been the dominant hatchery stock in this ESU since the construction of the Green River Hatchery in 1907. Substantial numbers of Green River fish have long been released in many rivers, as well as numerous smaller watersheds and saltwater release sites throughout Puget Sound (Appendix D), raising concerns that this strategy may erode genetic diversity (Busack and Marshall 1995). Although reliance on this stock in hatchery programs is declining as a result of recent policy changes in inter-hatchery transfer of chinook salmon (WDF 1991), 20 hatcheries and 10 net-pen programs still regularly released Green River fall-run chinook salmon as late as 1995 (Marshall et al. 1995). In a recent determination of salmon genetic diversity units in Washington, Busack and Marshall (1995) reported: “The extensive use of this stock has undoubtedly had an impact on among-stock diversity within the South Puget Sound, Hood Canal, and Snohomish summer/fall GDU (GDU 17), but may also have impacted GDUs elsewhere in Puget Sound and the Strait of Juan de Fuca.”

Chinook salmon abundance in watersheds throughout the Puget Sound ESU appears to be closely correlated with hatchery effort. The recent stock assessment by WDF et al. (1993) identified 28 fall- and spring-run chinook salmon stocks in Puget Sound from the Nooksack River to the Elwha River (boundaries of NMFS ESU 8). Seventeen of these 28 stocks were reported to be naturally produced runs, reflecting evidence that hatchery fish have had little or no influence on the spawning grounds. The status of 15 of the 17 (88%) natural Puget Sound chinook salmon stocks was classified as “critical,” “depressed,” or “unknown” (WDF et al. 1993). On the other hand, WDF et al. (1993) reported that 6 of the 28 Puget Sound chinook salmon stocks were of “mixed production,” based on a conclusion that hatchery fish have made a significant contribution to the spawning population. All six hatchery-influenced stocks have been designated as “healthy.” Therefore, there are several river systems in which a constant infusion of hatchery fish appears to have maintained population abundance to the point that the stocks have been determined to be healthy, albeit “mixed.”[8]

In at least one case, artificial propagation appears to have benefitted a declining stock. Spring-run chinook salmon in the White River have experienced a tremendous decline in abundance since the turn of the century, due principally to pronounced habitat alterations, although the harvest rate has been and is still estimated to be over 60% (WDFW et al. 1996). Several artificial propagation programs were initiated in the 1970s to boost the abundance of

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[8] “Mixed” is defined by Washington co-managers as: “A stock whose individuals originated from commingled native and non-native parents, and/or by mating between native and non-native fish (hybridization); or a previously native stock that has undergone substantial genetic alteration” (WDF et al. 1993, p. 6).

stocks of spring-run chinook salmon. The most successful of these was the propagation of White River spring-run by culturing fish in net-pens through maturity or releasing juveniles from a remote hatchery site. As a result of these artificial propagation programs, as well as harvest reductions to protect returning adults, abundance of this stock has steadily increased to the point that the captive broodstock portion is currently being phased out, and the remote hatchery program will be phased out in the future (WDFW et al. 1996). On the other hand, spring-run chinook salmon recovery programs on the Nooksack, Skagit, and Dungeness Rivers have been terminated or dramatically curtailed because of diminishing returns or the potential for interbreeding between different hatchery stocks or between wild and hatchery fish (WDF et al. 1993).

9) Lower Columbia River ESU

The first hatcheries in the Columbia River Basin were constructed by private companies in response to the declining abundance of chinook salmon that followed habitat destruction and overharvest. The first hatchery on the Oregon side was constructed on the Clackamas River in 1876, and the first Washington hatchery was built on Baker’s Bay near the mouth of the Columbia River in 1894 (Wahle and Smith 1979). The first state-operated hatchery in Washington, which was built in 1895 on the Lower Kalama River, is still in operation. In Oregon, several hatcheries were built around the turn of the century on the Clackamas River, although none of these is still in operation. The oldest operational hatchery on the Oregon side of the lower Columbia River was built in 1909 near the town of Bonneville (Wahle and Smith 1979). The first federal chinook salmon hatchery on the lower Columbia River was built on the Little White Salmon River in 1897 (Nelson and Bodle 1990). The first half of the twentieth century was marked by an explosive increase in hatcheries and hatchery production. For example, from 1913 to 1930, 319 million chinook salmon fry were released into the lower Columbia River by Washington State hatcheries alone (WDF 1934). Oregon state and federal hatchery efforts were on a similar scale. Federal hatcheries on the Big White Salmon and Little White Salmon Rivers collected 20-40 million eggs annually, and a large number of these were transferred to various Oregon and Washington state hatcheries. Although there were considerable cutbacks in the number of hatcheries during the Great Depression, egg production reported for Washington state hatcheries on the lower Columbia River from 1935 to 1939 was 143,000,000 (WDF 1936, 1937, 1938, 1939, 1940). After 1938, there was a dramatic increase in the number of chinook salmon hatcheries in the lower Columbia River, due primarily to federal obligations to mitigate harvest opportunities lost as result of the construction of upper Columbia and Snake River dams (Wahle and Smith 1979). There was an interruption in hatchery operations during World War II, when production declined to one-tenth of the prewar years at Washington State hatcheries. At present, about 25 ODFW, WDFW, and USFWS hatcheries release chinook salmon in this ESU. Since the 1960s, a large number of hatchery programs in the lower Columbia River have been dedicated to mitigating for lost production (Howell et al. 1985).

A variety of stocks were released from the early hatcheries, the majority being of lower Columbia River origin (Howell et al. 1985), although some upriver stocks were propagated as well (Appendix D). Presently, lower Columbia River fall-run chinook salmon hatchery stocks continue to make up the majority of all chinook salmon in ESU 9. A majority of spawners in Oregon tributaries to the Columbia River may be Big Creek Hatchery strays, based on CWT analysis, as well as Rogue River fall-run chinook salmon released in lower Columbia River streams (Kostow 1995). Since 1960, most natural fall run spawning on the Oregon side of the lower Columbia River has been attributed to hatchery strays (Olsen et al. 1992). In fact, straying, along with habitat degradation, overharvest, and competition from hatchery juveniles, has been identified as one of the major problems facing naturally spawning fall-run chinook salmon in Oregon's lower Columbia River tributaries (Kostow 1995). Oregon fall-run chinook salmon programs use a number of different broodstocks, including local and hatchery-origin "tule" stocks, and stocks imported from other areas. The Rogue River stock was introduced into several Columbia River tributaries to produce a south-migrating stock that would be available for harvest primarily by Oregon fishers (Appendix D) (Kostow 1995). About 70-75% of other lower Columbia River hatchery fall-run chinook salmon turn north and are harvested in Alaska, British Columbia, and Washington (Vreeland 1989).

Similarly, the fall-run chinook salmon populations in Washington tributaries are thought to be essentially one widely mixed stock as a result of straying and egg transfers between hatcheries (Howell et al. 1985, WDF et al. 1993, Marshall et al. 1995). The majority of natural spawners in the Grays, Elochoman, Cowlitz, Kalama, Washougal, and Klickitat Rivers have been of hatchery origin, and strays from several lower Columbia River hatcheries are often found in these streams (WDF et al. 1993, Marshall et al. 1995). Hatchery strays are also the most numerous spawners in several Washington streams not believed to originally have had a native run of fall-run chinook salmon, such as Abernathy, Germany, Mill, and Skamokowa Creeks (Marshall et al. 1995). Strays from Oregon's Rogue River fall-run chinook salmon program at Young's Bay have been observed in the Elochoman River and Abernathy Creek (WDF et al. 1993, Marshall et al. 1995). In 1982, upriver "bright" fall-run chinook salmon were released from the Little White Salmon NFH (WDF et al. 1993). The founding broodstock for various upriver "bright" stocks were collected by intercepting returning adults destined for Columbia River spawning sites above the Dalles Dam. Since the initiation of the upriver "bright" program at the Little White Salmon NFH, large numbers of upriver "bright" strays have been found naturally spawning in the Wind, White Salmon, and Klickitat Rivers (WDF et al. 1993). Similarly, in 1986 the Klickitat River Hatchery began releasing upriver "brights" in lieu of tule fall-run chinook salmon.

Spring-run chinook salmon populations in the lower Columbia River are all thought to be heavily influenced by hatchery programs. Approximately 1.5 and 10 million spring-run chinook salmon were released from Oregon and Washington hatcheries, respectively, in 1993. Populations of spring-run chinook salmon in the Sandy and Clackamas Rivers are considered by Oregon biologists to be a component of upper Willamette River hatchery populations due to many years of inter-hatchery transfer (Kostow 1995). Dam construction and volcanic episodes have eliminated most of the historic spawning habitat for spring-run chinook salmon on the Washington side of the lower Columbia River (Marshall et al. 1995). The Cowlitz River spring-run chinook salmon stock has received only limited transfers of non-native stocks, but is strongly influenced by hatchery-derived fish (WDF et al. 1993). Stocks on the Lewis and Kalama Rivers are a composite of the Cowlitz River spring-run chinook salmon stock and other lower Columbia and Willamette River spring-run chinook salmon stocks (WDF et al. 1993). Numerically, most of the spring-run chinook salmon spawning naturally in lower Columbia River tributaries on the Washington side are now hatchery strays (Marshall et al. 1995). All Washington populations of spring-run chinook salmon in the lower Columbia River are currently managed as populations of mixed origin (WDF et al. 1993).

10) Upper Willamette River ESU

Artificial propagation efforts on the upper Willamette River began early this century, when the state of Oregon began operating a hatchery on the McKenzie River in 1902 (Olsen et al. 1992). From 1909 to 1942 eggs were collected from spring-run adults returning to the Santiam and Middle Fork Willamette Rivers, incubated at the state's Bonneville Hatchery, and the resulting fry returned to the Willamette River Basin (Howell et al. 1985). Egg collections from the four primary state-run stations on the Willamette River Basin—North Santiam, South Santiam, McKenzie, and Middle Fork Willamette River stations—totalled 668 million eggs during the 1918-42 period (Craig and Townsend 1946). These eggs were largely the source for the 382 million fingerlings released into the basin during that interval. Although there were introductions of non-native fish into this ESU during the first half of this century, the vast majority of the eggs used originated from fish returning to the upper Willamette River (Howell et al. 1985, Olsen et al. 1992). Cramer et al. (1996) provided a detailed description of hatchery development in the Willamette River watershed.

Although not located within the boundaries of the Upper Willamette River ESU, the Clackamas River contains several artificial propagation facilities that have been strongly associated with the upper Willamette River. The U.S. Fish Commission began operating a hatchery on the Clackamas River in 1888 (USCFF 1893). Several million eggs were obtained annually until 1893, when dam construction limited spawner access to the hatchery collection facilities. Egg collecting substations on the upper Clackamas and Salmon Rivers (a tributary of the Sandy River) were constructed in 1894 and 1895, respectively, to provide eggs for the main Clackamas Hatchery (Ravenel 1899). Spawning times for fish arriving at these substations, July-September, were considerably earlier than those recorded at the Clackamas River Hatchery, September-October (Ravenel 1899). Additionally, egg transfers from the Baird NFH (Sacramento River) and the Little White Salmon Hatchery substation were also used to maintain production from the Clackamas River Hatchery. Dam construction and habitat degradation in the Clackamas River Basin nearly eliminated the spring run of chinook salmon. Restoration efforts for the Clackamas River chinook salmon utilized transfers of Mackenzie River spring-run chinook salmon and the construction of new artificial propagation facilities: the USFWS Eagle Creek NFH in 1957, and the ODFW Clackamas Hatchery in 1979 (Delarm and Smith 1990a,c). The original broodstocks for both hatcheries were developed from stocks originating above Willamette Falls (Delarm and Smith 1990c, Willis et al. 1995). Between 1975 and 1987, about 1.2 million spring-run chinook salmon were released from Eagle Creek NFH; none have been released since then. The Clackamas River Hatchery continues to produce between 0.5 and 1.2 million fish per year (NRC 1996) (Appendix D). Several broodstocks were originally developed from populations in the Clackamas, Santiam, McKenzie, and Middle Fork Willamette Rivers; inter-hatchery stock transfers have been frequent and the broodstocks have become essentially a single, homogenized breeding unit (Kostow 1995, Cramer et al. 1996). Therefore, spring-run chinook salmon currently inhabiting the Clackamas River are thought to most closely resemble hatchery populations throughout the Willamette River (Cramer et al. 1996).

Current hatchery programs in this ESU were initiated or expanded to mitigate the loss of natural spawning and rearing areas lost due to the construction of dams in the 1950s and 1960s (Cramer et al. 1996). Most of the historical geographic range of spring-run chinook salmon in the Willamette River Basin has received introductions of hatchery fish (Cramer et al. 1996, NRC 1996). Due to the large and continuous nature of artificial propagation programs in the Willamette River system, wild populations are thought to be small and “vastly dominated by hatchery fish” (Kostow 1995, p. 44). Hatchery fish have been observed spawning in the wild and appear to be successfully reproducing (Cramer et al. 1996).

Hatchery practices have reduced the early and late segments of the spawning cycle in this ESU. Historically, the several wild populations of spring-run chinook salmon in the Willamette River spawned sometime between mid-July and late October. However, current Willamette River populations, both wild and hatchery, all spawn at the same time, during September. Therefore, the majority of natural spawners are now thought to be of recent hatchery origin (Cramer et al. 1996). In addition, hatchery strays are thought to have a significant impact on population dynamics in this ESU. It has been estimated that the straying rate of adults returning from releases of trucked juveniles can be as high as 75% (Cramer et al. 1996). These strays are thought to contribute to the naturally spawning population (Kostow 1995).

Although fall-run chinook salmon are not indigenous to the Willamette River Basin (Howell et al. 1985), large numbers have been introduced there. Since the 1950s, about 200 million fall-run chinook salmon have been introduced into this ESU, primarily from lower Columbia River stocks (e.g., the ODFW Bonneville Hatchery), in addition to a large number of fish from the Trask River (Appendix D). Fall-run chinook salmon have been distributed into nearly all watersheds formerly and currently occupied by spring-run chinook salmon (Appendix D). Currently, the only facility releasing Bonneville Hatchery fall-run chinook salmon stock into the Willamette River above the falls is the Stayton Pond, a satellite of the South Santiam Hatchery, which produces about 5 million fall-run chinook salmon each year for release into various Willamette River tributaries (Delarm and Smith 1990c, NRC 1996). Little is known about the impact of introduced fall-run chinook salmon, as no observations of upper Willamette River fall-run chinook salmon were included in a recent review of wild chinook salmon stocks in Oregon (Kostow 1995). However, a previous review reported that between 16% and 46% of the adult fall-run chinook salmon in the upper Willamette River were of natural origin, suggesting at least a moderate amount of successful reproduction by straying hatchery fall-run chinook salmon (Howell et al. 1985). Spawning of fall-run chinook salmon in the upper Willamette River has been observed to occur primarily during September (Howell et al. 1985), closely overlapping the spawning period of Willamette River spring-run chinook salmon. We found no studies that evaluated genetic or ecological interactions between fall- and spring-run chinook salmon in the upper Willamette River.

11) Mid-Columbia River Spring-Run ESU

The artificial propagation of spring-run chinook salmon is a relatively new management strategy in this ESU. A hatchery program was initiated on the Klickitat River in 1899, but the facility was poorly sited and abandoned shortly thereafter (Mayhall 1925). It was not until 1950 that a hatchery was reestablished on the Klickitat River (Moore et al. 1960). This hatchery was the first Washington hatchery built under the Lower Columbia River Development Plan (Moore et al. 1960). Hatchery operations in the Deschutes River Basin began in 1947 with the construction of a hatchery and weir near Spring Creek on the Metolius River, a tributary to the Deschutes River (Nehlsen 1995). During the next 12 years, the Metolius Hatchery released an average of 125,000 spring-run chinook salmon juveniles annually (Nehlsen 1995). Additional spring-run chinook salmon hatcheries on the Deschutes River were built, in part, to mitigate for natural production lost as a result of the construction of Pelton and Round Butte Dams. The Round Butte Hatchery (1972), and Pelton Ladder (1974), a Round Butte satellite facility, are operated by ODFW (Delarm and Smith 1990c). The Warm Springs NFH (1977) is operated by the USFWS (Delarm and Smith 1990a). Additionally, the Deschutes River has received over 20 million fish since the late 1940s. The majority of these were derived from native Deschutes River spring-run chinook salmon (Howell et al. 1985), although a relatively limited number of fish from the Carson NFH and Willamette River hatcheries were released prior to 1969 (Olsen et al. 1992, Kostow 1995, NRC 1996).

Yakima River chinook salmon populations were not directly influenced by the artificial propagation efforts associated with the Grand Coulee Fish Maintenance Project during the 1940s. Despite irrigation diversion screening and improvements in fish ladders on the Yakima River from 1936 to 1941, massive water withdrawals for irrigation were the primary cause for the continuous decline in spring-run chinook salmon populations during most of this century (Davidson 1953), and eventually necessitated the use of artificial propagation to maintain fish numbers. Native Yakima River spring-run chinook salmon populations do not appear to have been significantly affected by hatchery supplementation or straying (Marshall et al. 1995), even though the number of hatchery smolts released into the Yakima River during the 1980s may have exceeded the number of naturally produced smolts migrating downstream (Fast et al. 1991, NRC 1996). While hatchery smolts were sometimes more numerous than wild smolts, they had only about 1/80th of the smolt-to-adult survival rate of naturally produced spring-run chinook salmon (Fast et al. 1991). The most commonly released stock in the Yakima River has been from the Leavenworth NFH (Appendix D), but these fish were apparently ill-adapted to the Yakima River (based on their extremely poor survival). In 1976, about 20,000 Klickitat Hatchery spring-run chinook salmon were introduced in Marion Drain, a tributary of the lower Yakima River (Appendix D). In general, spring-run chinook salmon populations in the Yakima River have been almost exclusively maintained by natural production (WDF et al. 1993). All transfers of spring-run chinook salmon into the Yakima ceased in 1988 (Appendix D).

The John Day River has been stocked with just a few fish, mostly from local stock, and has not been stocked at all since 1982 (Appendix D). Few hatchery strays from other river systems have been found there.

Native spring-run chinook salmon are thought to be extinct in the Hood, Umatilla, and Walla Walla Rivers on the Oregon side of this ESU (Kostow 1995). Reintroduction programs are currently underway in the Hood and Umatilla Rivers, with the Carson NFH (Wind River) and Lookingglass Hatchery (Grande Ronde River) being the predominant sources for spring-run chinook salmon used in these programs (Appendix D). The Umatilla River has received over 5 million Carson and Lookingglass Hatchery fish since 1986 (NRC 1996).

Large numbers of spring-run chinook salmon (approximately 11.8 million) have been released directly into the mainstem Columbia River since the 1970s, principally from WDFW Ringold Hatchery in the Hanford Reach, although smaller releases have occurred in the vicinity of Priest Rapids Dam (Appendix D). The stocks most commonly used in the Hanford Reach releases have been from the Carson NFH, and the WDFW Cowlitz and Klickitat River Hatcheries (Appendix D). There is no documented observation of spawning by spring-run chinook salmon in the Hanford Reach nor any other mainstem locations in the Columbia River (Fish and Hanavan 1948, Fulton 1968, WDF et al. 1993, Chapman et al. 1995). It is probable that many of the adults produced from these mainstem releases sought out tributary spawning areas. Stuehrenberg et al. (1995) observed adult hatchery spring-run chinook salmon from the Ringold Hatchery releases passing over Priest Rapids Dam. Spawned-out carcasses from Ringold Hatchery releases have been recovered in the Wenatchee River Basin (Peven 1994).

12) Upper Columbia Summer- and Fall-Run ESU

Artificial propagation in this ESU began in 1899, when hatcheries were constructed on the Methow and Wenatchee rivers (Mullan 1987). The Tumwater Hatchery on the Wenatchee River apparently released only 600,000 chinook salmon fry in 1903, while a hatchery on the Methow River produced primarily coho salmon, but a few chinook salmon were released as well before it was closed in 1913 (Craig and Suomela 1941, Nelson and Bodle 1990). The Leavenworth State Hatchery operated in the Wenatchee River Basin between 1913 and 1931. Eggs were procured from the Willamette River (spring-run chinook salmon), and from the Chinook Hatchery on the lower Columbia River (probably “tule” fall-run chinook salmon), apparently due to difficulties associated with collecting native stocks. In 1915, a hatchery at Pateros in the Methow River Basin released chinook salmon of lower river origin, but Craig and Suomela (1941) concluded that these fish probably were not able to successfully return to the Methow River . Between 1931 and 1939, no chinook salmon hatcheries were in operation above Rock Island Dam. Chinook salmon were released from the county trout hatchery at Kittitas, Washington from about 1923 to 1931. There is no record of any eggs being collected at this site, but approximately 6,500,000 chinook salmon fry (most likely fall-run chinook salmon from the Kalama River Hatchery) were released into the Yakima River Basin (WDF 1934).

The construction of Grand Coulee Dam (1941, RKm 959) prevented thousands of adult spring-run chinook salmon from reaching their natal streams. In an effort to mitigate the loss of spawning habitat above the dam, the Grand Coulee Fish Maintenance Project (GCFMP) was authorized by the federal government. The GCFMP sought to relocate all chinook salmon migrating past Rock Island Dam (RKm 730) into three of the remaining accessible tributaries to the Columbia River: the Wenatchee, Entiat, and Methow Rivers. As a part of this relocation, efforts were made to improve salmonid habitat (primarily through the screening of irrigation systems) and to increase run sizes through artificial propagation (Fish and Hanavan 1948). Several hatchery sites were designated as part of the GCFMP; the primary site on Icicle Creek, a tributary to the Wenatchee River, would later become the Leavenworth NFH (1940). Secondary substations were to be located on the Entiat (Entiat NFH, 1941), Methow (Winthrop NFH, 1941), and Okanogan Rivers. The hatchery on the Okanogan River was never developed due to the lack of a suitable site and wartime building restrictions (Fish and Hanavan 1948).

In 1938, the last salmon was allowed to pass upstream through the uncompleted Grand Coulee Dam. The trapping of adult salmon at Rock Island Dam began in May 1939 and continued until the autumn of 1943. Spring- and summer/fall-run fish were differentiated according to the time of their arrival at Rock Island Dam. A separation date of 9 July was established, based on weekly counts observed during 1933-38 (Fish and Hanavan 1948). However, Mullan (1987) estimated that 23 June was a more accurate discriminator between the two run times. It is likely that some summer-run fish were misidentified as belonging to the spring run. The GCFMP combined all late-run fish passing Rock Island Dam, including those destined for now-inaccessible spawning areas in Washington and British Columbia (Fish and Hanavan 1948). Offspring of these adults were reared at the newly constructed Leavenworth, Entiat, and Winthrop NFHs, and transplanted into the Wenatchee, Methow, and Entiat Rivers (Fish and Hanavan 1948). Furthermore, a number of late-run adults were transported to Nason Creek, a tributary to the Wenatchee River, and the Entiat River and allowed to spawn naturally.

The only tributary above Rock Island Dam that did not receive spawning adults or mixed-stock hatchery juveniles during the 5-year GCFMP was the Okanogan River (Fish and Hanavan 1948, Mullan et al. 1992). Chinook salmon adults destined for the Okanogan River from 1939 to 1943 were intercepted and included in the GCFMP mitigation efforts. With the exception of possibly a very small number of 6-year-old chinook salmon, native Okanogan River fish were eliminated or absorbed into other populations. The ocean-type chinook salmon now observed in the Okanogan River are likely strays originating from other tributaries or from the mainstem Columbia River (Mullan 1987).

Spawning channels were constructed near Wells, Rocky Reach, and Priest Rapids Dams in the mid-1960s and continued operations for several years, but were eventually abandoned due to high pre-spawning mortality and overall poor production of returning adults; these facilities were converted to conventional hatcheries and are currently in operation near these sites (Nelson and Bodel 1990). In addition, several acclimation ponds are now being used as a part of recent management changes to develop local stocks for Columbia River tributaries above Priest Rapids Dam (Chapman et al 1994).

Ocean-type chinook salmon in this ESU have been mixed considerably over the past five decades, not only among stocks, but among putative "runs" as well. This mixing was due to the variety of methods employed to collect broodstock at dams, hatcheries, or other areas and as a result of juvenile introductions into various areas (reviewed in Chapman et al. 1994). Recoveries of coded-wire-tagged adults derived from juvenile releases in the late 1970s and 1980s have indicated that wild and hatchery summer-run fish originating from above Rock Island Dam have spawned extensively with fall-run fish originating from the Hanford Reach and Priest Rapids Hatchery (Chapman et al. 1994). Similarly, a recent study of radio-tagged chinook salmon found that 10% of summer-run fish were distributed in the mainstem upper Columbia River (typically considered fall-run spawning habitat), while about 25% of fall-run chinook salmon (released from below the Priest Rapids Dam) were recovered as summer-run fish at Wells Hatchery and in the Okanogan River (Stuehrenberg et al. 1995). The possibility that substantial genetic exchange has taken place between chinook salmon populations above and below Rock Island Dam was hypothesized nearly 50 years ago (Fish and Hanavan 1948). Marshall et al. (1995) and Waknitz et al. (1995) reported that, partly as a result of hatchery practices, the genetic difference between summer- and fall-run chinook salmon in this ESU was "relatively small" and "essentially zero," respectively. Modifications in hatchery protocols and facilities in order to maintain discrete hatchery stocks have only recently been initiated (Utter et al. 1995).

There are currently no hatchery facilities on the Yakima River for ocean-type chinook salmon; however, the Yakima River has been heavily stocked with "upriver bright" ocean-type chinook salmon since 1980 (Appendix D). These transplanted stocks are reported to stray at substantial rates (Busack 1990, Hymer et al. 1992b, WDF et al. 1993). Similarities in the genetic composition among Yakima River, Hanford Reach, and Priest Rapids Hatchery ocean-type chinook salmon (Marshall et al. 1995, Waknitz et al. 1995) are thought to reflect the impact of hatchery releases of Hanford Reach/Priest Rapids fish on Yakima River chinook salmon (Busack et al. 1991). An average of 1 million "upriver bright" chinook salmon (none of which were derived from Yakima River returning adults) were released annually into the Yakima River Basin between 1980 and 1994 (Appendix D). In addition, strays from other programs, primarily the Umatilla River restoration effort, have been observed in the Yakima River (WDF et al. 1993). State and tribal management agencies have designated the Yakima River fall-run chinook salmon stock as of "unknown origin" and composite (mixed hatchery-derived and natural) production (WDF et al. 1993). There have been a limited number of unsuccessful summer-run chinook salmon introductions into the Yakima River as part of an effort to restore the early part of the ocean-type chinook salmon run (Appendix D).

Hatchery efforts with ocean-type chinook salmon in this ESU have been continuous and intensive since the implementation of the GCFMP, with numerous hatcheries constructed beginning in 1941 (Waknitz et al. 1995). From 1941 to the present, over 200 million ocean-type chinook salmon have been released into ESU 12 as either 0-age or yearling fish (Table 6). The percentage of non-indigenous stocks incorporated into this ESU has been low (about 3%), and does not appear to have had a significant impact on the integrity of this ESU (Chapman et al. 1995, Waknitz et al. 1995). However, the scale of hatchery chinook salmon elsewhere in the Columbia River Basin may pose risks for populations within this ESU. For example, as a result of large releases of ocean-type chinook salmon in the mainstem Columbia River and in the Yakima River in recent years, a substantial portion (approximately 50%) of the adults returning to ESU 12 appear to be of hatchery origin (Miller et al. 1990).

13) Upper Columbia River Spring-Run ESU

Early attempts to establish hatcheries on the Columbia River above the confluence of the Yakima River were generally unsuccessful. Beginning in 1899 with the construction of a fish hatchery on the Wenatchee River by the Washington Department of Fisheries and Game, hatcheries were constructed and subsequently abandoned on the Colville, Little Spokane, and Methow Rivers. Hatchery records indicate that relatively few chinook salmon were spawned (Craig and Suomela 1941). Attempts to improve the spring chinook salmon run with imported eggs (most notably from the upper Willamette River) were also apparently unsuccessful (Craig and Suomela 1941). By the 1930s, hatchery propagation of spring-run fish on the upper Columbia River had been terminated (WDF 1934).

The objectives and jurisdiction of the GCFMP are described in the previous ESU section. Adults collected for the GCFMP at Rock Island Dam were either transported to Nason Creek on the Wenatchee River to spawn naturally (1939-43), or to Leavenworth NFH for holding and subsequent spawning (1940-43). Over the course of 4 years, Nason Creek received 10,578 adult fish, of which an estimated 63.6% spawned successfully (Fish and Hanavan 1948). Beginning in 1940, some of the spring-run chinook salmon trapped at Rock Island Dam were spawned at the Leavenworth NFH. Eggs were incubated on site or transferred to the Entiat and Winthrop NFH. Almost 4 million fry and fingerlings were produced from adults collected at Rock Island Dam and subsequently released into the Wenatchee, Entiat, and Methow Rivers between 1940 and 1944 (Mullan 1987). In 1944, salmon were allowed to freely pass Rock Island Dam. In 1944 and 1945, a small number of spring-run adults returned to the Leavenworth and Winthrop NFHs; however, counts of fish migrating past Rock Island Dam indicated that a substantial number of fish probably spawned in the upriver tributaries (Fish and Hanavan 1948).

Artificial propagation efforts at Leavenworth NFH and Entiat NFH focused on the production of summer-run chinook salmon and other salmonids after 1943. In contrast, the culture of spring-run chinook salmon using local stocks continued at the Winthrop NFH through 1961. In the mid-1970s, there was a renewed effort to emphasize the production of spring-run chinook salmon at the three NFHs. In addition to the use of local stocks, there were large transfers of spring-run stocks from non-local sources: Carson NFH (Carson NFH stock), Little White Salmon NFH (Carson NFH stock), Klickitat WDFW hatchery (Klickitat River stock), and Cowlitz WDFW hatchery (Cowlitz River stock). In the early 1980s, imports of non-native eggs were reduced significantly, and thereafter the Leavenworth, Entiat, and Winthrop NFHs have relied on adults returning to their facilities for their egg needs (Chapman et al. 1995). Despite the current use of "local" fish in these hatcheries, a considerable amount of genetic introgression has probably occurred. Leavenworth, Entiat, and Winthrop NFH stocks are considered non-native (WDF et al. 1993), primarily derived from Carson NFH stocks (Hymer et al 1992b, Marshall et al. 1995). The current impact of hatchery fish on naturally spawning populations, especially those upriver from hatchery locations, appears to be slight, based on CWT recoveries from carcasses on the spawning grounds (Chapman et al. 1995).

Hatchery operations at the three NFHs in this ESU have been hampered by disease outbreaks, primarily BKD (Howell et al. 1985, Mullan et al. 1992, Hymer et al. 1992b, Chapman et al. 1995), which has been suggested as one of the causes of the generally low return rates observed for releases from these hatcheries (Mullan 1987, Chapman et al. 1995).

There are currently two hatcheries in this ESU operated by WDFW. The Methow Fish Hatchery Complex (MFHC, 1992) and Rock Island Fish Hatchery Complex (RIFHC, 1989) were both designed to implement supplementation programs for naturally-spawning populations on the Methow and Wenatchee Rivers, respectively (Chapman et al. 1995). The RIFHC uses broodstock collected at a weir on the Chiwawa River. Bugert (1998) discusses some of the difficulties these programs have experienced. Similarly, the MFHC uses returning adults collected at weirs on the Methow River and its tributaries, the Twisp and Chewuch Rivers (Chapman et al. 1995, Bugert 1998). Progeny produced from these programs are reared at and released from satellite sites on the tributaries where the adults were collected. Numerous other facilities have reared spring-run chinook salmon but on an intermittent basis.

14) Snake River Fall-Run ESU

In contrast to the lower and upper Columbia River, there was little effort directed toward the propagation of Snake River anadromous salmonids from the turn of the century through the 1960s, although a facility in the Grande Ronde River released an unknown number of fall-run chinook salmon between 1903 and 1907 (Howell et al. 1985). Early artificial propagation programs for fall-run chinook salmon in the Snake River were of limited scale and had little effect prior to 1976 (Howell et al. 1985, Waples et al. 1991b). Releases of marked fall-run chinook salmon (acquired from the Little White Salmon NFH) into the Salmon River in the 1920s did not result in any observed return of adults (Rich and Holmes 1928). In the early 1960s, eyed eggs from Snake River stocks were released above and below dams in the upper Snake River, but these efforts were apparently unsuccessful (Waples et al. 1991b).

In 1964, the Idaho Power Company was required to construct the Oxbow Hatchery below Oxbow Dam to mitigate the effects of the dam on fish returning to that section of the Snake River

(Wahle and Smith 1979). Several million juveniles were released in the upper Snake River and in reservoirs above Oxbow Dam, but few returns were observed and the program was abandoned shortly thereafter. From 1955 to the present, fall-run chinook salmon juveniles have been released in reservoirs, apparently to provide sport fishing opportunities (Appendix D).

In 1960 and 1970, eyed eggs and juveniles, respectively, from the Spring Creek NFH were introduced into the Clearwater River Basin, but these efforts produced limited numbers of returning adults (Howell et al. 1985, Waples et al. 1991b). From 1960 to 1967, between 0.4 and 1.6 million eggs were collected annually at Oxbow Dam and transferred to the Clearwater River, but probably did not contribute many returning adults to the system (Waples et al. 1991b). Egg transfers to the Clearwater River were terminated in 1968.

Hatchery efforts to mitigate the effects of dam construction on fall-run chinook salmon populations in the Snake River Basin increased after the initiation of the Lower Snake River Compensation Plan (LSRCP) in 1976 (Mathews and Waples 1991). This program included the development of an egg bank program to ensure the genetic integrity of Snake River fall-run chinook salmon prior to the construction of propagation facilities dedicated to the compensation plan (Bugert and Hopley 1989, Nelson and Bodle 1990). This program involved, in part, the release of Snake River fall-run chinook salmon from the Kalama Falls Hatchery (WDFW) on the Kalama River, with additional egg incubation and early rearing being undertaken at the Hagerman NFH in Idaho (Waples et al. 1991b). As many as 1,500 adult Snake River fall-run chinook salmon returned annually to the Kalama Falls Hatchery or Ice Harbor Dam from 1981 to 1986 (Howell et al. 1985, Waples et al. 1991b).

Broodstock operations were transferred to the WDFW Lyons Ferry Hatchery when it began operations in 1984 (Delarm and Smith 1990d, Waples et al. 1991b). The Lyons Ferry Hatchery broodstock was derived from the Kalama Falls egg bank program and fish collected at Ice Harbor and Lower Granite Dams (Chapman et al. 1991). As a result of low numbers of naturally produced fall-run chinook salmon and an increasing number of hatchery-produced fish, the Snake River fall chinook salmon run was thought to be a composite of hatchery- and naturally produced fish by the mid-1980s (Howell et al. 1985). There are concerns that hatchery fish may now comprise a disproportionate number of naturally spawning fish throughout the Snake River Basin (ODFW 1991). Tagged fish from the Lyons Ferry Hatchery have been recovered from the mainstem Snake River and the Tucannon River (Nelson and Bodle 1990, Marshall et al. 1995). Between 7% and 67% (mean 38%) of fall-run chinook salmon passing over Lower Granite Dam have been first-generation hatchery fish (ODFW 1991). In addition, strays from the upper Columbia River Basin have recently been observed in substantial numbers (4% to 39%) at Lyons Ferry Hatchery, Lower Granite Dam, and on the spawning grounds (Waples et al. 1991b, Garcia et al. 1996, Mendel et al. 1996). There have not been any hatchery programs for fall-run chinook salmon on the Oregon side of the lower Snake River, although strays of mixed ancestry from the reintroduction program on the Umatilla River (Columbia River tributary) have been observed in the Snake River since the late 1980s (Chapman et al. 1991, Mendel et al. 1996). All Umatilla River hatchery fall-run chinook salmon are now being marked so they can be intercepted at the

Snake River dams (Kostow 1995). Overall, with a few minor exceptions, native stocks have been used in Snake River fall-run chinook salmon hatchery programs (Table 6).

ODFW has also never had a fall-run chinook salmon hatchery on the Deschutes River (Kostow 1995). Small numbers of locally-derived and non-native fall-run chinook salmon were released into the Deschutes River up to the late 1970s; however, the success of these introductions is believed to have been very low (Howell et al. 1985). A limited number of strays from hatcheries on other rivers have been observed on the Deschutes River spawning grounds (Kostow 1995).

15) Snake River Spring- and Summer-Run ESU

Artificial propagation efforts did not occur in ESU 15 as early as in other regions, nor in the same magnitude. From 1921 to 1934, the U.S. Fish and Fisheries Commission operated a hatchery at Salmon, Idaho. Eggs were collected from spring- and summer-run chinook salmon adults returning to the Lemhi and Pahsimeroi Rivers and the Yankee Fork of the Salmon River (Bowles and Leitzinger 1991). In all, 26,483,000 eggs were collected from local sources, incubated, and the progeny released into local waters. An additional 9,720,000 eggs were transferred to the Salmon River Hatchery (Idaho) substation from outside sources (7,720,000 from the McKenzie River and 2,000,000 eggs from the Little White Salmon NFH). The majority of juvenile fish were released as fingerlings. Following the 1934 broodyear, the Salmon hatchery was primarily devoted to trout production (Wahle and Smith 1979). Overall, stock transfers into the Snake River Basin were minimal prior to the mid-1900s (Matthews and Waples 1991).

Currently, the major spring- and summer-run chinook salmon propagation facilities (satellite facilities or adult collection weirs in parentheses) operating in the Snake River Basin area are: WDFW's Tucannon and Lyons Ferry Hatcheries; ODFW's Lookingglass and Wallowa (Big Canyon) Hatcheries; IDFG's Sawtooth (East Fork Salmon River), McCall, and Clearwater (Powell, Red River) Hatcheries; IPC's Rapid River and Pahsimeroi Hatcheries; and USFWS's Dworshak and Kooskia Hatcheries (Delarm and Smith 1990b). Stocks used in most ESU 15 hatcheries were derived from mixtures of non-indigenous stocks, or from a mix of non-indigenous and native stocks. Among the fish released into various Snake River Basins, there have been introductions from the Carson, Little White Salmon and Leavenworth NFHs, various Willamette River hatcheries, and the Cowlitz and Klickitat state hatcheries (Matthews and Waples 1991). The Tucannon River spring-run chinook salmon stock used at the Lyons Ferry Hatchery, the Imnaha River spring-run chinook salmon stock (reared at the Lookingglass Creek Hatchery, but released into the Imnaha River), and the Upper Salmon River Sawtooth Hatchery spring-run stock appear to have had minimal influence from out-of-basin stocks (Matthews and Waples 1991, Keifer et al. 1992). Additionally, the South Fork Salmon River summer-run chinook salmon stock reared at the McCall Hatchery has probably had minimal influence from outside sources (Matthews and Waples 1991, Keifer et al. 1992).

Spring- and summer-run stocks currently in the Clearwater River Basin are not part of this ESU, but artificial propagation activities for the basin are covered here because of their potential impact on the ESU. Native runs of spring- and summer-run chinook salmon on the Clearwater River were probably eliminated following the construction of the Lewiston Dam (1927) on the lower Clearwater River (Keifer et al. 1992). Modifications in the fish migration facilities at the dam were made in 1940, and from 1947 to 1953 approximately 100,000 spring-run chinook salmon eggs from the Middle Fork Salmon River were introduced annually into the Little North Fork of the Clearwater River (Fulton 1968, Keifer et al. 1992). Spawning channels on the Selway River were used in restoration efforts in the Clearwater River Basin. From 1961 to 1985 nearly 50 million eggs from the Rapid River Hatchery, Carson NFH, Spring Creek NFH, and the Salmon River were placed into various rearing/spawning channels (Keifer et al. 1992). The success of these transfers is unknown. In an effort to mitigate the effects of the construction of the Dworshak Dam, the Kooskia and Dworshak NFHs were constructed in 1967 and 1969, respectively (Keifer et al. 1992). Broodstock for these hatcheries came primarily from the Rapid River Hatchery, with significant contributions from Carson-stock hatcheries (Leavenworth, Little White Salmon, and Carson NFHs) and Willamette River hatcheries. Millions of fish have been released from the Dworshak and Kooskia Hatcheries, primarily as yearling smolts. More recently, these facilities have utilized adults returning to the hatcheries or satellite collection sites to supply gametes for their programs (Keifer et al. 1992).

Prior to 1985, the Tucannon River spring-run chinook salmon population was maintained entirely by natural production (Howell et al. 1985). A limited number of non-native fish were introduced in the Tucannon River—16,000 Klickitat River and 10,500 Willamette River spring-run chinook salmon in 1962 and 1964, respectively. Native broodstock were used to establish the Tucannon Hatchery spring-run chinook salmon population, although the number of fish available was limited (the total adult run size was approximately 200 fish during the early 1980s) (Howell et al. 1985). The absence of other spring-run chinook salmon propagation facilities nearby has probably limited introgression by non-native stocks, although a limited number of CWT-tagged hatchery-derived fish from the Umatilla River and Grande Ronde River (Rapid River stock) have been recovered (Marshall et al. 1995).

Spring-run chinook salmon hatchery programs were established in Oregon in the early 1980s as part of the LSRCP (ODFW 1991). The founding stocks used were transferred from the Carson NFH, and from the IDFG Rapid River Hatchery, which was founded from a mixture of Snake River populations (Howell et al. 1985, ODFW 1991). The Lookingglass Creek Hatchery initially utilized stock from the Carson NFH in 1982; however, adult returns were so poor and straying rates so high that the use of Carson stock was discontinued (Chapman et al. 1991, Kostow 1995). Carson NFH juveniles were also released into several non-hatchery streams and the returning adults may have interbred with native fish (ODFW 1991). Several years ago it was suggested that the hatchery programs “may be impeding the recovery of the wild populations in streams where hatchery facilities are located or where hatchery fish have been outplanted” (ODFW 1991, p. 14). Rapid River stock was subsequently imported during the late 1980s

(Olsen et al. 1992). Beginning in 1989, returning adults (originating primarily from the Rapid River introductions) to Lookingglass Hatchery have provided gametes to produce subsequent releases (Olsen et al. 1992, Kostow 1995). Native stream-type chinook salmon populations in Lookingglass Creek are now thought to be extinct, and the location of current releases of the Lookingglass Hatchery stock has been restricted to prevent further introgression (Kostow 1995, Currens et al. 1996). For the past several years, stray hatchery fish of Rapid River stock origin have, on average, represented about half of all natural spawners throughout the Grande Ronde Basin (Crateau 1997). By contrast, the Imnaha River Acclimation Pond facility (1982) has collected gametes only from adults returning to the river, although the eggs have been incubated and juveniles reared at the Lookingglass Hatchery before being returned to the Imnaha site (Chapman et al. 1991, Olsen et al. 1992).

Several facilities for the propagation of spring- and summer-run chinook salmon exist in the Salmon River Basin. The Rapid River facility (1964) was constructed to mitigate the loss of spring-run chinook salmon spawning habitats resulting from the construction of the Hells Canyon Dam complex (Howell et al. 1985). Broodstock were collected from a trap at the Hells Canyon Dam on the Snake River from 1964 to 1969, and thereafter from broodstock returning to the hatchery weir on the Rapid River (Keifer et al. 1992). Fish from the Rapid River Hatchery and satellite facilities have been released in considerable numbers in the Rapid, Salmon, Snake, Clearwater, and Grande Ronde Rivers (Howell et al. 1985, Keifer et al. 1992). The Sawtooth Hatchery and satellite facilities (1985) on the Upper Salmon River have collected native returning spring chinook salmon for broodstock purposes (Howell et al. 1985, Delarm and Smith 1990b, Keifer et al. 1992). Rapid River fish were introduced into nearby watersheds through the 1980s (Keifer et al. 1992) and were used initially at the Sawtooth Hatchery.

Summer-run chinook salmon are propagated at McCall Hatchery (1980) and Pahsimeroi Hatchery (1969) (Delarm and Smith 1990b). The McCall Hatchery broodstock was initially collected at Little Goose and Lower Granite Dams and contained a mixture of Snake River summer-run stocks, with a lesser contribution by Snake River spring-run stocks (Chapman et al. 1991). Since 1981, a satellite facility on the South Fork Salmon River has collected adults (which consisted of returning McCall Hatchery releases and summer-run fish native to the South Fork Salmon River) to be used as broodstock for the McCall Hatchery (Keifer et al. 1992). The McCall Hatchery has been responsible for the majority of the 11 million juvenile summer chinook salmon released into the South Fork Salmon River (Appendix D). The Pahsimeroi Hatchery broodstock was founded with native summer-run fish returning to the Pahsimeroi River (Keifer et al. 1992). However, summer-run chinook salmon from the South Fork Salmon River (McCall Hatchery) were introduced into the Pahsimeroi River during 1985-90, and may have been integrated into the Pahsimeroi Hatchery broodstock (Keifer et al. 1992). Spring-run chinook salmon (Rapid River Hatchery stock) were also reared and released at the Pahsimeroi Hatchery for a limited time during the 1980s.

The Carson NFH stock has had a poor history in the Snake River Basin, not only for stock restoration, but also when used as a hatchery stock to increase harvest opportunities. Abundance in streams receiving Carson NFH fish is less than or no different than unenhanced streams (Chapman et al. 1991).

ASSESSMENT OF EXTINCTION RISK

Background

The U.S. Endangered Species Act (ESA) (Section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." NMFS considers a variety of information in evaluating the level of risk faced by an ESU. Important considerations include 1) absolute numbers of fish and their spatial and temporal distribution; 2) current abundance in relation to historical abundance and carrying capacity of the habitat; 3) trends in abundance, based on indices such as dam or redd counts or on estimates of spawner-recruit ratios; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., selective fisheries and interactions between hatchery and natural fish); and 6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the ESU. Additional risk factors, such as disease prevalence or changes in life-history traits, may also be considered in evaluating risk to populations.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. In this review, we did not evaluate likely or possible effects of conservation measures. Therefore, we do not make recommendations as to whether identified ESUs should be listed as threatened or endangered species, because that determination requires evaluation of factors not considered by us. Rather, we have drawn scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue (recognizing, of course, that natural demographic and environmental variability is an inherent feature of "present conditions"). Conservation measures will be taken into account by the NMFS Northwest and Southwest Regional Offices in making listing recommendations. Also, as noted in the “Introduction” above, this review does not attempt to fully evaluate causal factors leading to the present status of chinook salmon, nor to rank the importance of such factors. In this report, such factors are considered only to the extent that they contribute to an evaluation of risk presently facing these stocks. A separate document identifies factors for decline of chinook salmon from Washington, Oregon, California, and Idaho, and is prepared subsequent to any proposed listing recommendation.

Aspects of several of these risk considerations are common to all chinook salmon ESUs. These are discussed in general below; more specific discussion of factors for each of the 15 ESUs under consideration here can be found in the following sections. Status reviews have previously been conducted for some of the ESUs identified. Reevaluation of the risk faced by these ESUs was limited.

Absolute Numbers

The absolute number of individuals in a population is important in assessing two aspects of extinction risk. For small populations that are stable or increasing, population size can be an indicator of whether the population can sustain itself into the future in the face of environmental fluctuations and small-population stochasticity; this aspect is related to the concept of minimum viable populations (MVP) (Gilpin and Soulé 1986, Thompson 1991). For a declining population, the present abundance is an indicator of the expected time until the population reaches critically low numbers; this aspect is related to the concept of "driven extinction" (Caughley 1994). In addition to total numbers, the spatial and temporal distribution of adults is important in assessing risk to an ESU. Spatial distribution is important both at the scale of river basins within an ESU and at the scale of spawning areas within basins ("metapopulation" structure). Temporal distribution is important both among years as an indicator of the relative health of different brood-year lineages and within seasons as an indicator of the relative abundance of different life-history types or runs.

Traditionally, assessment of salmonid populations has focused on the number of harvestable and/or reproductive adults, and these measures comprise most of the data available for Pacific salmon and steelhead. In assessing the future status of a population, the number of reproductive adults is the most important measure of abundance, and we focus here on measures of the number of adults escaping to spawn in natural habitat. However, total run size (spawning escapement + harvest) is also of interest because it indicates potential spawning in the absence of harvest. Data on other life-history stages (e.g., freshwater smolt production) can be used as a supplemental indicator of abundance.

Because the ESA (and NMFS policy) mandates that we focus on viability of natural populations, we attempted to distinguish natural fish from hatchery-produced fish in this review. All statistics are based on data that indicate total numbers or density of adults that spawn in natural habitat ("naturally spawning fish"). The total of all naturally spawning fish ("total escapement") is divided into two components (Fig. 28): "hatchery produced" fish are reared as juveniles in a hatchery but return as adults to spawn naturally; and "natural" fish are progeny of naturally spawning fish. This approach does not distinguish natural fish of hatchery heritage from those of strictly native, natural origin. Although, such a distinction would be useful, in our experience there is rarely information available on which to make such a distinction. To the extent that stocking records and/or hatchery practices shed light on this distinction, that information is taken into account in considering genetic integrity of the population (discussed below).

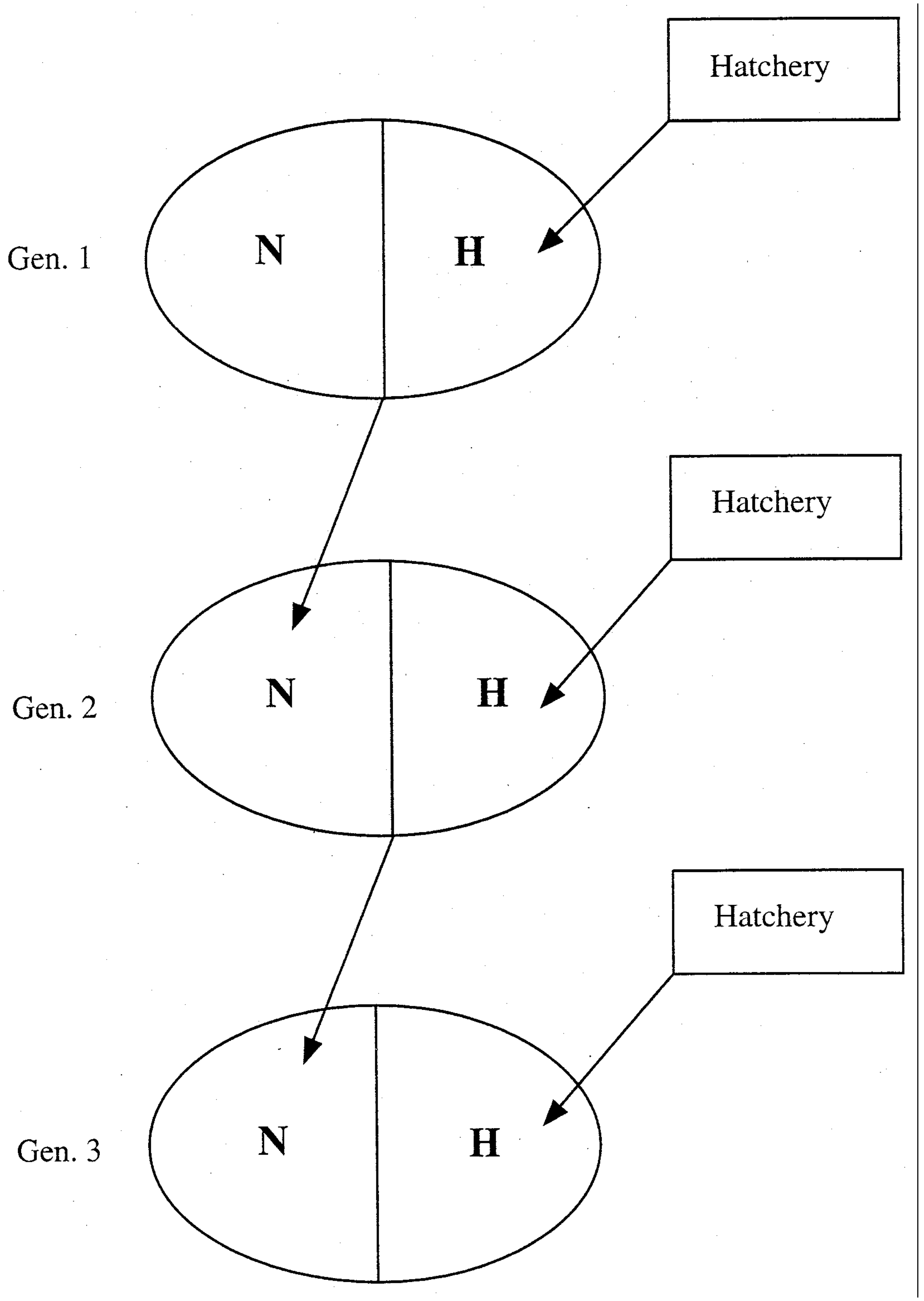

Figure 28. Schematic diagram of mixing of naturally (N) and hatchery- (H) produced fish in natural habitat. Ovals represent the total spawning in natural habitat each generation. This total is composed of naturally produced and hatchery-produced offspring of individuals in the previous generation.

Historical Abundance and Carrying Capacity

Knowing the relationship of present abundance to present carrying capacity is important for evaluating the health of populations; but the fact that a population is near its current capacity does not necessarily signify full health. A population near capacity implies that short-term management may not be able to increase fish abundance. This also implies that competition and other interactions between hatchery and natural fish may be an important consideration for increasing the abundance of naturally spawning populations, because releases of hatchery fish may further increase population density in a limited habitat.

The relationship of current abundance and habitat capacity to historical levels is an important consideration in evaluating risk. Knowledge of historical population conditions provides a perspective for understanding the conditions under which present populations evolved. Historical abundance also provides the basis for scaling long-term trends in populations. Comparison of present and past habitat capacity can also indicate long-term population trends and problems of population fragmentation.

In this review, application of these principles was limited by lack of reliable estimates of historic abundance and historic or current capacity for most chinook salmon populations.

Trends in Abundance

Short- and long-term trends in abundance are a primary indicator of risk in salmonid populations. Trends may be calculated from a variety of quantitative data, including dam or weir counts, stream surveys, and catch data. Regular sampling, of one kind or another, has been conducted on chinook salmon populations in the larger basins within the reviewed area. These data sources and methods are discussed in more detail below, under "Approach." Interpretation of trends in terms of population sustainability is difficult for a variety of reasons: First, chinook salmon are harvested in heavily managed fisheries, and shifting harvest goals directly affect trends in spawning escapement. Second, environmental fluctuations on short timescales affect trend estimates, especially for shorter trends; this is a particular problem in this review because numerous abundance data series began in the mid-1980s, a period of relatively high chinook salmon abundance throughout much of the West Coast. Third, artificial propagation has a strong influence on trends of many chinook salmon populations.

Naturally-spawning hatchery fish

Waples (1991a,b) and Hard et al. (1992) discussed the role of artificial propagation in ESU determination and emphasized the need to focus on natural production in the threatened or endangered status determination. Because of the ESA’s emphasis on ecosystem conservation, this analysis focuses on naturally reproducing fish. An important question in evaluating risk is thus: Is natural production sufficient to maintain the population without the constant infusion of artificially produced fish? A full answer to this question is difficult without extensive studies of relative production and interactions between hatchery and natural fish. When such information is lacking, the presence of hatchery fish in natural populations leads to substantial uncertainty in evaluating the status of the natural population. One method of approaching this issue involves calculating the natural cohort replacement ratio, defined as the number of naturally spawning adults that are naturally produced in one generation divided by the number of naturally spawning adults (regardless of parentage) in the previous generation. Data for chinook salmon are rarely sufficient for this calculation, and we have not attempted to estimate this ratio in this report. However, the ratio can be approximated from the average population trend if the degree of hatchery contribution to natural spawning can be estimated. Where such estimates were available, the presence of hatchery fish among natural spawners was taken into consideration in evaluating the sustainability of natural production for individual populations in this review.

Habitat

A major determinant of trends in salmon abundance is the condition of the freshwater, estuarine, and ocean habitats on which salmon depend. While we rarely have sufficient information to predict the population-scale effects of habitat loss or degradation with any precision, it is clear that habitat availability imposes an upper limit on the production of salmon, and any reduction in habitat reduces potential production. Even in areas where we have no information on trends in population abundance, evidence of widespread loss of habitat can indicate a serious risk for sustainability of natural populations. The National Research Council Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (NRCC 1996) identified habitat problems as a primary cause of declines in wild salmon runs. NMFS (1996b) identified habitat concerns as one of a suite of factors affecting the decline of salmon occurring within the range of West Coast steelhead. Some of the habitat impacts identified were the fragmentation and loss of available spawning and rearing habitat, alteration of streamflows and streambank and channel morphology, migration delays, degradation of water quality, alteration of ambient stream water temperatures, sedimentation, loss of spawning gravel, pool habitat and large woody debris, removal of riparian vegetation, and decline of habitat complexity (CACSST 1988, FEMAT 1993, NMFS 1996b). The Pacific Fishery Management Council (PFMC 1995) also identified loss of habitat as one of the main reasons for declines in salmon stocks, and identified fourteen "vital habitat concerns”: California's Central Valley Water Project, San Francisco Bay and Sacramento-San Joaquin River water quality standards, Columbia-Snake River hydropower operations, instream flow, unscreened or inadequately screened water diversions, inadequate fish passage at road culverts, water spreading (unauthorized use of federally developed water supplies), upland land use practices and polluted runoff, fish passage at existing hydroelectric projects, agricultural practices, urban growth and land conversion, contaminants in coastal wetlands and estuaries, offshore oil and gas development and transportation, and dredge spoil disposal. Several regional reports summarize many of the problems related to habitat for chinook salmon (for example, Bottom et al. 1985, Reynolds et al. 1993, Bishop and Morgan 1996). There are numerous other studies of habitat problems in local areas, many of which are cited in the "Analysis of Biological Information" below. However, a full evaluation of the extent to which habitat conditions or other factors contribute to the status of chinook salmon stocks, and identification which factors that are most important contributors to risk, is beyond the scope of this review.

Assessing the effects of habitat changes on future sustainability of populations is difficult. Human populations are projected to continue increasing in most areas of the West Coast, and water impoundments and diversions, as well as logging and agricultural activities, can be expected to continue into the future (Gregory and Bisson 1997). These facts indicate that there will be some continuing losses of salmon habitat for the foreseeable future. By contrast, recent changes in forest and agricultural practices and improved urban planning have reduced the rate of habitat loss in many areas, and many areas are recovering from severe past degradation. Whether natural recovery and active restoration in some areas will compensate for continued losses in other areas is unknown.

Regional perspective

Recent trends in coastwide chinook salmon abundance provide a larger perspective for this review. From the early part of the century through the 1980s, coastwide commercial landings of chinook salmon have declined by roughly half, but this may reflect changes in fisheries as much as declines in abundance. In the early part of the century, nearly all commercial fisheries in this region operated in freshwater, where they harvested only mature salmon. Most recent commercial harvest of chinook salmon in the region considered in this review occurs in saltwater troll fisheries, where immature fish are harvested at smaller sizes than mature fish. Over the same period, the fraction of the total harvest taken by recreational fisheries has grown. By all accounts, however, there has been significant replacement of natural production with hatchery fish. Over a large region (British Columbia, Washington, Oregon, California, and Idaho), chinook salmon stocks (both natural and hatchery) have exhibited recent decreases in survival which may be due at least in part to changes in climate and ocean productivity.

Factors Causing Variability

Variation in production and/or survival is, along with trend and abundance, a primary determinant of demographic extinction risk. Salmon abundance tends to be highly variable, with interannual fluctuations in the range of 40-70% (Bisson et al. 1997). Variability in the freshwater and marine environments is thought to be a primary factor driving fluctuations in salmonid run-size and escapement (Pearcy 1992, Beamish and Bouillon 1993, Lawson 1993). Recent changes in ocean condition are discussed below. Because salmon have evolved and are adapted to variable systems (Bisson et al. 1997), variation in itself is not an indicator of risk to healthy populations. Habitat degradation and harvest have probably made stocks less resilient to poor climate conditions, but these effects are not easily quantifiable.

Threats to Genetic Integrity

Artificial propagation poses a number of genetic risks for natural salmon and steelhead populations in addition to the complications it brings to evaluation of natural replacement rates. These risks have been known for some time (e.g., Hynes et al. 1981, Allendorf and Ryman 1987, Hindar et al. 1991, Waples 1991a), but no consensus has emerged on how best to incorporate these concerns into adaptive management because of difficulties in quantifying the risks, a paucity of empirical data, and disagreements about how to proceed given these uncertainties (Cuenco et al. 1993, Campton 1995, Hard 1995, Currens and Busack 1995). In this section we describe some of the adverse genetic effects for natural populations that can occur as a result of artificial propagation and briefly discuss the factors that were used in this status review to evaluate these risks. This is an important component to the overall risk analysis because these effects generally would not be reflected in other indices of population health (e.g., abundance and trends). For example, interbreeding with hatchery fish might reduce fitness and productivity of a natural population, but whether this had occurred would be difficult to determine if hatchery fish continued to spawn naturally.

Busack and Currens (1995) and Campton (1995) identified several types of genetic risk from hatcheries and alternative ways of describing such risks. Interbreeding of hatchery and natural fish can lead to loss of fitness in local populations. Grant (1997) reviews and discusses genetic concerns regarding straying by non-native hatchery fish. Ricker (1972) and Taylor (1991) summarized some of the evidence for local adaptations in Pacific salmonids that may be at risk from interbreeding of hatchery and natural fish. Hatchery-wild interbreeding can also lead to loss of genetic diversity among populations. Interpopulational genetic diversity can help maintain long-term viability of an ESU because it buffers overall productivity against periodic or unpredictable changes in the environment (Fagen and Smoker 1989, Riggs 1990).

Various fish culture and management practices can affect the frequency and magnitude of hatchery-wild genetic interactions. For example, stock transfers or other aspects of hatchery programs that lead to substantial straying into natural populations can result in much higher rates of genetic exchange than would naturally occur among populations. Because the consequences of hatchery straying are determined by the proportion of natural spawners of hatchery origin rather than by the proportion of hatchery fish that stray (Grant 1997), the effects of a successful hatchery program can be substantial even if stray rates are modest. Management actions such as avoiding stock transfers, adopting release strategies that minimize straying, and marking and selectively harvesting hatchery fish can substantially reduce adverse effects on natural populations. The degree to which such actions succeed in isolating natural and hatchery production varies considerably from program to program and depends on a variety of factors.

Similarly, a number of approaches can be used in fish culture to minimize genetic changes and hence reduce the consequences of hatchery-wild genetic interactions when they do occur. For example, inbreeding and genetic drift are well understood at the theoretical level, and researchers have found inbreeding depression in various fish species, including some salmonids

(Allendorf and Ryman 1987). There is also good reason to believe that inbreeding can be an important concern for Pacific salmon hatcheries (Waples and Teel 1990, Ryman and Laikre 1991, Waples and Do 1994). However, we are not aware of empirical evidence for inbreeding depression or substantial loss of genetic variability in any natural or hatchery populations of Pacific salmon or steelhead (Hard and Hershberger 1995). Furthermore, some fairly straightforward fish culture practices (especially suitable broodstock collection and mating protocols) can significantly reduce the likelihood that hatchery populations will increase levels of inbreeding (Simon et al. 1986, Allendorf and Ryman 1987, Withler 1988, Waples and Do 1994). In contrast, selective changes arising from fish culture cannot be avoided even with the best fish culture practices. Because the selective regime in the hatchery environment differs in many important ways from that in the wild, and because a successful salmon hatchery profoundly changes the mortality profile of the population, some genetic divergence of a cultured population from a natural population is inevitable (Waples 1991a, Busack and Currens 1995, Campton 1995). The changes that do occur as a result of fish culture are unlikely to be beneficial to locally adapted natural populations.

In supplementation programs, which involve the intentional integration of hatchery and natural production, genetic risks posed by fish culture must be weighed against potential benefits to the natural population such as reducing short-term extinction risk and speeding recovery. Conducting a comprehensive risk/benefit analysis for salmon supplementation should be an integral part of adaptive management. We did not attempt such an exercise here because the focus of this report is on evaluating the status of natural populations rather than the merits of hatchery programs. Although a successful supplementation program might help move a natural population toward recovery, the existence of a hatchery program designed to assist recovery can be taken as an indication that the natural population is presently at some risk in its natural habitat, and that is an important consideration in the status review.

Finally, even if naturally spawning hatchery fish leave few or no surviving offspring, they still can have ecological and indirect genetic effects on natural populations. On the spawning grounds, hatchery fish may interfere with natural production by competing with natural fish for territory and/or mates and, if they are successful in spawning with natural fish, may divert production from more productive natural X natural crosses (Chapman et al. 1995). The presence of large numbers of hatchery juveniles or adults may also alter the selective regime faced by natural fish.

To evaluate genetic risks posed by artificial propagation, we consider a variety of factors related to the nature, scale, and duration of the hatchery programs that may interact with natural populations. These factors include the source of hatchery broodstock, the number of hatchery fish released, the number of years hatchery fish have been released into the system, differences in genetic and life-history characteristics (e.g., age structure and body size) between hatchery and natural fish, and the effectiveness of management strategies to isolate hatchery and natural fish. In cases where it is available, information on the numbers and proportions of hatchery and natural fish spawning naturally and their relative reproductive success is also considered. Studies that monitor genetic characteristics over time can also provide valuable insight into the consequences of hatchery-wild interactions.

Human actions other than artificial propagation can also affect the genetic characteristics and integrity of salmon populations. These factors include size-selective harvest regimes (Nelson and Soulé 1987, Thorpe 1993), introduction of non-native species, alterations of freshwater migration corridors by hydropower development, and other types of habitat modification. Unfortunately, empirical information for these types of genetic changes is even more sparse than it is for the effects of artificial propagation.

Recent Events

A variety of factors, both natural and human-induced, affect the degree of risk facing salmonid populations. Because of timelags in these effects and variability in populations, recent changes in any of these factors may affect current risk without any apparent change in available population statistics. Thus, consideration of these effects must go beyond examination of recent abundance and trends, but forecasting future effects is rarely straightforward and usually involves qualitative evaluations based on informed professional judgement. Events affecting populations may include natural changes in the environment or human-induced changes, either beneficial or detrimental. Possible future effects of recent or proposed conservation measures have not been taken into account in this analysis, but we have considered documented changes in the natural environment. A key question regarding the role of recent events is: Given our uncertainty regarding the future, how do we evaluate the risk that a population may not persist?

Climate conditions are known to have changed recently in the Pacific Northwest. Most Pacific salmonid stocks south of British Columbia have been affected by changes in ocean production that occurred during the 1970s. Pearcy (1992) and Lawson (1993) attribute this decline largely to ocean factors, but do not identify specific effects. Much of the Pacific Coast has also experienced drought conditions in recent years, which may depress freshwater production. At this time, we do not know whether these climate conditions represent a long-term shift in conditions that will continue affecting stocks into the future or short-term environmental fluctuations that can be expected to be reversed in the near future. Although recent conditions appear to be within the range of historic conditions under which local salmon populations have evolved, the risks associated with poor climate conditions may be exacerbated by human influence on these populations (Lawson 1993).

Other Risk Factors

Other risk factors typically considered for salmonid populations include disease prevalence, predation, and changes in life-history characteristics such as spawning age or size. Such factors may be important for individual populations, as noted in the ESU summaries below.

Approach

None of the elements of risk outlined above are easy to evaluate, particularly in light of the great variety in quantity and quality of information available for various populations. Two major types of information were considered: previous assessments that provided integrated reviews of the status of chinook salmon populations in our region, and data regarding individual elements of population status, such as abundance, trend, hatchery influence, and habitat conditions.

A major problem in evaluations of risk for salmon is combining information on a variety of risk factors into a single overall assessment of risk facing a population. Formal model-based population viability analysis (PVA) attempts to do this integration in a quantitative manner, resulting in a single estimate of extinction risk. Current models of salmon populations are inadequate for this type of analysis. In the absence of integrative models, it is still possible to define criteria for some individual risk categories, and use these criteria to devise simple rules for categorizing risk levels; Allendorf et al. (1997) advocated such an approach. However, this limits assessment to those factors for which adequate measurements are available for all population units under consideration. As our ability to measure some of the important risk and other factors is limited, data is often lacking for the populations most at risk. Our researchers need methods that allow inclusion of both quantitative and qualitative information. In this review, we have used a risk-matrix approach through which the BRT members applied their best scientific judgement to combine qualitative and quantitative evidence regarding multiple risks into an overall assessment. The matrix is more fully described in Appendix F.

It is also possible to construct simple demographic models to evaluate risks associated with population abundance, trend, and variability (e.g., Goodman in press). Such models can provide a partial quantification of risks if adequate data are available. We have not attempted to construct such models for this review but have considered results from such efforts where available (e.g., Emlen 1995, Ratner et al. 1997).

Previous Assessments

In considering the status of the ESUs, we evaluated both qualitative and quantitative information. Qualitative evaluations included aspects of several of the risk considerations outlined above, as well as recent, published assessments by agencies or conservation groups of the status of chinook salmon stocks (Nehlsen et al. 1991, Higgins et al. 1992, Nickelson et al. 1992, WDF et al. 1993, Huntington et al. 1996). These evaluations are summarized in Appendix E. Additional information presented by the petitioners (ONRC and Nawa 1995) was considered, as discussed under “Summary of Information Presented by the Petitioners” above.

Nehlsen et al. (1991) considered salmonid stocks throughout Washington, Idaho, Oregon, and California and enumerated all stocks that they found to be extinct or at risk of extinction. Stocks that do not appear in their summary were either not at risk of extinction or the researchers lacked sufficient information to classify them. Nehlsen et al. (1991) classified stocks as extinct (X), possibly extinct (A+), at high risk of extinction (A), at moderate risk of extinction (B), or of special concern (C). Nehlsen et al. (1991) considered it likely that stocks at high risk of extinction have reached the threshold for classification as endangered under the ESA. Stocks were placed in this category if they had declined from historic levels and were continuing to decline, or had recent spawning escapements less than 200. Stocks were classified as at moderate risk of extinction if they had declined from historic levels but presently appear to be stable at a level above 200 spawners. They felt that stocks in this category had reached the threshold for threatened under the ESA. They classified stocks as of special concern if a relatively minor disturbance could threaten them, insufficient data were available for them, they were influenced by large releases of hatchery fish, or they possessed some unique character. For chinook salmon, they classified 112 stocks as follows: 49 extinct, 10 possibly extinct, 27 high risk, 14 moderate risk, and 12 special concern (Appendix E).

Higgins et al. (1992) used the same classification scheme as Nehlsen et al. (1991) but provided a more detailed review of some northern California salmonid stocks. In this review, their evaluation is relevant only to the Southern Oregon and California Coastal and Upper Klamath and Trinity Rivers ESUs. They classified 15 chinook salmon populations in these two ESUs as follows: 6 high risk, 1 moderate risk, and 8 as stocks of special concern (Appendix E).

Nickelson et al. (1992) rated wild coastal (excluding Columbia River Basin) Oregon salmon and steelhead stocks on the basis of their status over the past 20 years, classifying stocks as "healthy" (spawning habitat fully seeded and stable or increasing trends), "depressed" (spawning habitat underseeded, declining trends, or recent escapements below long-term average), "of special concern" (300 or fewer spawners or a problem with hatchery interbreeding), or "unknown" (insufficient data). The following additional comments were noted for salmonid populations when relevant: "1" (may not be a viable population), "2" (hatchery strays), and "3" (small, variable run). They classified 55 chinook salmon populations in coastal Oregon as follows: 30 healthy (2 with small, variable runs), 8 depressed, 8 special concern due to hatchery strays, and 9 unknown (4 of which they suggested may not be viable) (Appendix E).

WDF et al. (1993) categorized all salmon and steelhead stocks in Washington on the basis of stock origin ("native," "non-native," "mixed," or "unknown"), production type ("wild," "composite," or "unknown"), and status ("healthy," "depressed," "critical," or "unknown"). Status categories were defined as follows: healthy, "experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock”, depressed, "production is below expected levels...but above the level where permanent damage to the stock is likely”, and critical, "experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred." Of the 106 chinook salmon stocks identified, 54 were classified as healthy, 5 as critical, 35 as depressed, and 12 as unknown (Appendix E). Most of those classified as unknown are small stocks without large fisheries.

Huntington et al. (1996) surveyed the condition of healthy native/wild stocks of anadromous salmonids in the Pacific Northwest and California. Stocks were classified as healthy based upon abundance, self-sustainability, and not having been previously identified as facing a substantial risk of extinction. Healthy stocks were separated into two levels: Level I ("...adult abundance at least two-thirds as great as would be found in the absence of human impacts") and Level II ("...adult abundance between one-third and two-thirds as great as expected without human impacts"). Of the 35 healthy chinook salmon stocks identified, 9 were classified as Level I and 26 as Level II (Appendix E).

There are problems in applying results of these studies to ESA evaluations. A major problem is that the definition of "stock" or "population" varied considerably in scale among studies, and sometimes among regions within a study. Identified units range in size from large, complex river basins (e.g., "Sacramento River" in Nehlsen et al. 1991), to minor coastal streams and tributaries. A second problem is the definition of categories used to classify stock status. Only Nehlsen et al. (1991) and Higgins et al. (1992) used categories intended to relate to ESA "threatened" or "endangered" status, and they applied their own interpretations of these terms to individual stocks, not to ESUs as defined here. WDF et al. (1993) used general terms describing status of stocks that cannot be directly related to the considerations important in ESA evaluations. For example, the WDF et al. (1993) definition of healthy could conceivably include a stock that is at substantial extinction risk due to loss of habitat, hatchery fish interactions, and/or environmental variation, although this does not appear to be the case for any Washington chinook salmon stocks. A third problem is the selection of stocks or populations to include in the review. Nehlsen et al. (1991) and Higgins et al. (1992) did not discuss stocks not perceived to be at risk, so it is difficult to determine the proportion of stocks they considered to be at risk in any given area. For chinook salmon, WDF et al. (1993) included only stocks considered to be substantially "wild" and included data only for the "wild" component for streams that have both hatchery and natural fish escaping to spawn, giving an incomplete evaluation of chinook salmon utilizing natural habitat.

Data Evaluations

Quantitative evaluations of data included comparisons of current and historical abundance of chinook salmon, calculation of recent trends in escapement, and evaluation of the proportion of natural spawning attributable to hatchery fish. Historical abundance information for these ESUs is largely anecdotal. Time series data are available for many populations, but data extent and quality varied among ESUs. We compiled and analyzed this information to provide several summary statistics of natural spawning abundance, including (where available) recent total spawning escapement, percent annual change in total escapement (both long-term and the most recent ten years), recent naturally produced spawning escapement, and average percentage of natural spawners that were of hatchery origin.

Although this evaluation used the best data available, it should be recognized that there are a number of limitations to these data, and not all summary statistics were available for all populations. For example, spawner abundance was generally not measured directly; rather, it often had to be estimated from catch (which itself may not always have been measured accurately) or from limited survey data. In many cases, data to separate hatchery production from natural production were also limited. Specific limitations of the data are discussed under the individual ESUs as part of the "Analysis of Biological Information" below.

Quantitative methods

Information on stock abundance was compiled from a variety of state, federal, and tribal agency records. We believe it to be complete in terms of long-term adult abundance records for chinook salmon in the region covered. Principal data sources were angler catch estimates, dam or weir counts, and stream surveys. None of these provides a complete measure of adult spawner abundance for any of the streams. Specific problems are discussed below for each data type.

Data types

For chinook salmon, quantitative abundance estimates are available on a limited basis and the quality of these estimates varies considerably. Quantitative assessments were based on historical and recent run-size estimates, time series of freshwater spawner survey data, harvest rate estimates, and counts of adults migrating past dams. Juvenile survey data were available in some areas but data coverage was insufficient for quantitative assessment. We considered this information separately for each ESU. Because of the disparity of data sources and quality in the different ESUs, the data sources and analysis are described separately for each ESU; here we present only a brief regional overview of information types considered.

Quantitative estimates of spawning escapement are available for the Sacramento-San Joaquin and the Klamath River Basins in California and for most coastal and Puget Sound rivers in Washington. Within the Columbia River Basin, quantitative estimates are available for many lower Columbia River tributaries in Washington and for the Willamette and Deschutes Rivers in Oregon. On the mainstem of the Columbia and Snake Rivers, dam counts provide quantitative estimates of run-size, but in most cases, these counts cannot be resolved to the individual population level and are subject to errors stemming from fallback, run classification, and unaccounted mortality. Run reconstructions providing estimates of both adult spawning abundance and fishery recruits are being prepared for many stream-type chinook salmon populations in the Columbia River Basin (Beamsderfer et al. 1997 unpubl. draft report), but were not available in final form for this review.

Sport harvest and peak index spawner survey information were the main abundance data available for most Oregon coastal populations. In 1952, Oregon instituted a punchcard system to record all salmon and steelhead caught by species. There are a variety of problems in interpreting abundance trends from sport harvest data; for this reason, angler catch was used only for estimating recent abundance, not for trend analyses.

Dam and weir counts are available in several river basins along the coast. These counts are probably the most reliable estimates available of total spawning run abundance, but often represent only small portions of the total population in each river basin and may be biased by incomplete (less than 24 hours per day) counting, fallback, and reascension. As with angler catch, these counts typically represent a combination of hatchery-produced and natural fish, and thus are not a direct index of natural population trends.

Stream surveys for chinook salmon spawning abundance have been conducted by various agencies within most of the ESUs considered here. The methods and time-spans of the surveys vary considerably among regions, so it is difficult to assess the general reliability of these surveys as population indices. For most streams where these surveys are conducted, they are the best local indication we have of population trends.

Information on harvest impacts were compiled from a variety of sources (see citations for specific ESUs below). In presenting this information, we have tried to maintain a clear distinction between harvest rates (usually calculated as catch divided by catch plus escapement for a cohort or brood year) and exploitation rates (age-specific rates of exploitation in individual fisheries). Most of the estimates presented here are for harvest rate. We have also classified harvest as “low” (average harvest rate less than 40%), “moderate” (rate between 40% and 60%) or “high” (rate above 60%) as an aid in summarizing information; this classification is not meant to imply an associated degree of risk.

As noted above, we attempted to distinguish natural and hatchery production in our evaluations. Doing this quantitatively would require good estimates of the proportion of natural escapement that was of hatchery origin, and knowledge of the effectiveness of spawning by hatchery fish in natural environments. Unfortunately, this type of information is rarely available, and for most ESUs we have been limited to reporting whatever estimates of escapement of hatchery fish to natural systems that were made available to us.

Computed statistics

Recent average abundance is reported as the geometric mean of the most recent five years of data. Where totals are given for an ESU they are the sum of these geometric means. Because the year of the most recent abundance estimate often differs for components of an individual ESU, if abundances were totaled for the ESU and a geometric mean calculated from the total, the most recent years would be incomplete in most cases. We opted instead to calculate sums for components with different time periods. We tried to use only estimates that reflect the total abundance for an entire river basin or tributary, avoiding index counts or dam counts that represent only a small portion of available habitat. For Oregon angler catch data for coastal streams, catch was expanded to total run-size and escapement (run-size minus catch) using the methods and harvest rate estimates of Nicholas and Hankin (1988). Where time-series data were not available, we have relied on recent estimates from state agency reports. Time periods included in such estimates varied considerably.

Historic run-size estimates from cannery pack data were made by converting the largest number of cases of cans packed in a single season to numbers of fish in the spawning run (Big Eagle et al. 1995, based on summary tables in Shepard et al. 1985). The conversion was made by assuming each case of 48 packed (454 g) cans represented 80 lb (36.3 kg) of salmon landed, the average weight of chinook salmon was 10 kg (Rich 1940b), and the fishery harvested 50% of the run (PSC 1994).

Population trends were calculated by least-squares linear regression of the natural logarithm of abundance on year, using all data collected after 1950. This assumes that the individual data series is increasing or decreasing exponentially over the entire period of record, and generates an estimate of the rate of increase or decrease as a fraction of abundance per year. We also calculated recent trends from the most recent 10 years, using data collected after 1984 for series having at least 7 observations since 1984. No attempt was made to account for the influence of hatchery-produced fish on these estimates, so the estimated trends include any contribution of hatchery fish to escapement.

Analysis of Biological Information

Biological information related to risk assessments is presented below. This section is organized by broad geographic regions, with general information for each region summarized before the specific analysis for each ESU within the regions.

Central Valley Region

Historically, chinook salmon were abundant in the Central Valley. Early estimates did not differentiate run timing, so the following estimates are assumed to be totals for all runs. Eggs were collected from at least 30,000 adults in the upper Sacramento River in 1905; the total run in the Sacramento River could have been 10 times higher (ca. 300,000) (Reynolds et al. 1993). Gill-net catches suggest peak Central Valley chinook salmon in-river runs may have been 800,000 to 1,000,000 fish, with average run size about 600,000 fish prior to 1915 (Reynolds et al. 1993). Total Central Valley chinook salmon spawning escapement was estimated in 1965 to be about

421,000 fish (332,000 fall- & late-fall-run, 61,000 winter-run, and 28,000 spring-run) (CDFG 1995).

Chinook salmon in this region have been strongly affected both by losses and alterations of freshwater and estuarine habitats and by a long history of hatchery production. Reynolds et al. (1993) discussed habitat problems extensively. They reported a 95% loss of Central Valley freshwater salmon habitat due to damming, migration blockages, or severe degradation. The most severe losses began in 1849 with the discovery of gold, and culminated in the 1970s with the completion of major water diversion and conveyance facilities. Hydraulic mining caused sedimentation of spawning grounds, water diversions blocked migrations and depleted flows, and explosive human population growth led to major settlement and disturbance (including logging and agricultural activities) along Central Valley streams and rivers (CSLC 1993). Construction of levees for flood protection reduced off-channel habitat availability. By the 1930s, only 25% of the valley floor was subject to periodic inundation. Dam and water project construction further reduced habitat substantially between the 1930s and 1960s.

Direct relationships exist between water temperature, water flow, and survival of juvenile salmonids. Elevated water temperature in the Sacramento River has limited the survival of young salmon (Mitchell 1987, DWR 1988). Survival of juvenile salmon in the Sacramento River is also positively correlated with June streamflow and June and July delta outflow (Dettman et al. 1987).

Since 1872, chinook salmon have been continuously produced at a number of hatchery facilities. Millions of eggs were exported from the region during the 1800s. The majority of fish released prior to 1913 were unfed fry, whose contribution to the run was probably minimal (Clark 1929). By 1919, some 1.3 billion chinook salmon fry had been released into the Sacramento River Basin (Cobb 1930). Artificial propagation resources have been devoted primarily to fall-run chinook salmon. In the last 50 years, 1.6 billion fall-run fish have been released into the Central Valley; this is approximately 40 times more than the number of spring-run fish and 600 times more than the number of winter-run fish released (Table 6, Appendix D). The production of spring- and winter-run chinook salmon has been limited by the lack of suitable facilities for holding returning adults during the summer months.

Three hatcheries—Coleman NFH (1946), Feather River Hatchery (1969), and Nimbus Hatchery (1955)—have been responsible for most of the chinook salmon produced in the latter half of this century. Fish from these hatcheries have been released throughout the Sacramento and San Joaquin River Basins and in San Francisco Bay.

1) Sacramento River Winter-Run ESU

This ESU has been extensively reviewed by NMFS (1987, 1989, 1990a,b, 1994b), and that information is briefly summarized and updated here.

Historically, the winter run was abundant and comprised populations in the McCloud, Pit, Little Sacramento, and Calaveras Rivers. Construction of Shasta Dam in the 1940s eliminated access to all of the historic spawning habitat for winter-run chinook salmon in the Sacramento River Basin. Since then, the ESU has been reduced to a single spawning population confined to the mainstem Sacramento River below Keswick Dam (Reynolds et al. 1993). The last documented sighting of adult winter-run chinook salmon in the Calaveras River was made in 1984 (CDFG 1984).

Historic abundance has been estimated from anecdotal accounts, habitat capacity, and river gillnet fishery landings, but quantitative estimates of run-size are not available for the period prior to the completion of Red Bluff Diversion Dam in 1966. CDFG (1965) estimated spawning escapement of Sacramento River winter-run chinook salmon at 61,300 (60,000 mainstem, 1,000 in Battle Creek, and 300 in Mill Creek) in the early 1960s, but this estimate was based on "comparisons with better-studied streams" rather than actual surveys. Fish ladders at Red Bluff Diversion Dam permitted counting of the spawning runs after 1966. During the first 3 years of operation of the counting facility (1967-69), the spawning run of winter-run chinook salmon averaged 86,500 fish. The most recent 3-year (1994-96) average run-size wa s 830 fish. Since counting began in 1967, the population has been declining at an average rate of 18% per year, or roughly 50% per generation (Fig. 29). The trend in the most recent 10 years has been the same as the trend over the entire 27 years of data (Fig. 30, Appendix E).

The focus of artificial propagation efforts for winter-run chinook salmon has been a supplementation and captive broodstock program initiated in 1989. Recently, hatchery efforts may have resulted in the hybridization of spring- and winter-run chinook salmon

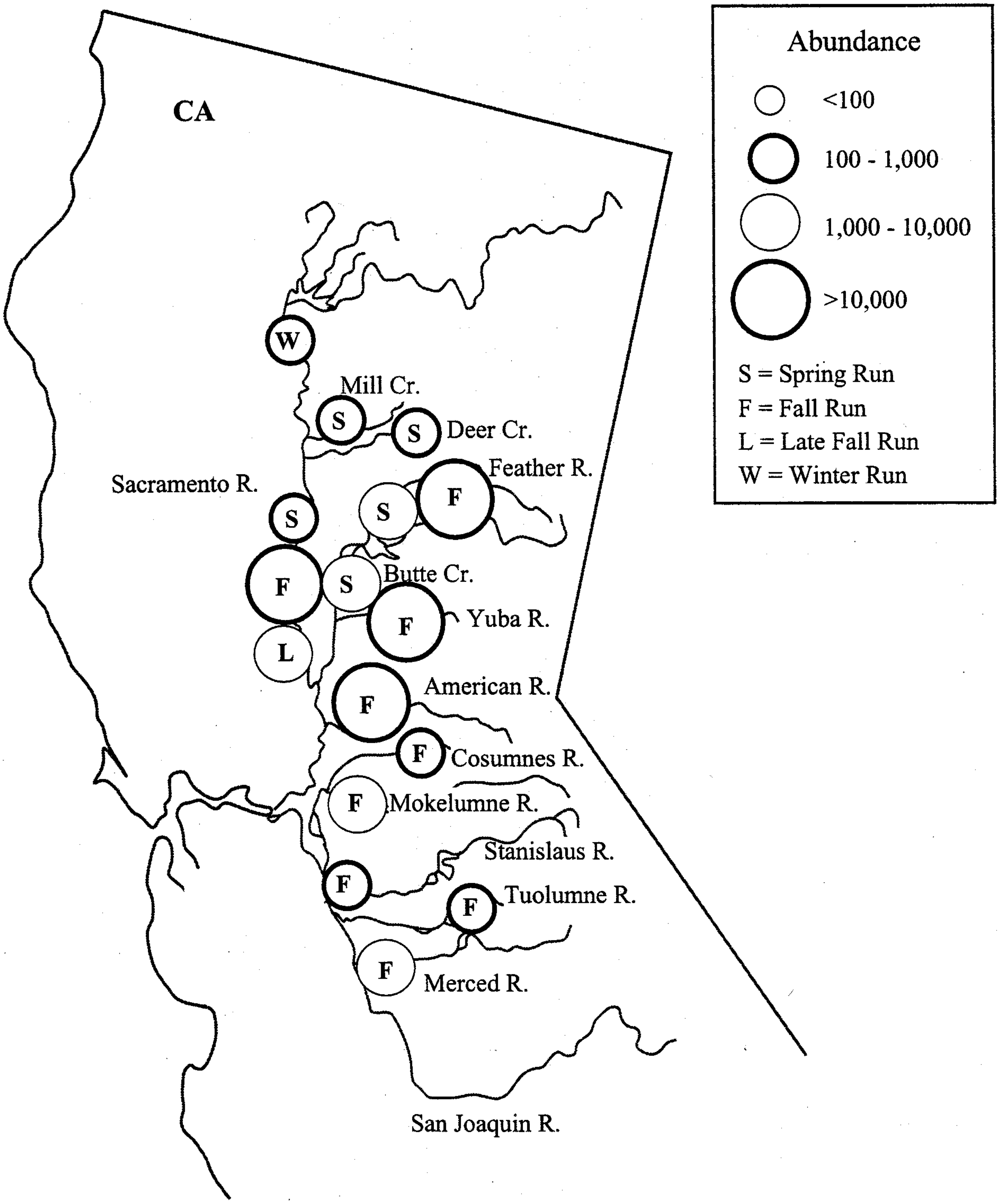

Figure 29. Recent 5-year geometric mean spawning escapement for chinook salmon populations in Sacramento River Winter Run (1), Central Valley Spring Run (2), and Central Valley Fall Run (3) ESUs (see Appendix E for details).

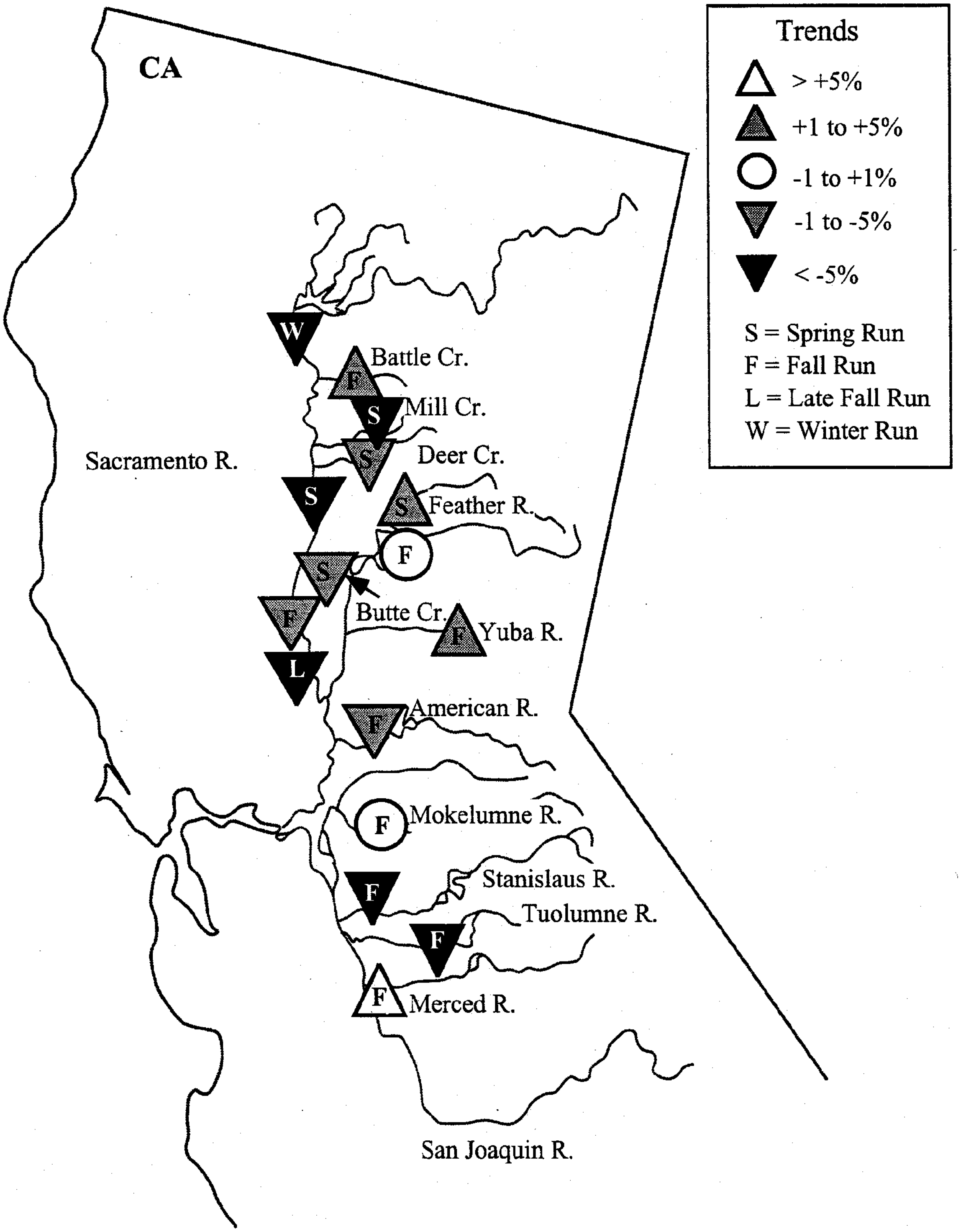

Figure 30. Trends (percent annual change) in abundance for chinook salmon populations in

Sacramento River Winter Run (1), Central Valley Spring Run (2), and Central Valley Fall Run (3) ESUs (see Appendix E for details).

(Hedgecock 1995). Furthermore, the fish reared at Coleman NFH (Battle Creek) were released into the mainstem Sacramento River where the winter run naturally spawns (USFWS 1996b), but rather than returning to their point of release they returned to Battle Creek where no suitable spawning habitat exists.

Freshwater harvest is negligible, but there is moderately high ocean harvest on this stock. In 1994, the ratio of ocean harvest to ocean harvest plus escapement (catch /(catch + escapement)) was estimated from CWT recoveries to be 0.54. This estimate was similar to one developed in the early 1970s from a fin-clip study. The recent reductions in ocean harvest are intended to insure that winter-run chinook salmon have a positive population growth rate, on average.

Historically, contribution of hatchery fish to this population has been negligible. Recently a captive-broodstock and smolt supplementation program has been initiated as part of recovery efforts.

The fact that this ESU is comprised of a single population with very limited spawning and rearing habitat increases its risk of extinction due to local catastrophe or poor environmental conditions. There are no other natural populations in the ESU to buffer it from natural fluctuations.

This ESU is currently listed as endangered under the California Endangered Species Act and was listed as threatened in 1989 and reclassified as endangered in 1994 under the US Endangered Species Act (NMFS 1990a, NMFS 1994b). The only other assessment of risk to stocks in this ESU was that made by Nehlsen et al. (1991), who identified one stock (Calaveras River) as extinct. Due to lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of this stock to the existing Sacramento River winter-run is uncertain. It is listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991) (Appendix E).

2) Central Valley Spring-Run ESU

Historically, spring-run chinook salmon were abundant in the Sacramento River system and constituted the dominant run in the San Joaquin River Basin (Reynolds et al. 1993). Clark (1929) estimated that there were historically 6,000 stream miles of salmonid habitat in the Sacramento-San Joaquin River Basin, but only 510 miles remained by 1928. Subsequently, elimination of access to spawning and rearing habitat resulting from construction of impassable dams has extirpated spring-run chinook salmon from the San Joaquin River Basin and the American River. Construction of impassible dams has also curtailed access to habitat in the upper Sacramento and Feather Rivers.

In 1939, an estimated 5,786 spring-run chinook salmon passed the Cottonwood-Anderson Dam (Redding) on the upper Sacramento River (Hanson et al. 1940). Calkins et al. (1940)

estimated a spawning escapement of 38,792 fish for the Sacramento River based on fishery landings. In the mid-1960s, CDFG (1965) estimated total spawning escapement of spring-run chinook salmon to be 28,500, with the majority (15,000) spawning in the mainstem Sacramento River and the remainder scattered among Battle, Cottonwood, Antelope, Mill, Deer, Big Chico, and Butte Creeks and the Feather River. CDFG (1965) reported spring-run chinook salmon to be extinct in the Yuba, American, Mokelumne, Stanislaus, Tuolumne, Merced, and San Joaquin Rivers. Today, spawner survey data are available for the mainstem Sacramento River, Feather River, Butte Creek, Deer Creek and Mill Creek (Big Eagle & Assoc. and LGL Ltd 1995). Small populations are also reported in Antelope, Battle, Cottonwood, and Big Chico Creeks (Campbell and Moyle 1990, Reynolds et al. 1993, Yoshiyama et al. 1996).

Spawning escapement has been estimated by a combination of methods, including snorkel surveys, aerial surveys, boat surveys, foot surveys, and fishway counts at Red Bluff Diversion Dam (Reavis 1985). The California Department of Fish and Game has estimated spawning escapement since the late 1940s or 1950s for the remaining populations except those in the mainstem Sacramento River, which has been counted at Red Bluff Diversion Dam since 1967. The sum of the 5-year geometric mean escapements for this ESU is 6,700 spawners, of which 4,300 (64%) have returned to the Feather River (Fig. 29, Appendix E). The Feather River Hatchery releases several million spring-run chinook salmon annually, with the bulk of their production released off-site into the Sacramento River Delta. Therefore, the origin of the fish returning to the Feather River is uncertain, and fish from these releases may stray to other parts of the valley. Of the remaining 2,400 spawners, 435 are in the mainstem Sacramento River where their spawning overlaps in both time and space with the more abundant fall run. Sacramento River mainstem spawners have declined sharply since the mid-1980s, from 5,000-15,000 to a few hundred fish. The Feather River population is believed to be hybridized with the fall run in the Sacramento River (Reynolds et al. 1993), and probably includes many hatchery strays from the Feather River Hatchery program. The remaining three natural populations (Butte, Deer, and Mill Creeks) are small, and all have long-term declining trends in abundance (Fig. 30, Appendix E).

Efforts to enhance runs of Sacramento River spring-run chinook salmon through artificial propagation date back over a century, although programs were not continuously in operation during that period. We found no recent records of introduction of spring-run fish from outside the Sacramento-San Joaquin River Basin. In the 1940s, trapping of adult chinook salmon that originated from areas above Keswick and Shasta Dams may have resulted in stock mixing, and further mixing with fall-run fish apparently occurred with fish transferred to Coleman Hatchery. Deer Creek, one of the locations generally believed most likely to retain essentially native spring-run fish, was a target of adult outplants from the 1940s trapping operation, but the success of those transplants is uncertain. Since 1967, artificial production has focused on the program at the Feather River Hatchery (discussed above). Cramer (1996) reported that half of the hatchery-reared spring-run fish returning to the Feather River did not return to the hatchery, but spawned naturally in the river. Given the large number of juveniles released off station, the potential contribution of straying adults to rivers throughout the Central Valley is considerable. The termination of CWT marking programs for hatchery-derived spring-run fish and the absence of spring-run carcass surveys for most river systems prevented the accurate estimation of the contribution of naturally spawning hatchery strays. Cramer (1996) reported that up to 20% of the Feather River spring-run chinook salmon are recovered in the American River sport fishery. Furthermore, the use of a fixed date to distinguish returning spring- and fall-run fish at the Feather River Hatchery may have resulted in considerable hybridization between the two runs (Campbell and Moyle 1990).

Harvest rates appear to be moderate. Ocean fishery management focuses on the fall run, with no defined management objectives for spring-run fish. Because of the similarity in ocean distribution with fall-run fish and smaller average size, spring-run harvest rates are probably lower than those for the fall run.

Reynolds et al. (1993) reported that spring-run fish were likely to have interbred with fall-run fish in the mainstem Sacramento and Feather Rivers, but the extent of hybridization was unknown. They also reported that pure strain spring-run fish may still exist in Deer and Mill Creeks.

The only previous assessment of risk to stocks in this ESU is that of Nehlsen et al. (1991), who identified several stocks as being at risk or of special concern (Appendix E). Four stocks were identified as extinct (spring/summer-run chinook salmon in the American, McCloud, Pit, and San Joaquin [including tributaries] Rivers) and two stocks (spring-run chinook salmon in the Sacramento and Yuba Rivers) were identified as being at a moderate risk of extinction. Due to lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991).

3) Central Valley Fall-Run ESU

The historical abundance of Central Valley fall- and late-fall run chinook salmon is poorly documented. For the San Joaquin River, Reynolds et al. (1993) reported recent abundance to be only a remnant of the historical abundance. They estimated that production (ocean-run size) of San Joaquin River fall- and late-fall-run chinook salmon historically approached 300,000 adults and probably averaged approximately 150,000 adults. In the mid-1960s, escapement to the San Joaquin River Basin totaled only about 2,400 fish, spawning in the Stanislaus, Tuolumne, and Merced Rivers.

Calkins et al. (1940) estimated abundance at 55,595 fish in the Sacramento River Basin during the period 1931-39. In the early 1960s, adult escapement was estimated to be 327,000, predominantly in the mainstem Sacramento River (187,000), but with substantial populations in the Feather (50,000), American (36,000), and Yuba (22,000) Rivers and in Battle Creek (21,000); remaining escapement was scattered among numerous tributaries (CDFG 1965). At that time, total Central Valley fall-run chinook salmon escapement (including the Sacramento, Mokelumne, and San Joaquin River Basins) was estimated at 331,700 adults (CDFG 1965).

Much of the historical fall-run spawning area in the Sacramento River was below major dam sites, and therefore the fall run was not as severely affected by early water projects as were spring and winter runs (Reynolds et al. 1993). Extreme stream temperatures are a major limiting factor in juvenile production; gravel depletion, fluctuating flows, flow reversals in the delta, point and non-point source pollution, rearing habitat limitations, and losses at diversions also limit natural production (Dettman et al. 1987, CACSST 1988).

Spawning escapement has been estimated using a variety of survey methods. The larger spawning populations are estimated using modified Schaeffer or Jolly-Seber multiple mark-recapture methods with tagged carcasses (Reavis 1984). The fall and late-fall runs in the mainstem Sacramento River have been monitored since 1967 by counts in the fishways at Red Bluff Diversion Dam. Since 1992, the dam reservoir has been drawn down until May to allow the winter run to pass unimpeded. This has precluded counting the late-fall run since 1992 and has only permitted monitoring the last 15% of the winter run.

The bulk of the spawning escapement has been to the Feather and American Rivers and to Battle Creek (Fig. 29, Appendix E). The long-term trends in escapement are relatively stable, while the recent trends are mixed (Fig. 30, Appendix E). These are all streams with major salmon hatcheries. State hatcheries on the American and Feather Rivers transport their smolts to saltwater for release to avoid mortality in the delta due to flow reversals, unscreened diversion dams, and predators. Transportation of smolts increases the straying rate of adults when they return and makes it more difficult to account for hatchery strays in the spawning escapement (Cramer 1989). In the San Joaquin River Basin, homing fidelity may be more dependent on the presence of sufficient instream flows (CDFG 1997f).

Estimates of the relative contribution of hatchery and natural fish to spawning escapements are difficult to obtain. According to Dettman et al. (1987), for 1978-84 an average of 20% of the ocean catch of Central Valley salmon, originated at Feather River Hatchery and 24% at Nimbus Hatchery. For the same period, total Sacramento River spawning escapement was comprised of 22% Feather River Hatchery origin and 26% Nimbus Hatchery origin; 78% of the total Feather River run and 87% of the American River run were hatchery fish. For this period, natural production averaged only 12,000 fish in the Feather River and 8,000 fish in the American River. An alternative analysis (Cramer 1989) concluded that total hatchery contribution to the Sacramento River run for 1978-87 was only about one-third, and hatchery proportions in escapement were only 26% in the Feather River and 29% in the American River. Methods used in both studies have biases; Dettman and Kelley's estimates were biased toward hatchery fish and Cramer's estimates toward natural fish. Cramer suggested that the true proportions are probably somewhere between the two groups of estimates.

Fall- and late-fall-run chinook salmon in the Central Valley have been propagated for more than a century. In general, a relatively small number of hatcheries have accounted for the tens of millions of fall-run fish planted annually. The overwhelming majority of fish used have come from stocks within this ESU (Table 6, Appendix D). However, the practice of releasing fish off-station, especially into the Sacramento River Delta region, has resulted in widespread straying by hatchery-reared fish (Bartley and Gall 1990, Fisher 1995). Hatchery strays represent a considerable proportion of fish spawning naturally in many rivers, even those without hatcheries. Straying, in conjunction with frequent exchanges of surplus eggs between hatcheries, may be responsible for the low levels of genetic differentiation among fall-run chinook salmon stocks in the Central Valley (Bartley and Gall 1990). The high contribution of hatchery fish to naturally spawning escapement may be due, in part, to the high survival of hatchery fish that are transported to the Sacramento River Delta (Dettman et al. 1987).

In contrast to the situation with the fall run, the culture of late-fall-run fish has been relatively limited. The majority of production has come from one hatchery (Coleman NFH) and only within the last 20 years. Late-fall-run fish releases constituted less than 2% of the combined fall- and late-fall-run releases for this ESU.

Recent (1990-94) ocean harvest rate indices (Central Valley Index=catch / [catch + escapement]) have been in the range of 71-79% (PFMC 1996b). Freshwater recreational harvest is believed to be increasing and approaching 25% (PFMC 1997). Late fall fish are larger in size and experience higher harvest rates. The Central Valley Index is not a true harvest rate since it does not distinguish between races or cohorts, does not include freshwater catch or ocean catch landed north of Point Arena, California, and does not include shaker mortality (hook and release mortality of undersized fish).

Angler harvest in the Sacramento River Basin was estimated by creel census in 1991, 1992, and 1993 (Wixom see footnote 10, Wixom et al. 1995). The creel census data provide a harvest estimate of approximately 20% in freshwater.

The only previous assessment of risk to stocks in this ESU is that of Nehlsen et al. (1991), who identified two stocks (San Joaquin and Cosumnes Rivers) as of special concern (Appendix E). The Cosumnes River has had no documented spawning escapement of fall-run chinook salmon since 1989, and surveys in 1991 through 1994 have failed to find spawning salmon (Big Eagle & Assoc. and LGL Ltd. 1995).

Southern Coastal Region

Historically, chinook salmon were abundant in this region. Early estimates based on peak cannery pack suggest a total run size in excess of 300,000 fish in the 1910s. Total chinook salmon spawning escapement for the California portions of this region was estimated to be about

256,000 (168,000 in the Klamath River Basin and 88,000 elsewhere) in 1965 (CDFG 1995). An escapement of 250,000 fish in 1969 was estimated by expanded angler catch.

Chinook salmon in this region have been strongly affected both by losses and alterations of freshwater habitats and by a long history of hatchery production. PFMC (1995) identified all of the major rivers in this area as having chronic instream flow problems. Bottom et al. (1985) cited low stream flows and high summer temperatures as problems throughout the southern Oregon coastal area. Timber harvesting and associated road building occur throughout the region on federal, state, tribal and private lands. These activities may increase sedimentation and debris flows and reduce cover and shade, resulting in aggradation, embedded spawning gravel, and increased water temperatures (CACSST 1988, NMFS 1996b). The Rogue and Klamath River Basins have been sites of active mining since the mid-1800s and suction dredge mining still occurs.

Hatchery facilities in this area began operations late in the nineteenth century. These early hatcheries were operated by private companies and state and federal agencies with the goal of restoring declining fisheries. With the exception of operations on the Rogue River, which propagated spring-run chinook salmon, these hatcheries primarily reared fall-run chinook salmon. Dam construction and habitat degradation reduced or eliminated several runs and forced the closure of a number of hatcheries. Currently the Cole Rivers Hatchery and Trinity River Hatchery produce the majority of all spring-run chinook salmon in this area. A number of smaller hatcheries release locally derived fall-run chinook salmon, but the major proportion of fall-run releases comes from the Iron Gate Hatchery (197 million since 1966) and Trinity River Hatchery (69 million since 1969) (Appendix D).

4) Southern Oregon and California Coastal ESU

The peak historic cannery pack of chinook salmon in the range of this ESU was 31,000 cases in 1917, indicating a run-size of about 225,000 at that time. CDFG (1965) estimated escapement for the California portion of the ESU at about 88,000 fish, predominantly in the Eel River (55,500) with smaller populations in the Smith River (15,000), Redwood Creek, Mad River, Mattole River (5,000 each), Russian River (500), and several smaller streams in Del Norte and Humboldt counties. Based on the 1968 angler catch records for the Oregon portion of the ESU (which estimated escapements of about 90,000 fish), the average escapement for the entire ESU in the 1960s was estimated to be 178,000 fish.

Within this ESU, recent abundance data vary regionally. Dam counts of upstream migrants are available on the South Fork Eel River at Benbow Dam from 1938 to 1975, and at Gold Ray Dam on the Rogue River from 1944 to the present. Counts at Cape Horn Dam on the upper Eel River are available from the 1940s to the present, but they represent a small, highly variable portion of the run.

In the Oregon portion of this ESU, coastal rivers are monitored by surveys of index reaches. Surveys were begun in 1948 with the intent of monitoring trends in escapement rather than estimating total escapement (Cooney and Jacobs 1994). Because the original selection criteria for index reaches included ease of access and availability of spawners, spawner densities in these index reaches are not representative of spawner densities in other areas. Consequently, though the spawner counts in index reaches may be relatively precise, they are not accurate for assessing abundance.

In 1953 Oregon began using catch report cards, called "punch cards," to report angler catch in rivers and estuaries (Nicholas and Hankin 1988). This reporting system provides precise estimates of catch on a river-by-river basis, which can be expanded by the harvest rate for each river to provide estimates of terminal run-size. Unfortunately, freshwater and estuarine harvest rates are poorly known for most rivers, and vary considerably. Harvest rates depend on fishing effort and angler success rates. Fishing effort varies with run-size, weather, river conditions, and angler success rate. Angler success rates, in turn, depend on weather and river conditions, as well as run-size. Nicholas and Hankin (1988) used estimates of average angler harvest rates to convert angler catch to run-size. These estimates, although imprecise, are probably more accurate for estimating average run-size than expansions based on peak index counts.

In assessing abundance and trends we used expansions of angler catch from ODFWs punch card database (ODFW 1993) and Nicholas and Hankin's (1988) average harvest rates to calculate geometric means of terminal run-size and spawning escapement for the most recent 5-year period (1990-94). Trends were calculated from either the peak index counts or from dam counts, where they were available.

Expanded angler catch data produce a 5-year geometric mean spawning escapement of 132,000 (run-size of 148,000) for the Oregon portion of this ESU. The majority of this escapement (126,000) has been the spring and fall runs in the Rogue River (Fig. 31, Appendix E). No total escapement estimates are available for the California portion of this ESU, although partial counts indicate that escapement in the Eel River exceeds 4,000. Data available to assess trends in abundance are limited. Recent trends have been mixed, with predominantly strong negative trends in the Rogue and Eel River basins, and mostly upward trends elsewhere. Longer term trends, where data are available, are flatter (e.g. Rogue River) (Fig. 32, Appendix E).

Habitat loss and/or degradation is widespread throughout the range of the ESU. The California Advisory Committee on Salmon and Steelhead Trout (CACSST 1988) reported

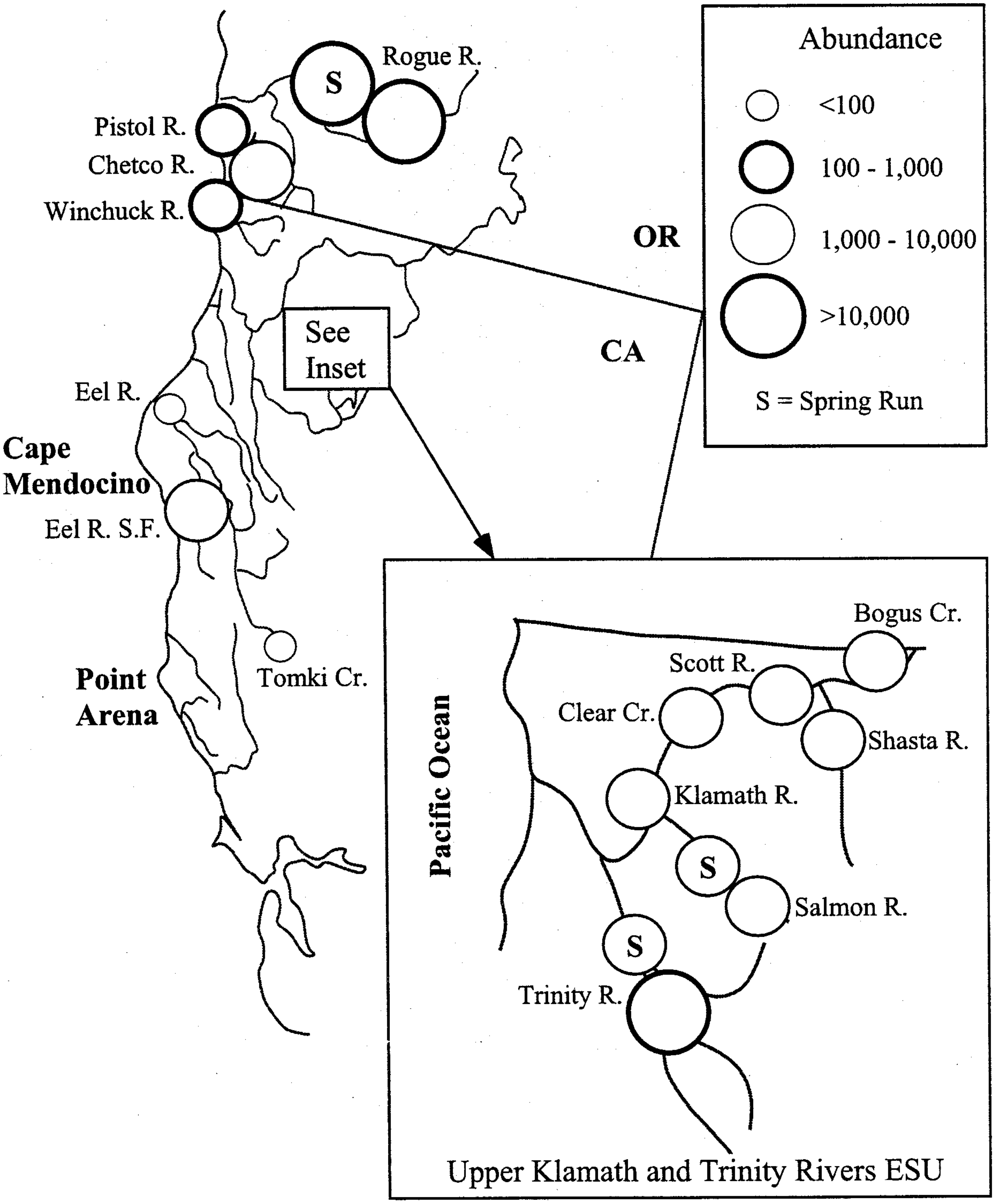

Figure 31. Recent 5-year geometric mean spawning escapement for chinook salmon populations in Southern Oregon and California Coastal (4) and Upper Klamath and Trinity rivers (5) ESUs. All data are for fall run, except as noted (see Appendix E for details).

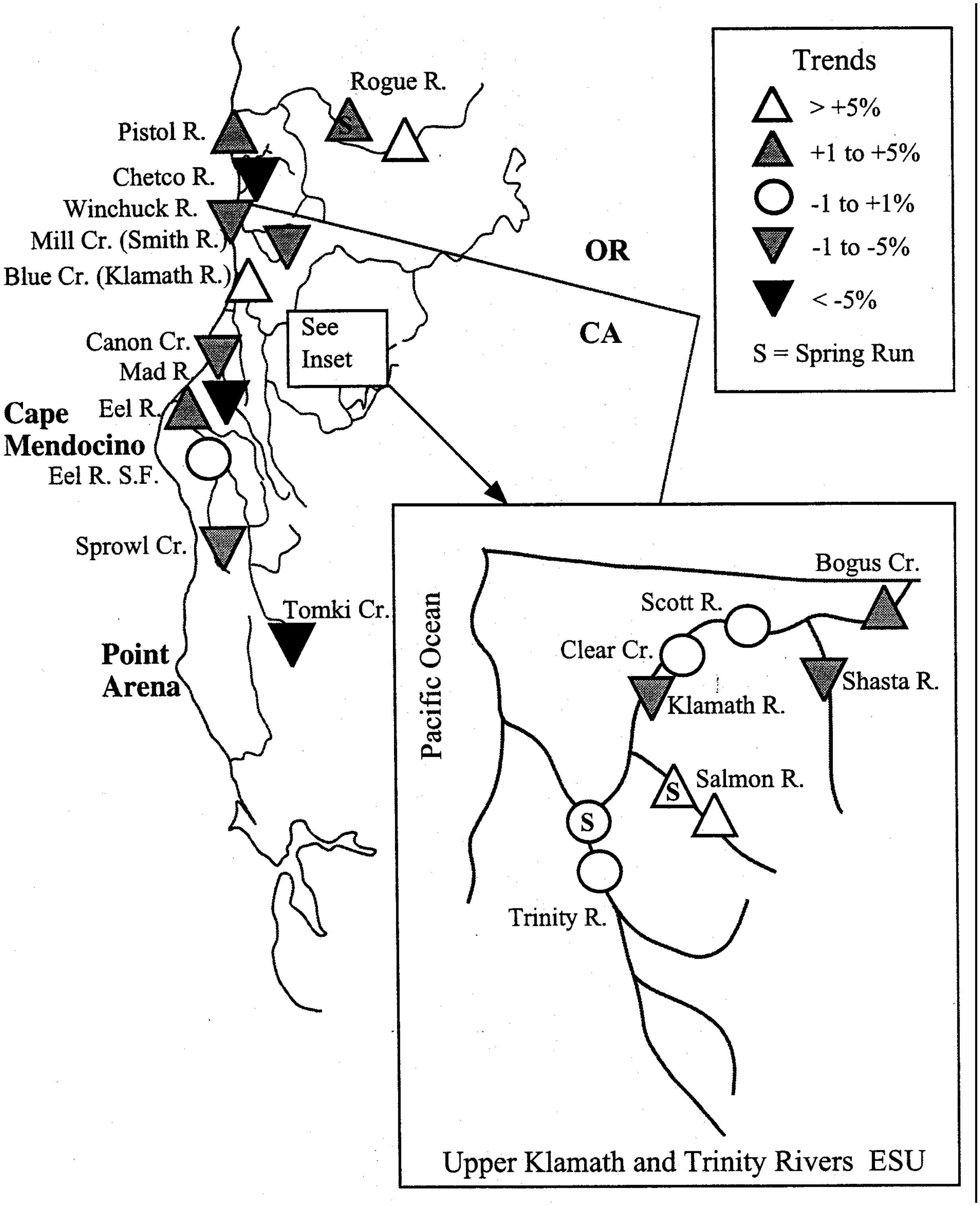
Rogue R.
S
Pistol R.
Chetco R.
Winchuck R.
Mill Cr. (Smith R.)
Blue Cr. (Klamath R.)
OR
CA
See Inset
Canon Cr.
Mad R.
Eel R.
Cape Mendocino
Eel R. S.F.
Sprowl Cr.
Tomki Cr.
Point Arena
Trends
△ > +5%
▲ +1 to +5%
○ -1 to +1%
▽ -1 to -5%
▼ < -5%
S = Spring Run
Pacific Ocean
Bogus Cr.
Scott R.
Clear Cr.
Shasta R.
Klamath R.
Salmon R.
S
S
Trinity R.
Upper Klamath and Trinity Rivers ESU

Figure 32. Trends (percent annual change) in abundance for chinook salmon populations in Southern Oregon and California Coastal (4) and Upper Klamath and Trinity (5) ESUs. All data are for fall run, except as noted (see Appendix E for details).

habitat blockages and fragmentation, logging and agricultural activities, urbanization, and water withdrawals as the most predominant problems for anadromous salmonids in California's coastal basins. They identified associated habitat problems for each major river system in California. CDFG (1965, Vol. III, Part B) reported that the most critical habitat factor for coastal California streams was "degradation due to improper logging followed by massive siltation, log jams, etc." They cited road building as another cause of siltation in some areas. They identified a variety of specific critical habitat problems in individual basins, including extremes of natural flows (Redwood Creek and Eel River), logging practices (Mad, Eel, Mattole, Ten Mile, Noyo, Big, Navarro, Garcia, and Gualala Rivers), and dams with no passage facilities (Mad, Eel, and Russian Rivers), and water diversions (Eel and Russian Rivers). We expect that such problems also occur in Oregon streams within the ESU. The Rogue River Basin in particular has been affected by mining activities and unscreened irrigation diversions (Rivers 1963) in addition to problems resulting from logging and dam construction. Kostow (1995) estimated that one-third of spring-run chinook salmon spawning habitat in the Rogue River was inaccessible following the construction of Lost Creek Dam (RKm 253) in 1977. Recent major flood events (February 1996 and January 1997) have probably affected habitat quality and survival of juveniles within this ESU. Although we have little information on the effects of these floods in this ESU, the effects are probably similar to those discussed for the Oregon and Washington Coastal Region below.

Artificial propagation programs have been less extensive in the Southern Oregon and Coastal California ESU than in neighboring regions. The Rogue, Chetco and Eel River Basins and Redwood Creek have received numerous releases, derived primarily from local sources. In contrast, releases into the Russian River have been predominately from a variety of sources from outside the ESU (Table 6, Appendix D). In the absence of genetic information, it is not possible to evaluate the long-term impact of these transfers into the Russian River. San Francisco Bay has also received considerable numbers of introduced fish, the majority of which are off-station releases of Central Valley fall-run chinook salmon. Information on the impact of hatchery-derived fish on naturally spawning populations is limited. For the entire ESU, the hatchery contribution to total spawning escapement is probably low. However, the hatchery-to-wild ratio of Rogue River spring-run chinook salmon, as measured at Gold Ray Dam (RKm 201), has exceeded 60% in some years (Kostow 1995). The majority of the hatchery fish counted at Gold Ray Dam probably return to Cole Rivers Hatchery (located above the dam), but rates of straying into natural spawning habitat are unknown.

Ocean harvest rates for this ESU have not been estimated, but should be comparable to ocean harvest rates on Klamath fall-run chinook salmon (21% in 1991 [PFMC 1996a]). Freshwater and estuarine harvest rates are on the order of 25-30% (calculated from data in PFMC 1996b - Table B4).

Previous assessments of stocks within this ESU have identified several stocks as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified seven stocks as at high extinction risk and seven stocks as at moderate extinction risk. Higgins et al. (1992) provided a more detailed analysis of some of these stocks, and identified nine chinook salmon stocks as at risk or of concern. Four of these stocks agreed with the Nehlsen et al. (1991) designations, while five fall-run chinook salmon stocks were either reassessed from a moderate risk of extinction to stocks of concern (Redwood Creek, Mad River, and Eel River) or were additions to the Nehlsen et al. (1991) list as stocks of special concern (Little and Bear Rivers). In addition, two fall-run stocks (Smith and Russian Rivers) that Nehlsen et al. (1991) listed as at moderate extinction risk were deleted from the list of stocks at risk by Higgins et al. (1992), although the USFWS (1997a) reported that the deletion for the Russian River was due to a finding that the stock was extinct. Nickelson et al. (1992) considered 11 chinook salmon stocks within the ESU, of which 4 (Applegate River fall run, Middle and Upper Rogue River fall runs, and Upper Rogue River spring run) were identified as healthy, 6 as depressed, and 1 (Chetco River fall run) as of special concern due to hatchery strays. Huntington et al. (1996) identified three healthy Level II fall-run stocks in their survey (Applegate and Middle and Upper Rogue Rivers).

5) Upper Klamath and Trinity River ESU

Peak run-size in this ESU was estimated to be about 130,000 chinook salmon in 1912 (from peak cannery pack of 18,000 cases). CDFG (1965) estimated spawning escapement of chinook salmon within the range of this ESU to be about 168,000 adults, split about evenly between the Klamath (88,000) and Trinity (80,000) Rivers.

Recent spawning escapements and run-sizes to the Klamath and Trinity Rivers are monitored by a combination of state, federal and tribal agencies. Hatchery returns to Iron Gate and Trinity Hatcheries are enumerated by the state. CDFG has also estimated escapement to the Trinity River, Scott River, Salmon River, and Shasta River using Petersen estimates from marks applied to upstream migrants at weirs, or tags applied to carcasses in stream surveys (Pisano 1993, Aguilar et al. 1996). Escapement to smaller tributaries is generally estimated from redd counts. The fall run on the Klamath River was counted at Klamathon Racks beginning in 1929, but these counts were discontinued when Iron Gate Dam was constructed and the mitigation hatchery began operation in the early 1960s. Escapement of fall-run chinook salmon to the Shasta River has been counted at a weir, or estimated on the basis of recovery of marks applied at the weir, since 1930 by CDFG. Escapement of spring-run chinook salmon to the Salmon River has been estimated by the U.S. Forest Service by snorkel surveys of holding habitat in the summer since 1980. Tribal commercial, subsistence, and ceremonial harvest has been monitored by the U.S. Fish and Wildlife Service, the Hoopa Valley Tribe, and the Yurok Tribe.

The 5-year (1992-96) geometric mean of recent spawning escapements to natural spawning areas was about 48,000 fish (Fig. 31, Appendix E). Fish returning to the two hatcheries in the basin accounted for 38% of the total (natural + hatchery) spawning escapement. Trends in escapement are relatively stable (Fig. 32, Appendix E). The long-term trend statistics mask the fact that minimal abundances were observed in all areas in 1989-91, and populations have increased sharply since then.

For over a hundred years, hatcheries have operated in the Upper Klamath and Trinity River Basins. Several million chinook salmon eggs were introduced into the region from the Central Valley, but the success of these introductions is doubtful, especially given the practice of releasing fry during the early part of this century. Dam construction on the Klamath and Trinity Rivers led to the construction of two major hatchery complexes (Iron Gate Hatchery and Trinity River Hatchery) to mitigate the loss of spawning and rearing habitat. Within the last 30 years, these 2 mitigation hatcheries have accounted for the overwhelming majority of artificially propagated fish in this region. Between 1964 and 1994, 50 million spring and 236 million fall-run chinook salmon (almost all from local sources) have been released (Table 6, Appendix D). It has been estimated that 11.2% of the spring-run fish and 31.2% of the fall-run fish naturally spawning in the mainstem Trinity River were of hatchery origin in 1994 (Aguilar 1995). Similarly, Barnhart (1995) reported that considerable numbers of coded-wire-tagged fish from the Iron Gate Hatchery are recovered among naturally spawning populations in Bogus Creek, and to a lesser extent in the Shasta River. Information on the contribution of hatchery fish to naturally spawning populations in other tributaries is lacking. Since systematic monitoring of spawning escapement began, the percentage of hatchery returns to total escapement has increased from 18% in 1978-82 to 26% in 1991-95 (PFMC 1996b).

The current management goal for fall-run chinook salmon in the Klamath River Basin is an escapement of 33-34% of potential spawners in each brood while providing a minimum of 35,000 adult spawners to natural spawning areas (PFMC 1994). Because of low abundance, recent management has been for a minimum escapement goal rather than the brood escapement rate. As a result, ocean fishery impact rates have decreased from 44-65% during the period 1986 to 1990 to 21% in 1991. Ocean fishery impact rates have remained below 20% since 1991 (PFMC 1996a).

Habitat loss and/or degradation is widespread throughout the range of the ESU. Upper basin habitat has been blocked by dam construction in both the Klamath and Trinity River Basins (KRBFTF 1991). NMFS (1996b) cited several factors affecting the habitat in this region, including water diversion/extraction, habitat blockages, hydropower development, and logging, mining, and agricultural activities. CDFG (1965, Vol. III, Part B) identified several critical habitat factors: water diversions and resulting low flows and high temperatures (Shasta, Scott, and Trinity Rivers), logging resulting in log jams and siltation (Klamath River), and small dams for present water diversion and at abandoned gold mines (Klamath River). They also cited siltation resulting from past mining activities as a problem in the Scott River, and noted that habitat in the Salmon River Basin was in very good condition. Timber harvesting and associated road building are widespread in the basin and result in increased sedimentation and debris flow and reduced cover and shade (KRBFTF 1991). Fifty percent of the spawning habitat in the Trinity River Basin was lost following the construction of Lewiston Dam at RKm 249 (Moffett and Smith 1950). Gold mining has occurred in this area since the mid-1800s. Lode mining for gold, copper, and chromite, which may introduce cyanide into the water and result in fish kills, continued in the Klamath River Basin until 1987. Suction dredge mining, which directly results in gravel disturbance and sedimentation, still continues in the basin (KRBFTF 1991).

Previous assessments of stocks within this ESU have identified several stocks as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified seven stocks as extinct, two stocks (Klamath River spring-run chinook salmon and Shasta River fall-run chinook salmon) as at high extinction risk, and Scott River fall-run chinook salmon as of special concern. Due to lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). Higgins et al. (1992) provided a more detailed analysis of some of the stocks identified by Nehlsen et al. (1991), classifying three chinook salmon stocks as at risk or of concern. Of the three stocks Higgins et al. (1992) listed as at high risk of extinction, two matched with the Nehlsen et al. (1991) findings (Klamath River spring run and Shasta River fall run), while one stock was added to the list (South Fork Trinity River spring run). Additionally, three chinook salmon stocks were identified as of special concern. Of these, Higgins et al. (1992) classified one (Scott River fall run) in agreement with that of Nehlsen et al. (1991), while two others (Trinity River spring run and South Fork Trinity River fall run)were additions to the earlier list.

Oregon and Washington Coastal Region

This region includes the Oregon Coast, Washington Coast, and Puget Sound ESUs. Chinook salmon were abundant in this region near the turn of the century, when estimates based on peak cannery pack suggested peak runs of near one million fish in the three ESUs combined. This region includes the Coastal Range and Puget Lowlands ecoregions (see "Ecological Features" above) and is characterized by numerous short rivers and streams draining the coast ranges and west slope of the northern Cascade Mountains, with relatively few large rivers (Umpqua, Chehalis, and Skagit Rivers).

Chinook salmon in this region have been strongly affected by losses and alterations of freshwater habitats. Bottom et al. (1985) and Bishop and Morgan (1996) provide thorough reviews of habitat problems. Timber harvesting and associated road building occur throughout the region on federal, state, tribal and private lands. These activities may increase sedimentation and debris flows, reduce cover and shade, and may reduce recruitment of large woody debris to streams, resulting in aggradation, embedded spawning gravel, loss of pools, and increased water temperatures. Agriculture is also widespread in the lower portions of river basins and has resulted in widespread removal of riparian vegetation, rerouting of streams, degradation of streambanks, and summer water withdrawals. Urban development has substantially altered watershed hydrodynamics and affected stream channel structure in many parts of Puget Sound and the Oregon Coast.

This region (and parts of the southern coastal region discussed above) has experienced severe winter floods in recent years which could have affected chinook salmon habitat and survival of in-stream juveniles during the flood events. The following discussion summarizes information available regarding floods in February 1996.

Between November 1995 and April 1996, the Pacific Northwest and California experienced a series of storm and flood events. High winds, heavy rainfall, rapid snowmelt, numerous landslides and debris torrents, mobilization of large woody debris and high runoff occurred over portions of California, Oregon, Washington, Idaho, and Montana (USFS and USBLM 1996). These storms also had a potentially large effect on northern California and Oregon coast coho salmon and their freshwater habitats. Abnormally high rainfall and warm temperature, on top of already elevated stream levels and saturated soils resulted in the floods of February 1996; considered to be 100-year floods in many Oregon coastal basins (USFS and USBLM 1996, Bush et al. 1997). USFS and USBLM (1996) estimated landscape-scale habitat impacts from the February 1996 flood on federal lands in Washington and Oregon. They identified the Wilson-Trask-Nestucca, Siuslaw, and Alsea Basins as experiencing landslides, gullies/surface erosion, bedload deposition, channel migration, and LWD deposition, and considered the Wilson-Trask-Nestucca area as one of four areas with the highest rates of disturbance from the flood, and the Siuslaw as one of four areas with the second highest rates of disturbance from the flood. Pacific Watershed Associates (PWA undated) conducted aerial surveys to provide an assessment of the nature, magnitude and spatial distribution of watershed erosion and impacts to streams channels in the middle Coast Range, including the Smith (Umpqua), Siuslaw, Alsea, and Yaquina Basins. They report that areas with the greatest impact included Hadsall and Knowles Creeks (Siuslaw River) and Lobster Creek (Alsea River), and those watersheds with a combination of steep slopes, unstable bedrock geology, recent timber harvesting, and high road densities within an altitude range where precipitation intensities were probably the greatest (500 m. in the Coast Range). They also stressed that landslides were highly correlated with forestry management activities and originated from recent clear-cuts and forest roads at much higher frequencies than from wilderness or unmanaged areas. In addition to these observations, PWA concluded that the floods may have had long-term effects on watershed habitats. Siuslaw National Forest (SNF 1996) staff surveyed 500,000 hectares of central Oregon coast forests using aerial photographs to assess the frequency and character of landslides. They detected 1,686 slides, 41% of which were associated with roads, 36% with recent (<20 year old) clear cuts, and 23% with forested areas. They also found that subbasins in the southern portion of the area assessed (Coos, Umpqua, Siltcoos and Siuslaw) experienced from 1.5 to 2.5 times more landslides by area than more northern areas. They attribute this difference to both landtype associations of the basins and the differential intensity of the storm as it moved onshore. They also determined that "stabilized" roads (those treated to reduce failure) were less likely to be the source of large (>1700 m^3) landslides than untreated roads.

With regard to impacts to in-stream coho salmon habitat, ODFW has conducted random resurveys of habitat for 105 reaches since the floods (Moore and Jones 1997). This survey effort indicated that along the North Oregon Coast (Salmon River to Columbia River), 7.5% of habitats received "no impact" (no perceivable impact), 60% of habitats received "low impact" (high water and scour and deposition impacts), 28% received "moderate impact" (channel modified impact), and 3.4% received "torrents" (and of these levels associated with debris torrents or dam break floods). Along the mid coast (Siuslaw River to Devils Lake tributaries), 2% of habitats received "no impact," 91% received "low impact," 7% "moderate impact," and 0.1% "torrents." Habitat changes included both positive and negative effects, depending on the area. Bush et al. (1997) noted that there were substantial changes in pool and riffle areas, large woody debris, and streambed substrates in streams following the floods, based on differences in stream reaches initially surveyed in 1992-95 and resurveyed in 1996. Decreases in pool area ranged from 10 to 50%, and largely resulted from a 60% loss of beaver pond habitat. Large woody debris decreased by approximately 25% from the initial surveys, although much of the lost wood had been pushed up onto the floodplain or out of the active channel. Overall, large amounts of gravel were added to most streams, and new gravel bars were common. Dewberry et al. (1996) documented changes in salmon habitats in Knowles Creek. (Siuslaw River). Twenty four debris torrents occurred in anadromous fish-bearing reaches of the basin, four of which exceeded 3,000 m^2. Although the floods had little impact on parts of the basin, including an old-growth section, other areas were highly affected.

Within the last 50 years, over 2.5 billion spring-, summer-, and fall-run chinook salmon have been released from state, federal, and/or tribal hatcheries in this region, with the fall run constituting the majority of these releases. In addition, large, privately owned sea-ranching programs operated in recent years on the Oregon coast. A number of hatcheries already were in existence on rivers around Puget Sound by the turn of the century, and many of those are still in operation. In coastal areas, the earliest and most intense artificial propagation efforts have been, and continue to be, in coastal rivers near the mouth of the Columbia River. The majority of these hatcheries have been built primarily for fisheries enhancement, rather than mitigation for habitat loss. However, hatcheries on the Skagit, White, Skokomish, and Elwha Rivers operate to mitigate the loss of habitat due to dam construction (WDF et al. 1993, Kostow 1995). Although there have been numerous introductions of lower Columbia River chinook salmon stocks into the region, the majority of fish released have been derived from local stocks (Table 6, Appendix D). Some artificial propagation programs on the Oregon and Washington coasts have recently begun to alter their primary mission from fisheries enhancement to the supplementation of natural populations.

6) Oregon Coast ESU

ODFW has identified 45 populations of chinook salmon in the range of this ESU (Kostow 1995). Historical abundance estimates for this ESU are available only from cannery pack data. Peak cannery pack was 30,967 cases in 1896, suggesting a peak run-size of about 225,000 fish at that time. Abundance at that time does not reflect "pristine" conditions, as extensive logging with associated splash dams were already impacting stream habitat.

Types of data available in this ESU were much the same as within the Oregon portion of the Northern California/Southern Oregon ESU. Punch card data and average estimated harvest rates were used to estimate recent spawning run-size from freshwater angler harvest. Survey data from spawner surveys conducted by ODFW were used to estimate trends in abundance. The only other data available that provided reasonably long time series were fish counts of spring and fall runs at Winchester Dam on the North Umpqua River.

The 5-year geometric mean of terminal run-size calculated from angler catch was approximately 170,000 fish (spawning escapement of 136,000) distributed among numerous spawning populations (Fig. 33, Appendix E). Most long-term trends in escapement indices were stable or increasing, with only one population declining at more than 10% per year; short-term trends were more variable, with a mix of increases and decreases (Fig. 34, Appendix E).

Bottom et al. (1985) cited low streamflows and high summer temperatures exacerbated by water withdrawals as problems for many streams (notably Tillamook Bay tributaries and Alsea, Siletz, Siuslaw, and Umpqua Rivers) and noted that agricultural and logging practices have led to serious riparian habitat losses. They also cited serious modification of stream structure by logging, splash dams, and widespread removal of beaver dams, but concluded that recent efforts have resulted in more stream miles being accessible to anadromous fish now than 100 years ago. Effects of recent floods were discussed for the Oregon and Washington Coastal Region above.

The first hatcheries were built in this area in 1902. Since the 1930s, artificial propagation programs have released nearly 400 million fall- and spring-run fish into this area, with nearly one-quarter of all the fish released coming from sources outside the ESU (Table 6, Appendix D). During much of this period, the impact of these releases may have been reduced by the large size of naturally spawning runs in most rivers. However, during the 1940s and 1950s many rivers were experiencing record low natural runs, and hatchery releases may have had a significant impact on local populations during this period (Kostow 1995). Chinook salmon from the Trask River have been used to establish hatchery broodstock in other systems in the Tillamook and Nestucca River Basins (Kostow 1995).

The contribution of hatchery-derived fish to total escapement is generally thought to be rather low (Kostow 1995). In 1990, the hatchery contribution to the Tillamook Bay fishery was only 15% (Kostow 1995). In contrast, hatchery contribution to total spawning escapement has been reported to be highest (approximately 50%) among fall-run chinook salmon populations in the Salmon and Elk Rivers (ODFW 1995). Additionally, hatchery-reared spring-run chinook salmon constituted 50% of the spring run on the North Fork Umpqua River in the 1980s,

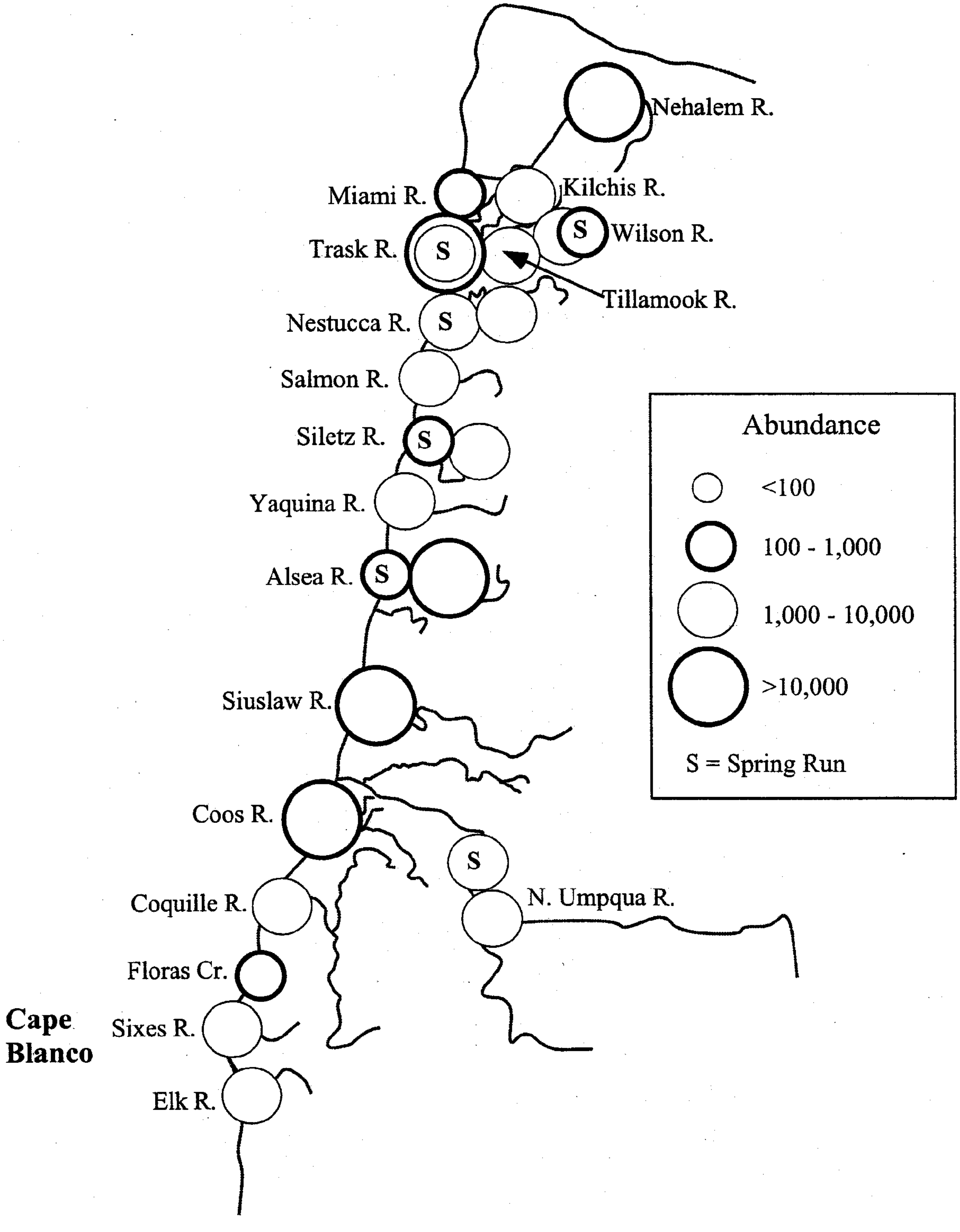
Nehalem R.
Miami R.
Kilchis R.
Wilson R.
S
Trask R.
S
Tillamook R.
Nestucca R.
S
Salmon R.
Siletz R.
S
Yaquina R.
Alsea R.
S
Siuslaw R.
Coos R.
S
N. Umpqua R.
Coquille R.
Floras Cr.
Cape Blanco
Sixes R.
Elk R.
Abundance
<100
100 - 1,000
1,000 - 10,000
>10,000
S = Spring Run

Figure 33. Recent 5-year geometric mean spawning escapement for chinook salmon populations in Oregon Coast (6) ESU. All data are for fall run, except as noted (see Appendix E for details).

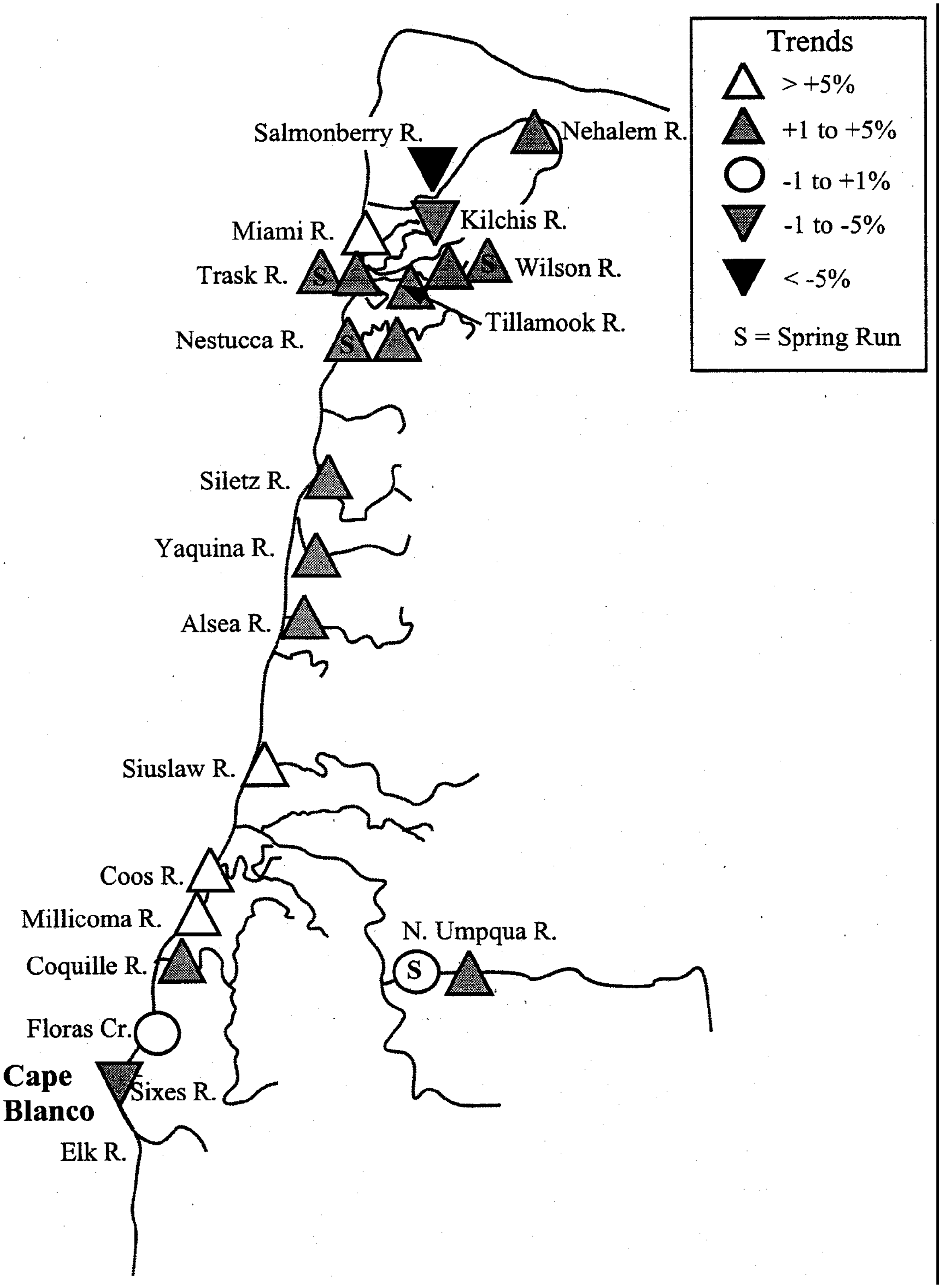

Figure 34. Trends (percent annual change) in abundance for chinook salmon populations in Oregon Coast (6) ESU. All data are for fall run, except as noted (see Appendix E for details).

although currently the figure may be as low as 30% (Kostow 1995). Estimates of the impact of hatchery strays is limited, but in the Sixes River, hatchery strays were reported to constitute up to 20% of the natural spawners (Kaczynski and Palmisano 1993).

Freshwater/estuarine harvest rates are on the order of 20-25% (Nicholas and Hankin 1988). Ocean exploitation rates have ranged from 24% to 48%, with total exploitation rates in the range of 45-68%, and an average near 60% (brood years 1982-89) (PSC 1994).

Previous assessments of stocks within this ESU have identified several stocks at risk or of concern; however, the preponderance of stocks have been identified as healthy (Appendix E). Nehlsen et al. (1991) identified two stocks as at high extinction risk (South Umpqua River and Coquille River spring run), one stock as at moderate extinction risk (Yachats River fall run) and five stocks as of special concern. Of the 44 stocks within this ESU considered by Nickelson et al. (1992), 26 were identified as healthy (with 2 stocks containing small, variable runs), 2 as depressed (South Umpqua River and Coquille River spring-run chinook salmon), 7 as of special concern due to hatchery strays, and 9 of unknown status (4 of which they suggested may not be viable). Huntington et al. (1996) identified 18 stocks in their survey: 6 healthy Level I and 12 healthy Level II stocks.

7) Washington Coast ESU

Historical harvest of chinook salmon in this ESU reached a peak in 1911, when 26,490 cases were packed at canneries. This corresponds to a peak run-size of about 190,000 fish.

At the present time, run-size and spawning escapement in this ESU are monitored by WDFW and the Western Washington Treaty Indian Tribes. Management objectives, terminal fisheries and monitoring methods vary considerably over the ESU. Willapa Bay is managed for hatchery production and is monitored by WDFW (WDF et al. 1993). Since 1988, 65% or more of the natural escapement in Willapa Bay has consisted of hatchery fish (WDF et al. 1993). Escapement is monitored by redd counts, and natural production is not believed to be self-sustaining. Monitoring of Grays Harbor is also conducted by WDFW through redd counts. Most spawning populations in Grays Harbor are believed to have little hatchery influence.

In rivers further north, monitoring is conducted by the Western Washington Treaty Indian Tribes. Time series of spawning escapement estimates are relatively short, and the longest abundance data series are from tribal net fisheries conducted in the estuaries. Most spawning stocks are believed to be of native origin with little hatchery influence. Notable exceptions are Sol Duc River spring-run chinook salmon, which are an introduced stock, and the Quinault River fall-run chinook salmon stock, which is propagated as a Pacific Salmon Treaty indicator stock.

Recent average natural spawning escapement, the sum of 5-year geometric means for individual populations, has been over 50,000 spawners (Fig. 35, Appendix E). Long-term trends are about evenly split between increases and declines, but with most larger populations increasing (Fig. 36, Appendix E). Short-term trends are predominantly negative, strongly so in the Quillayute Basin and Willapa Bay tributaries.

All basins are affected (to varying degrees) by habitat degradation. Tributaries inside Olympic National Park have been least affected by human activities For other areas, major habitat problems are related primarily to forest practices, including mass wasting resulting in sedimentation in spawning grounds, lack of large woody debris, and lack of streamside shade. For example, WDF et al. (1993) reported that the Hoko River has been heavily impacted by past logging practices, with over 300 mass-wasting events recorded in the last 50 years. Clearing of instream wood was common practice until the 1970s, resulting in channel downcutting and bedload scour and fill which, in combination with moderate to high levels of fine sediments in gravel beds, affects egg survival in many areas. Bishop and Morgan (1996) identified a variety of critical habitat issues for streams in the range of this ESU, including changes in flow regime (Hoko and, Quillayute Rivers), sedimentation (Chehalis, Hoh, Hoko, and Quillayute Rivers), high temperatures (Chehalis, Hoko, and Quillayute Rivers), streambed instability (Hoko and Quillayute Rivers), estuarine loss (Chehalis River), loss of large woody debris (Hoko River), and loss of pool habitat (Hoko River). Of the streams they reviewed, only in the Queets and Quinault River Basins were chinook salmon not considered to be substantially limited by habitat problems. Upper basins of several streams in this region lie within Olympic National Park and are fully protected from effects of logging and most other habitat changes. The Puget Sound Salmon Stock Review Group (PSSSRG 1997) reviewed causes of declines in western Strait of Juan de Fuca and described habitat conditions for rivers in that portion of this ESU, concluding that timber harvest and hydromodifications have reduced both capacity and quality of salmon habitats.

WDF et al. (1993) classified 9 out of 31 stocks in this ESU as having cultured or composite production (indicating that a stock is sustained to some extent by artificial propagation). Some 319 million chinook salmon have been released into Washington coastal waters since 1952. Fall-run chinook salmon have been propagated in much larger numbers than spring-run chinook salmon (309 vs. 10 million). On average, approximately 19% of all hatchery releases have been from sources outside of the ESU. However, the Pysht, Hoko, and Chehalis Rivers have received proportionally larger introductions of fish from outside the ESU. Releases into these three rivers constitute more than half of the total of all non-ESU releases (Table 6, Appendix D).

Significant numbers of hatchery strays have been found in naturally spawning populations in the Satsop and Willapa Bay Rivers (Marshall et al. 1995), although their reproductive success is unknown. Furthermore, there has been considerable interbreeding between the non-native Sol Duc Hatchery spring-run chinook salmon stock and the native

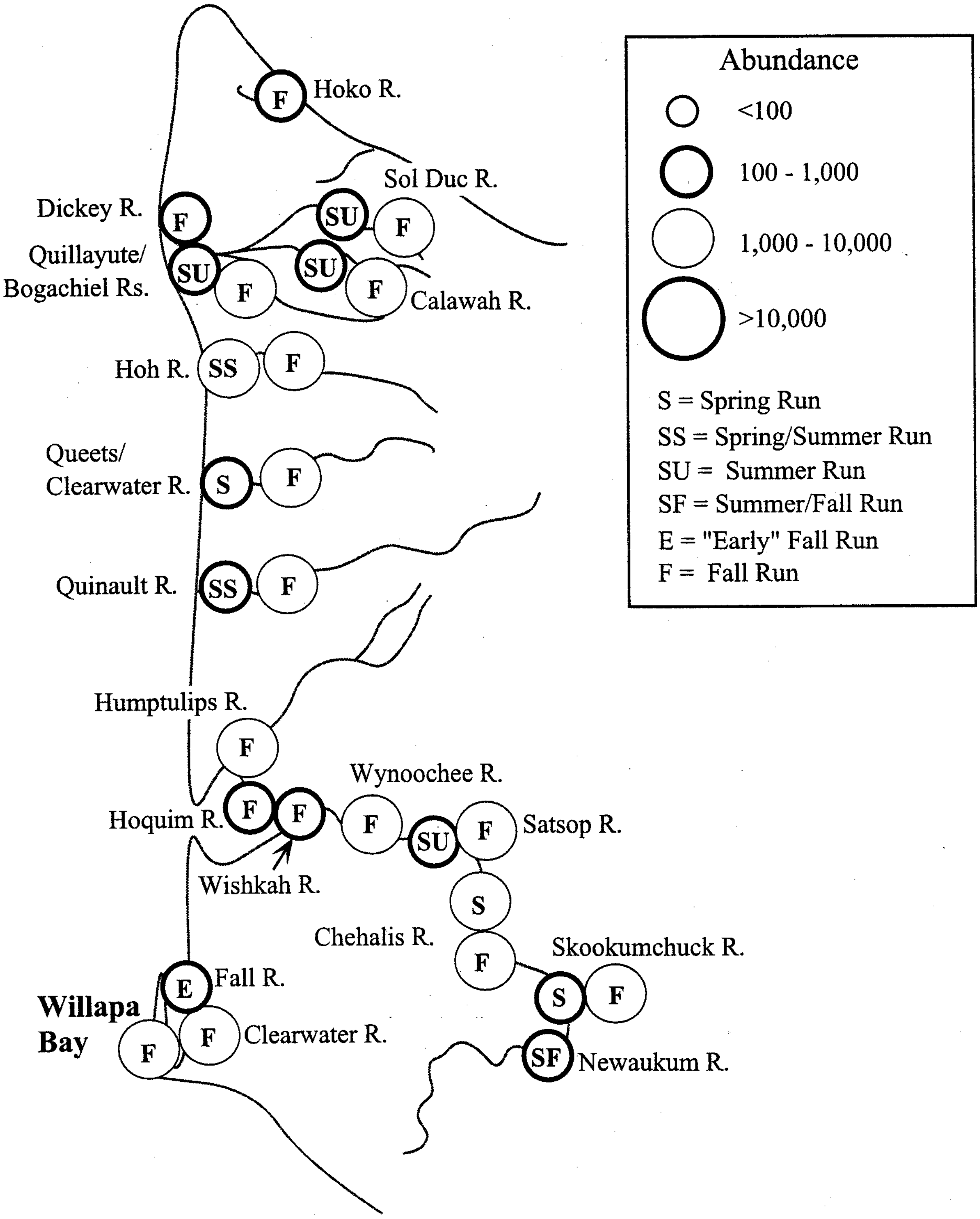

Figure 35. Recent 5-year geometric mean spawning escapement for chinook salmon populations in Washington Coast (7) ESU (see Appendix E for details).

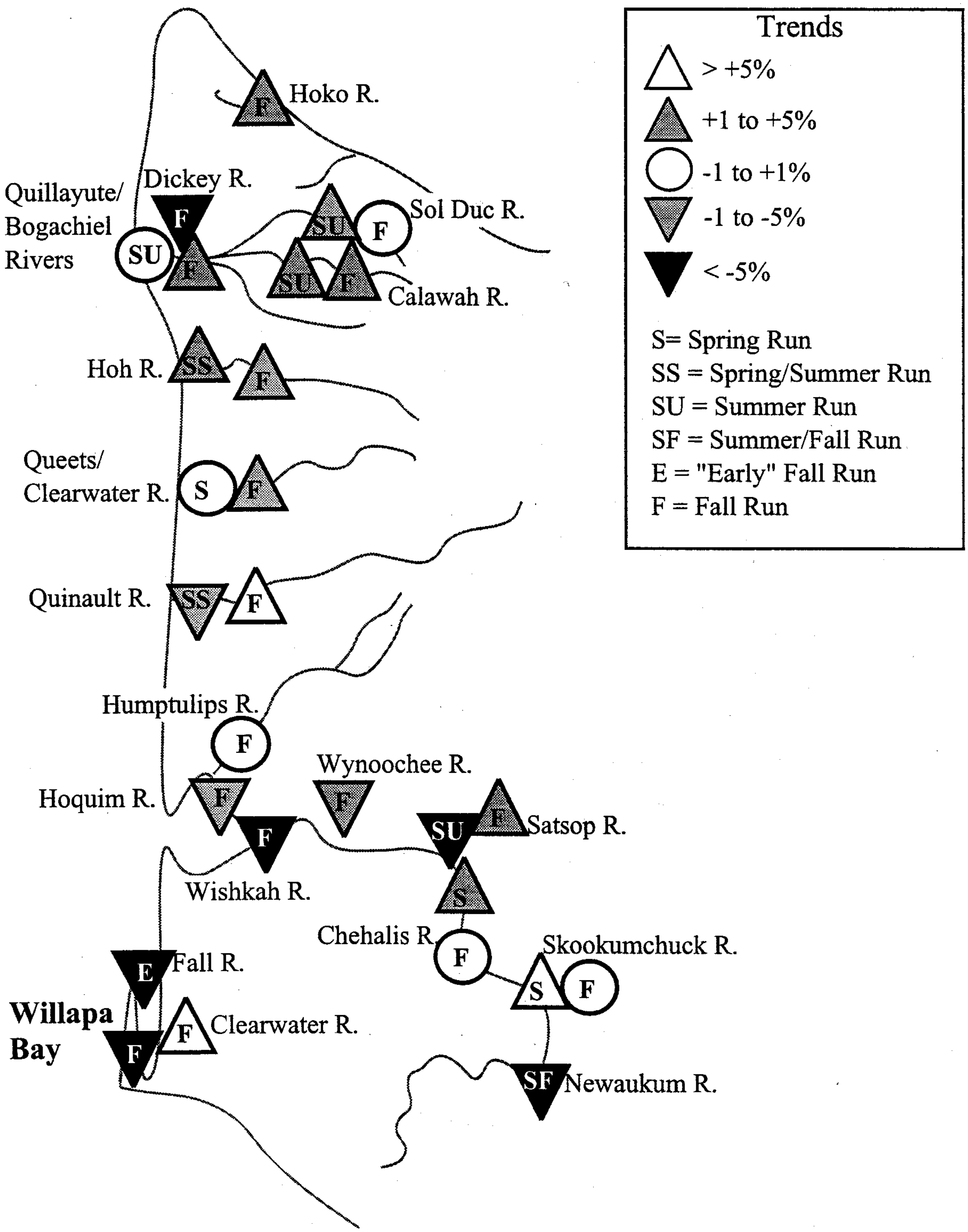
Trends
> +5%
+1 to +5%
-1 to +1%
-1 to -5%
< -5%
S= Spring Run
SS = Spring/Summer Run
SU = Summer Run
SF = Summer/Fall Run
E = "Early" Fall Run
F = Fall Run
Hoko R.
F
Quillayute/
Bogachiel
Rivers
Dickey R.
F
SU
F
SU
F
Sol Duc R.
SU
F
Calawah R.
Hoh R.
SS
F
Queets/
Clearwater R.
S
F
Quinault R.
SS
F
Humptulips R.
F
Hoquim R.
F
F
Wishkah R.
Wynoochee R.
F
SU
F
Satsop R.
S
Chehalis R.
F
Skookumchuck R.
S
F
SF
Newaukum R.
E
Fall R.
Willapa
Bay
F
F
Clearwater R.

Figure 36. Trends (percent annual change) in abundance for chinook salmon populations in Washington Coast (7) ESU (see Appendix E for details).

summer-run chinook salmon run in the Sol Duc River (WDF et al. 1993). With the exception of the Sol Duc Hatchery spring run, most of the introductions of non-native spring-run fish are thought to have been unsuccessful (WDF et al. 1993, Marshall et al. 1995).

Harvest rates on Washington coast chinook salmon stocks have been moderate, with ocean exploitation rates averaging 44-52%, and total exploitation rates averaging 48-56% (1982-89) for Hoko and Sooes stocks (PSC 1994).

Previous assessments of stocks within this ESU have identified several as being at risk or of concern, but more stocks have been identified as healthy than at risk (Appendix E). Nehlsen et al. (1991) identified one stock as extinct (Pysht River fall run), one as possibly extinct (Ozette River fall run), and one as at high risk of extinction (Wynoochee River spring run), although there is some question whether the Wynoochee River spring run ever existed (WDFW 1997a). WDF et al. (1993) considered 31 stocks within the ESU, of which 18 were reported to be of native origin and predominantly natural production. The status of these 18 stocks was 11 healthy, 4 depressed, and 3 unknown. The status of the remaining (not native/natural) stocks was nine healthy, two depressed, and two unknown. The Sol Duc River spring-run and Raft River fall-run chinook salmon were not considered an ESA issue by the BRT (stocks were not historically present in the watershed or current stocks are not representative of historical stocks) but was included to give a complete presentation of stocks identified by WDF et al. (1993). Huntington et al. (1996) identified 12 stocks in their survey: 1 healthy Level I stock (Quillayute/Bogachiel River fall run) and 11 healthy Level II stocks.

8) Puget Sound ESU

The peak recorded harvest landed in Puget Sound occurred in 1908, when 95,210 cases of canned chinook salmon were packed. This corresponds to a run-size of approximately 690,000 chinook salmon at a time when both ocean harvest and hatchery production were negligible. (This estimate, as with other historical estimates, needs to be viewed cautiously; Puget Sound cannery pack probably included a portion of fish landed at Puget Sound ports but originating in adjacent areas, and the estimates of exploitation rates used in run-size expansions are not based on precise data.) Recent mean spawning escapements totaling 71,000 correspond to a run entering Puget Sound of approximately 160,000 fish. Based on an exploitation rate of one-third in intercepting ocean fisheries, the recent average potential run-size would be 240,000 chinook salmon (PSC 1994).

Currently, escapement to rivers in Puget Sound and Hood Canal is monitored by WDFW and the Northwest tribes. Populations least affected by hatcheries are in the northern part of the sound in the Nooksack, Skagit, Stillaguamish, and Snohomish River systems.

The Nooksack River has spring/summer runs in the north and south forks. The North Fork escapement is monitored by carcass surveys and is influenced by a hatchery on Kendall Creek (part of a native stock rebuilding program). Escapement to the South Fork is monitored by redd counts, and the stock is believed to have little hatchery influence. Both stocks are considered critical by WDFW because of chronically low spawning escapements. The Skagit River supports three spring runs, two summer runs, and a fall run. Mean spawning escapement of the summer/fall run has been below the escapement goal and declining (Fig. 37-38, Appendix E). Terminal run-size has been declining, and escapement has been maintained at the expense of terminal fisheries. Of the five stocks identified by WDF et al. (1993), two are rated healthy, two depressed, and one of unknown status. On the Stillaguamish River, two runs have been identified. The combined escapement goal has been met only twice since 1978, and both runs are considered depressed. Of four runs identified in the Snohomish system, two are rated depressed, one unknown, and one as healthy. The single stock identified as “healthy” (Wallace River) is considered to be derived from hatchery strays and has experienced a severe recent decline.

The 5-year geometric mean of spawning escapement of natural chinook salmon runs in North Puget Sound for 1992-96 is approximately 13,000 (Fig. 37, Appendix E). Both long- and short-term trends for these runs were negative, with few exceptions. In south Puget Sound, spawning escapement of the natural runs has averaged 11,000 spawners (Fig. 37, Appendix E). In this area, both long- and short-term trends are predominantly positive.

In Hood Canal, summer/fall-run chinook salmon spawn in the Skokomish, Union, Tahuya, Duckabush, Dosewallips and Hamma Hamma Rivers. Because of transfers of hatchery fish, these spawning populations are considered a single stock (WDF et al. 1993). Fisheries in the area are managed primarily for hatchery production and secondarily for natural escapement; high harvest rates directed at hatchery stocks have resulted in failure to meet natural escapement goals in most years (USFWS 1997a). The 5-year geometric mean natural spawning escapement has been 1,100 (Fig. 37, Appendix E), with negative short- and long-term trends (except in the Dosewallips River).

The ESU also includes the Dungeness and Elwha Rivers, which have natural chinook salmon runs as well as hatcheries. The Dungeness River has a run of spring/summer-run chinook salmon with a 5-year geometric mean natural escapement of 105 fish (Fig. 37, Appendix E). The Elwha River has a 5-year geometric mean escapement of 1,800 fish (Fig. 37, Appendix E), but contains two hatcheries, both lacking adequate adult recovery facilities. Egg take at the hatcheries is augmented from natural spawners, and hatchery fish spawn in the wild. Consequently, hatchery and natural spawners are not considered discrete stocks (WDF et al. 1993). Both of these populations exhibit downward recent trends (Appendix E).

Habitat throughout the ESU has been blocked or degraded. In general, upper tributaries have been impacted by forest practices and lower tributaries and mainstem rivers have been

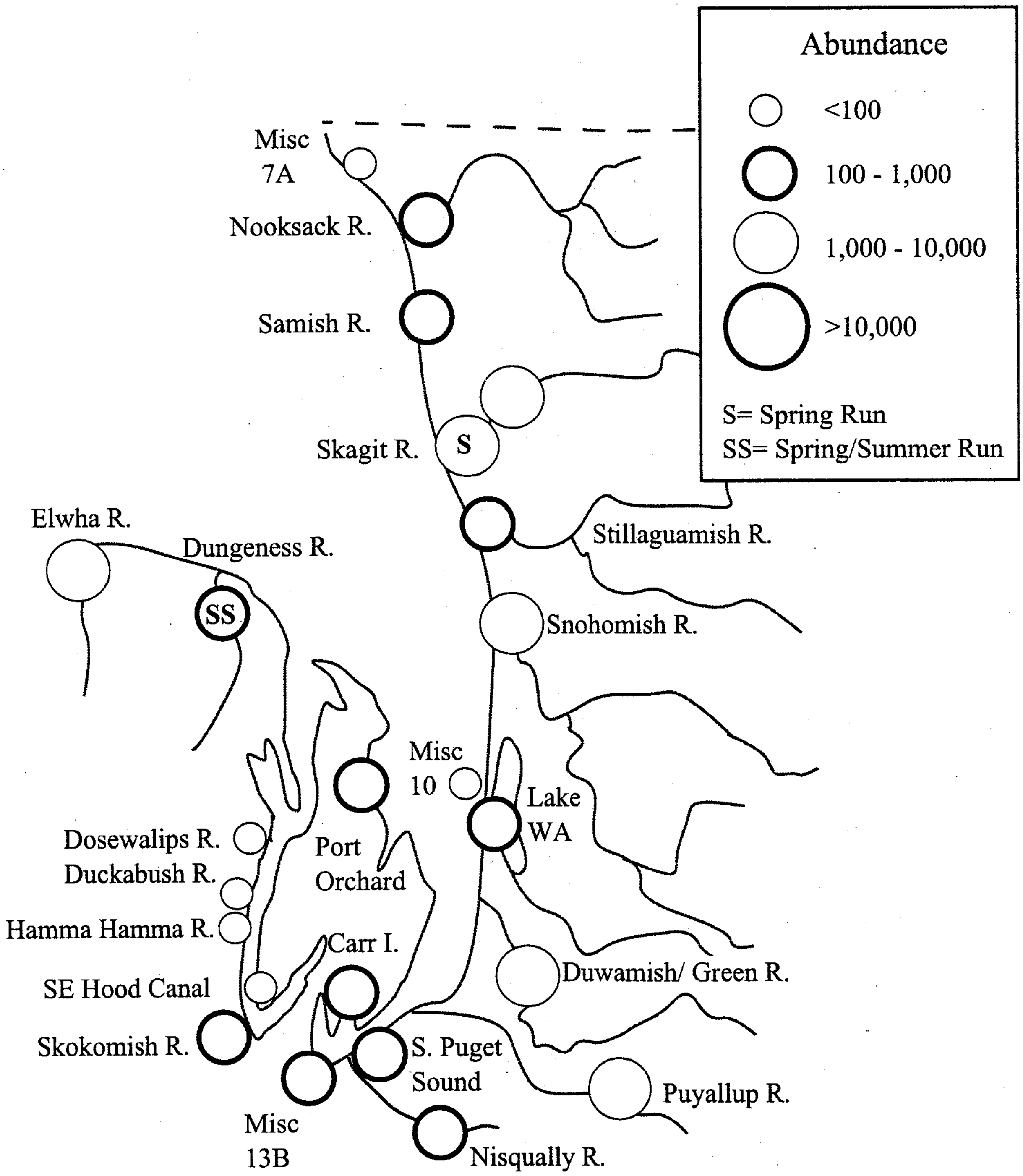

Figure 37. Recent 5-year geometric mean spawning escapement for chinook salmon populations in Puget Sound (8) ESU. 7A, 10, and 13B designate combined escapements for smaller stream systems within a fishery management region. All data are for summer/fall run, except as noted (see Appendix E for details).

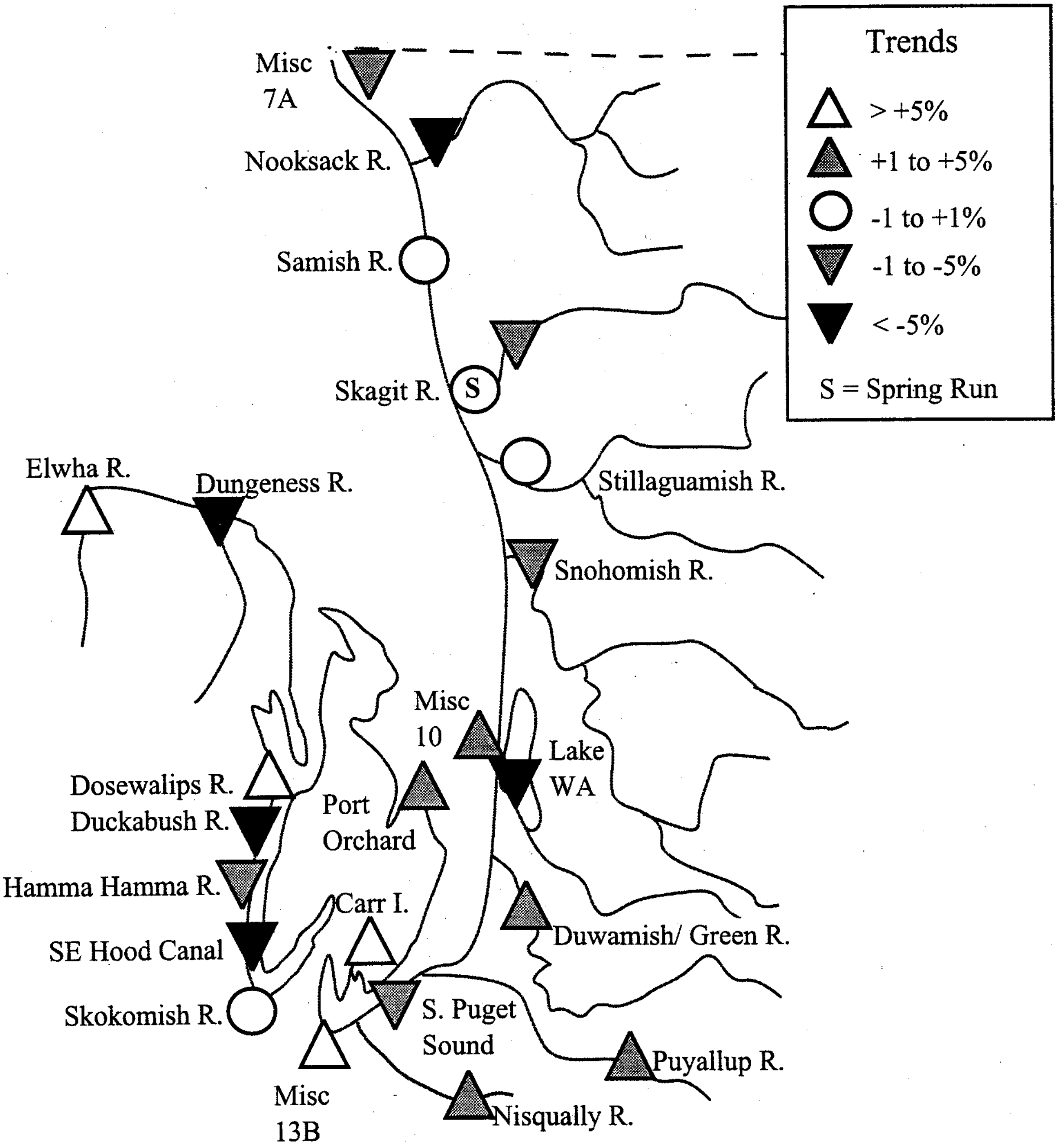

Figure 38. Trends (percent annual change) in abundance for chinook salmon populations in Puget Sound (8) ESU. 7A, 10, and 13B designate combined escapements for smaller stream systems within a fishery management region. All data are for summer/fall run, except as noted (see Appendix E for details).

impacted by agriculture and/or urbanization. Diking for flood control, draining and filling of freshwater and estuarine wetlands, and sedimentation due to forest practices and urban development are cited as problems throughout the ESU (WDF et al. 1993). Blockages by dams, water diversions, and shifts in flow regime due to hydroelectric development and flood control projects are major habitat problems in several basins. Bishop and Morgan (1996) identified a variety of critical habitat issues for streams in the range of this ESU including 1) changes in flow regime (all basins), 2) sedimentation (all basins), 3) high temperatures (Dungeness, Elwha, Green/Duwamish, Skagit, Snohomish, and Stillaguamish Rivers), 4) streambed instability (most basins), 5) estuarine loss (most basins), 6) loss of large woody debris (Elwha, Snohomish, and White Rivers), 7) loss of pool habitat (Nooksack, Snohomish, and Stillaguamish Rivers), and 8) blockage or passage problems associated with dams or other structures (Cedar, Elwha, Green/Duwamish, Snohomish, and White Rivers). The Puget Sound Salmon Stock Review Group (PSSSRG 1997) provided an extensive review of habitat conditions for several of the stocks in this ESU. It concluded that reductions in habitat capacity and quality have contributed to escapement problems for Puget Sound chinook salmon. It cited evidence of direct losses of tributary and mainstem habitat, due to dams; of slough and side-channel habitat, caused by diking, dredging, and hydromodification; and also cited reductions in habitat quality due to land management activities.

WDF et al. (1993) classified 11 out of 29 stocks in this ESU as being sustained, in part, through artificial propagation. Nearly 2 billion fish have been released into Puget Sound tributaries since the 1950s (Table 6, Appendix D). The vast majority of these have been derived from local returning fall-run adults. Returns to hatcheries have accounted for 57% of the total spawning escapement, although the hatchery contribution to spawner escapement is probably much higher than that, due to hatchery-derived strays on the spawning grounds. In the Stillaguamish River, summer-run chinook have been supplemented under a wild broodstock program for the last decade. In some years, returns from this program have comprised from 30% to 50% of the natural spawners, suggesting that the unaided stock is not able to maintain itself (NWIFC 1997a). Almost all of the releases into this ESU have come from stocks within this ESU, with the majority of within-ESU transfers coming from the Green River Hatchery or hatchery broodstocks that have been derived from Green River stock (Marshall et al. 1995). The electrophoretic similarity between Green River fall-run chinook salmon and several other fall-run stocks in Puget Sound (Marshall et al. 1995) suggests that there may have been a significant effect from some hatchery transplants. Overall, the pervasive use of Green River stock throughout much of the extensive hatchery network, that exists in this ESU, may reduce the genetic diversity and fitness of naturally spawning populations.

Harvest impacts on Puget Sound chinook salmon stocks have been quite high. Ocean exploitation rates on natural stocks average 56-59%; total exploitation rates average 68-83% (1982-89 brood years) (PSC 1994). Total exploitation rates on some stocks have exceeded 90% (PSC 1994).

Previous assessments of stocks within this ESU have identified several stocks as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified four stocks as extinct, four stocks as possibly extinct, six stocks as at high risk of extinction, one stock as at moderate risk (White River spring run), and 1 stock (Puyallup River fall run) as of special concern. WDF et al. (1993) considered 28 stocks within the ESU, of which 13 were considered to be of native origin and predominantly natural production. The status of these 13 stocks was: 2 healthy (Upper Skagit River summer run and Upper Sauk River spring run), 5 depressed, 2 critical (South-Fork Nooksack River spring/summer run and Dungeness River spring/summer run), and 4 unknown. The status of the remaining (composite production) stocks was eight healthy, two depressed, two critical, and three unknown. The Nooksack/Samish River fall run and Issaquah Creek summer/fall run were not considered an ESA issue by the BRT (stocks were not historically present in the watershed or current stocks are not representative of historical stocks) but were included to give a complete presentation of stocks identified by WDF et al. (1993).

Lower Columbia River Region

The Lower Columbia River Region includes portions of the Coastal Range, Willamette Valley, and Cascades ecoregions (see "Ecological Features," p. 12) and is characterized by numerous short- and medium-length rivers and streams draining the coast ranges and west slope of the Cascade Mountains, with a single large river (Willamette River). We have no estimates of historic abundance of chinook salmon in this region. Peak cannery pack for the entire Columbia River Basin occurred in 1883, when 629,400 cases were packed, suggesting a total run-size of about 4.6 million chinook salmon.

Chinook salmon in this region have been strongly affected by losses and alterations of freshwater habitats. Bottom et al. (1985), WDF et al. (1993), and Kostow (1995) provide reviews of habitat problems. Timber harvesting and associated road building occur throughout the region on federal, state, and private lands. These activities may increase sedimentation and debris flows and reduce cover and shade, resulting in aggradation, embedded spawning gravel, and increased water temperatures. Timber harvest in the Oregon portion of the region peaked in the 1930s, but habitat impacts remain (Kostow 1995). Agriculture is also widespread in the lower portions of river basins, and has resulted in widespread removal of riparian vegetation, rerouting of streams, degradation of streambanks, and summer water withdrawals. Urban development has had substantial impacts in the lower Willamette Valley, including channelization and diking of rivers, filling and draining of wetlands, removal of riparian vegetation, and pollution (Kostow 1995).

Intensive hatchery programs were initiated more than 100 years ago in this region. Nearly 4.5 billion hatchery-derived fish have been released during the last 70 years, equal to the total for all the other regions combined (Table 6, Appendix D). The majority of these have been “tule” fall-run chinook salmon released into the lower Columbia River for fisheries enhancement. Because of the advanced degree of maturation that “tules” exhibit at the time of freshwater entry, the economic value of these fish is rather low; therefore, efforts have been made to introduce Rogue River “bright” fall-run chinook and upper Columbia River upriver “bright” fall-run chinook into this region (WDF et al. 1993, Kostow 1995, Marshall et al. 1995). In addition, fall-run chinook salmon from the lower Columbia River were introduced into the upper Willamette River Basin beginning in the 1950s to exploit underutilized habitat.

9) Lower Columbia River ESU

We have no estimates of historic abundance for this ESU, but there is widespread agreement that natural production has been substantially reduced over the last century. Currently, spawning escapement to populations on the Washington side of the Columbia River are monitored primarily by peak fish counts in index areas (WDF et al. 1993). Peak index-area spawning counts are expanded to estimate total spawning escapement. In most lower Columbia River tributaries in Oregon, foot surveys are conducted and escapement estimates are based on peak spawner counts or redd counts (Theis and Melcher 1995), with dam counts available for the Sandy and Clackamas Rivers.

For fishery monitoring purposes, these individual spawning populations are combined into stock groupings: Lower Columbia River Wild, Lower Columbia River Hatchery, and Spring Creek Hatchery stocks of fall-run chinook salmon designated for fishery management purposes(WDFW and ODFW 1994, PFMC 1996b).

The ESU also includes spring-run chinook salmon in the Cowlitz, Lewis, Kalama, Sandy, and Clackamas Rivers. Estimates of spring runs to the mainstem Columbia River tributaries are routinely reported by fishery management agencies (WDFW and ODFW 1994, PFMC 1996b), with the exception of the spring run to the Clackamas River. For fishery monitoring purposes, the Clackamas River spring-run chinook salmon are included with the Willamette River. Cramer et al. (1996) reported escapement to the Clackamas River (as hatchery returns), North Fork Dam counts, and spawners below the dam (from Bennett 1994).

Recent abundance of spawners includes a 5-year geometric mean natural spawning escapement of 11,200 spring-run fish (1992-96) (Fig. 39, Appendix E). The fall run includes 29,000 natural spawners (Fig. 39, Appendix E) and 37,000 hatchery spawners (1991-95), but according to the accounting of PFMC (1996b), approximately 68% of the natural spawners are first-generation hatchery strays. Long-term trends in escapement for the fall run are mixed, with most larger stocks positive, while the spring run trends are positive or stable (Fig. 40, Appendix E). Short-term trends for both runs are more negative.

All basins are affected (to varying degrees) by habitat degradation. Major habitat problems are related primarily to blockages, forest practices, urbanization in the Portland and

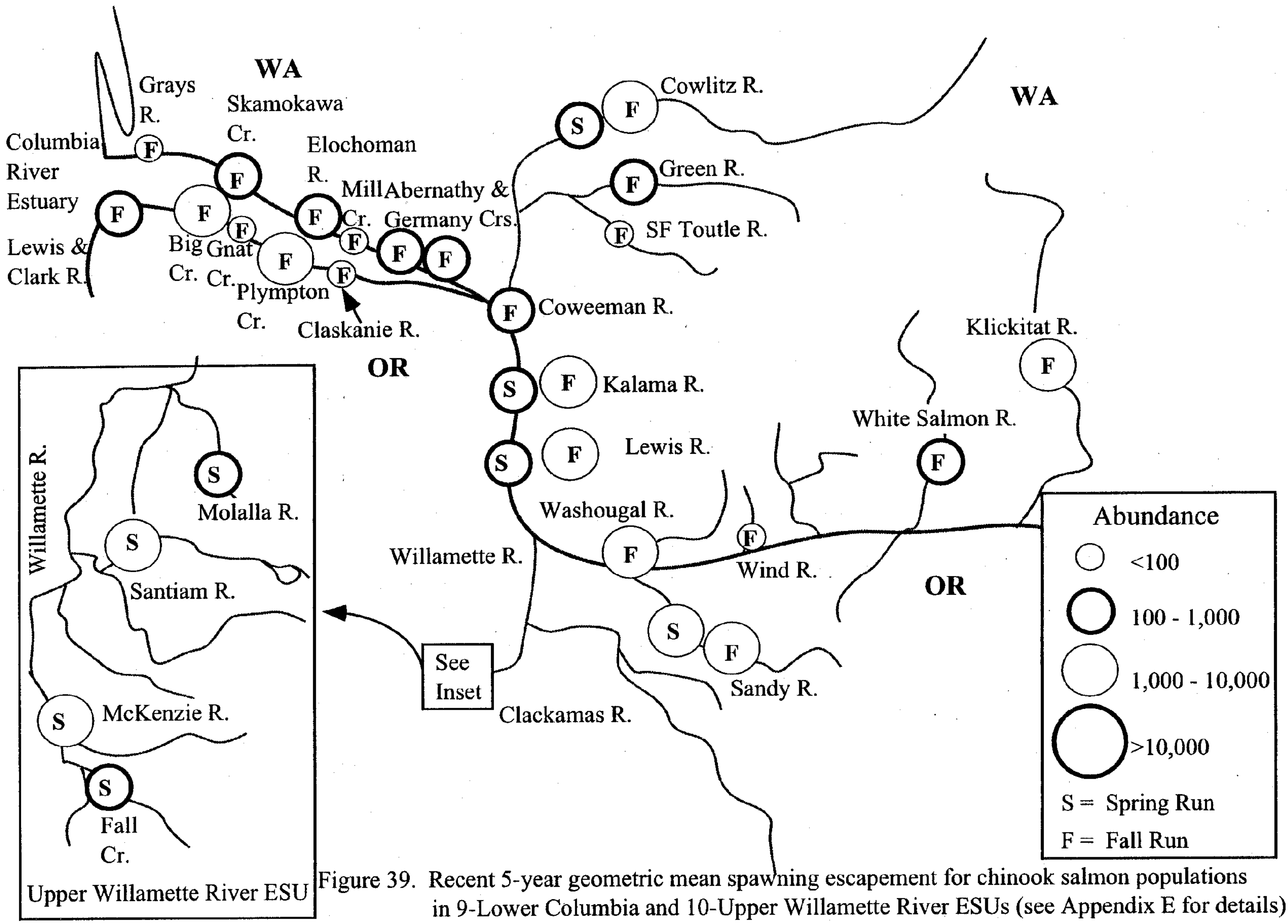

Figure 39. Recent 5-year geometric mean spawning escapement for chinook salmon populations in 9-Lower Columbia and 10-Upper Willamette River ESUs (see Appendix E for details).

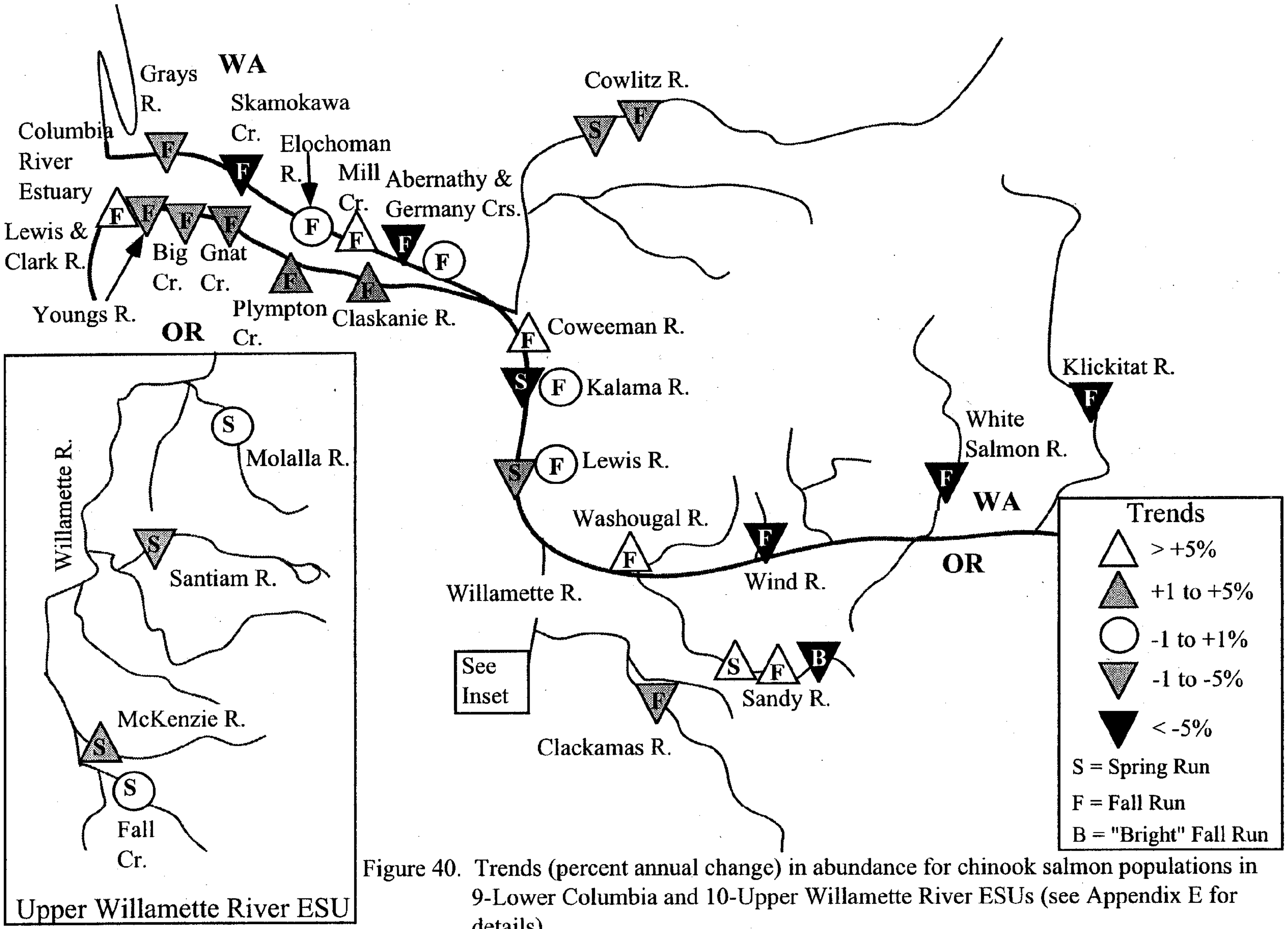

Figure 40. Trends (percent annual change) in abundance for chinook salmon populations in 9-Lower Columbia and 10-Upper Willamette River ESUs (see Appendix E for details).

Vancouver areas, and agriculture in floodplains and low-gradient tributaries. Substantial chinook salmon spawning habitat has been blocked (or passage substantially impaired) in the Cowlitz (Mayfield Dam 1963, RKm 84), Lewis (Merwin Dam 1931, RKm 31), Clackamas (North Fork Dam 1958, RKm 50), Hood (Powerdale Dam 1929, RKm 7), and Sandy (Marmot Dam 1912, RKm 48; Bull Run River dams in the early 1900s) Rivers (WDF et al. 1993, Kostow 1995).

Hatchery programs to enhance chinook salmon fisheries in the lower Columbia River began in the 1870s, expanded rapidly, and have continued throughout this century. Although the majority of the stocks have come from within this ESU, over 200 million fish from outside the ESU have been released since 1930 (Table 6, Appendix D). A particular concern at the present time is straying by Rogue River fall-run chinook salmon, which are released into the lower Columbia River to augment harvest opportunities. Available evidence indicates a pervasive influence of hatchery fish on natural populations throughout this ESU, including both spring- and fall-run populations (Howell et al. 1985, Marshall et al. 1995). In addition, the exchange of eggs between hatcheries in this ESU has led to the extensive genetic homogenization of hatchery stocks (Utter et al. 1989).

Harvest rates on fall-run stocks are moderately high, with an average total exploitation rate of 65% (1982-89 brood years) (PSC 1994). The average ocean exploitation rate for this period was 46%, while the freshwater harvest rate on the fall run has averaged 20%, ranging from 30% in 1991 to 2.4% in 1994. Harvest rates are somewhat lower for spring-run stocks, with estimates for the Lewis River averaging 24% ocean and 50% total exploitation rates in 1982-89 (PSC 1994). Inriver fisheries harvest approximately 15% of the lower river hatchery stock, 29% of the lower river wild stock, and 58% of the Spring Creek hatchery stock (PFMC 1996b). The average inriver exploitation rate on the stock as a whole is 29% (1991-95).

Previous assessments of stocks within this ESU have identified several stocks as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified two stocks as extinct (Lewis River spring run and Wind River fall run), four stocks as possibly extinct, and four stocks as at high risk of extinction. The Sandy River spring run and Hood River spring and fall runs were not considered an ESA issue by the BRT (stocks were not historically present in the watershed or current stocks are not representative of historical stocks) but were included to give a complete presentation of stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered 20 stocks within the ESU, of which only 2 were considered to be of native origin and predominantly natural production (Lewis River and East Fork Lewis River fall runs). Nehlsen et al. considered the status of these two stocks to be healthy, and the status of the remaining (not native/natural) stocks as: 14 healthy and 4 depressed. Huntington et al. (1996) identified one healthy Level I stock in their survey (Lewis River fall run).

10) Upper Willamette River ESU

The spring run has been counted at Willamette Falls since 1946 (ODFW and WDFW 1995) but, counts were not differentiated into adults and jacks until 1952. In the first 5 years (1946-50), the geometric mean of the counts for adults and jacks combined was 31,000 fish. The most recent 5-year (1992-96) geometric mean escapement above Willamette Falls was 26,000 adults (Appendix E). Willamette River spring-run chinook salmon are targeted by commercial and recreational fisheries in the lower Willamette and Columbia Rivers. During the same 5-year period, the geometric mean of the run-size to the mouth of the Columbia River was 48,000 fish (PFMC 1997). The majority of the Willamette River fish are hatchery produced.

Estimates of the naturally produced run have been made only for the McKenzie River in 1994 and 1995 (Nicholas 1995). Nicholas (1995) estimated the escapement of naturally produced spring-run chinook salmon in the McKenzie River to be approximately 1,000 spawners. Primarily on the basis of professional judgement, they estimated the 1994-95 natural escapement of spring-run chinook salmon to the entire ESU as approximately 7,700 spawners, with 2,100 to 3,500 naturally produced natural spawners. However, Nicholas (1995) included the Sandy and Clackamas Rivers in their Willamette River spring-run chinook salmon unit; the BRT does not consider these introduced populations to be part of the ESU. Without these 2 rivers, the remaining escapement was approximately 3,900 natural spawners, with approximately 1,300 of these spawners naturally produced (Fig. 39, Appendix E). Long-term trends of escapement are mixed, ranging from slightly upward to moderately downward (Fig. 40, Appendix E). Short-term trends are all strongly downward.

Although the abundance of Willamette River spring-run chinook salmon has been relatively stable over the long term, and there is evidence some of natural production, it is apparent that at present production and harvest levels the natural population is not replacing itself. With natural production accounting for only one-third of the natural spawning escapement, it is questionable whether natural spawners would be capable of replacing themselves even in the absence of fisheries. Although hatchery programs in the Willamette River Basin have maintained broodlines that are relatively free of genetic influences from outside the basin, they may have homogenized the population structure within the ESU. Prolonged artificial propagation of the majority of the production from this ESU may also have had deleterious effects on the ability of Willamette River spring-run chinook salmon to reproduce successfully in the wild.

Habitat blockage and degradation are significant problems in this ESU. Available habitat has been reduced by construction of dams in the Santiam, McKenzie, and Middle Fork Willamette River Basins, and these dams have probably adversely affected remaining production via thermal effects. Agricultural development and urbanization are the main causes of serious habitat degradation throughout the basin (Bottom et al. 1985, Kostow 1995).

Historically, only spring-run fish were able to ascend Willamette Falls to access the upper Willamette River (Fulton 1968). Following improvements in the fish ladder at Willamette Falls, some 200 million fall-run chinook salmon have been introduced into this ESU since the 1950s. In contrast, the upper Willamette River has received relatively few introductions of non-native spring-run fish from outside this ESU (Table 6, Appendix D). Artificial propagation efforts have been undertaken by a limited number of large facilities (McKenzie, Marion Forks, South Santiam, and Willamette [Dexter] Fish Hatcheries). These hatcheries have exchanged millions of eggs from various populations in the upper Willamette River Basin. The result of these transfers has been the loss of local genetic diversity and the formation of a single breeding unit in the Willamette River Basin (Kostow 1995). Considerable numbers of hatchery spring-run strays have been recovered from natural spawning grounds, and an estimated two-thirds of natural spawners are of hatchery origin (Nicholas 1995). There is also evidence that introduced fall-run chinook salmon have successfully spawned in the upper Willamette River (Howell et al 1985). Whether hybridization has occurred between native spring-run and introduced fall-run fish is not known.

Total harvest rates on stocks in this ESU are moderately high with the average total harvest mortality rate estimated to be 72% in 1982-89, and a corresponding ocean exploitation rate of 24% (PSC 1994). This estimate does not fully account for escapement, and ODFW is in the process of revising harvest rate estimates for this stock; revised estimates may average 57% total harvest rate, with 16% ocean and 48% freshwater components (Kostow 1995). The inriver recreational harvest rate (Willamette River sport catch/estimated run size) for the period from 1991 through 1995 was 33% (data from PFMC 1996b).

The only previous assessment of risk to stocks in this ESU is that of Nehlsen et al. (1991), who identified the Willamette River spring-run chinook salmon as of special concern (Appendix E). They noted vulnerability to minor disturbances, insufficient information on population trend, and the special life-history characteristics of this stock as causes for concern.

Upper Columbia and Snake Rivers Region

We have no estimates of historic abundance of chinook salmon specific to this region, but there is widespread agreement that natural production has been reduced substantially over the last century. Peak cannery pack for the entire Columbia River Basin occurred in 1883, when 629,400 cases were packed, suggesting a total run-size of about 4.6 million chinook salmon. This region includes all or part of the Cascades, Columbia Basin, Blue Mountains, Snake River Basin/High Desert, and Northern Rockies ecoregions (see "Ecological Features," p. 12) and is characterized by mostly long rivers with large, semi-arid or arid drainage basins.

Chinook salmon in this region have been strongly affected by losses and alterations of freshwater habitats. Bottom et al. (1985), WDF et al. (1993), Kostow (1995), and PFMC (1995) reviewed habitat problems in the region, which include blockages of large areas by major dams, hydrologic modifications of main migration corridors by dam and reservoir construction, dewatering of rivers by irrigation diversions, unscreened diversions, and degradation of spawning and juvenile rearing habitat by land use activities including logging, grazing, and mining. Bottom et al. (1985) summarized habitat studies in the Deschutes, John Day, Umatilla, and Grande Ronde River drainages and reported that 1,594 miles of streams in those drainages were in need of habitat restoration. They cited temperature extremes and low flows as primary limiting factors for salmonid production in eastern Oregon streams, and noted adverse effects of past mining activities in the John Day River and Powder River Basins, and noted severe sedimentation or erosion problems in the Crooked, John Day, Hood, Malheur River Basins and in the Umatilla Plateau and Wallowa Mountain regions. They also cited overgrazing and farming as causes of devastating losses of streamside vegetation. In contrast, substantial areas of chinook salmon habitat in the Snake River Basin are in designated wilderness areas with limited human impact on habitat quality.

Artificial propagation facilities in this region were constructed primarily to mitigate the construction of dams in the mainstem Columbia River and its tributaries. Hatchery programs were not prominent in this region until the authorization of the GCFMP and the construction of three national fish hatcheries in 1940 (Fish and Hanavan 1948). The LSRCP and mainstem Columbia River Dam mitigation mandated the construction of several more hatcheries in the 1960s through the 1980s. Initially, many of these hatcheries utilized local stocks, primarily those intercepted at the dams for which the hatcheries were mitigating. In many cases these broodstocks were supplemented with introductions of non-native fish to maintain production levels (Table 6, Appendix D).

11) Middle Columbia River Spring-Run ESU

We have no estimates of historical abundance specific to this ESU. WDFW monitors five spring-run stocks geographically located within this ESU. The Wind River historically had no spring run until Shipperd Falls at RKm 5 was laddered in 1956 and spring-run chinook salmon were introduced at Carson Hatchery. This stock was not considered an ESA issue. Spring-run escapements to the Klickitat, Upper Yakima, Naches, and American Rivers are monitored by redd counts. Escapement to the Upper Yakima River is also counted at Roza Dam (RKm 185) above the confluence of the Yakima and the Naches Rivers.

In Oregon, escapement is monitored at Pelton trap on the Deschutes River and at Warm Springs Hatchery on the Warm Springs River. Run-size is estimated as the sum of these two counts and the catch at the sport and tribal fisheries at Sherars Falls (RKm 69). This is believed to account for most of the spring run except for a small run into Shitike Creek (Olsen et al. 1994a). Escapement trends are monitored in the John Day River by redd counts (Olsen et al. 1994d). Populations of spring-run chinook salmon are also present in the Hood and Umatilla Rivers, but the historic populations originally present were believed to have been extirpated, and the present runs are not representative of what was historically there. For this reason they were not considered an ESA issue by the BRT.

Although exhaustive estimates of spawning escapements are not routinely made, dam passage, hatchery returns, and fishery landings are regularly monitored (WDFW and ODFW 1994). By subtracting hatchery returns and Zone 6 fishery landings from the difference between Bonneville Dam counts and the sum of Priest Rapids and Ice Harbor Dam counts, we can get a rough estimate of the total in-river run to the ESU. The 5-year geometric mean of this dam-count-based estimate is approximately 25,000 adults (based on data from PFMC 1997). This estimate does not account for recreational harvest or prespawning mortality and includes the Wind River and Umatilla River stocks, so it must be viewed as an upper bound of escapement to the ESU. The two largest stocks for which we have recent average (1991-96) escapement estimates are the John Day River (2,400 spawners) and Yakima River (1,100 spawners) (Fig. 41). Trends are mixed, with long-term trends mostly negative (except Klickitat, Umatilla, and Yakima Rivers) and short-term trends more strongly negative (Fig. 42, Appendix E).

Habitat problems are common in the range of this ESU. The only large blockage of spawning area for spring-run chinook salmon is at the Pelton/Round Butte dam complex on the Deschutes River, which probably eliminated a natural population utilizing the upper Deschutes River Basin (Kostow 1995, Nehlsen 1995). Spawning and rearing habitat are affected by agricultural activities including water withdrawals, grazing, and riparian vegetation management. Mainstem Columbia River hydroelectric development has caused a major disruption of migration corridors and affected flow regimes and estuarine habitat.

The major rivers in this ESU—Klickitat, Hood, Deschutes, John Day, Umatilla, and Yakima Rivers—have experienced very different levels of artificial propagation activity. Since 1950, the Klickitat River Hatchery has released over 5 million spring-run chinook salmon from the Willamette and Wind Rivers (Table 6, Appendix D). The degree to which these non-local stocks were represented in subsequent releases of Klickitat River “native” stocks from the hatchery is unknown. Since their construction in the 1970s, hatcheries in the Deschutes River Basin have released over 27 million fish, the majority of which were derived from local stocks. The Deschutes River also contains relatively large numbers of naturally spawning spring-run chinook salmon. Although hatchery fish appear to stray onto Deschutes River spawning grounds in some areas, all hatchery fish are removed at the Warm Springs weir, so there is essentially no natural spawning of hatchery fish in the upper Warm Springs River (Kostow 1995). Very few hatchery strays have been recovered in the John Day River (Kostow 1995). Currently, there are no spring-run chinook salmon hatchery programs on the Yakima or John Day Rivers. It has been estimated that the influence of introduced non-native spring-run chinook salmon in these rivers has been minimal (Kostow 1995, Marshall et al. 1995). In contrast, the Umatilla River and Hood River spring-run chinook salmon stocks were extirpated, and a number of non-native stocks have been introduced in an effort to reestablish runs in these rivers (Kostow 1995). Although more

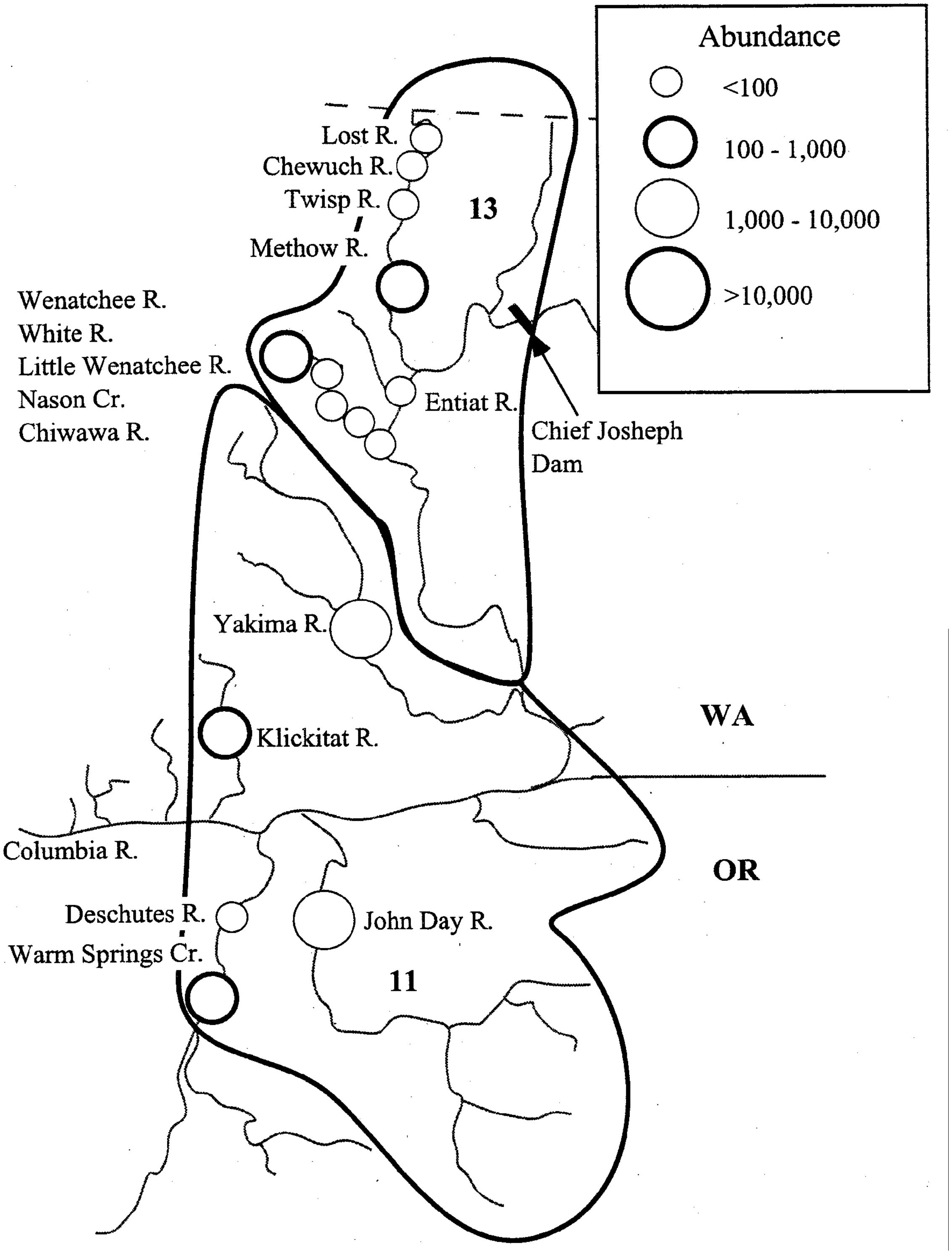

Figure 41. R
ecent 5-year geometric mean spawning escapement for stream-type chinook salmon populations in

Middle Columbia River Spring-Run (11) and Upper Columbia River Spring-Run (13) ESUs. All data are for spring run (see Appendix E for details).

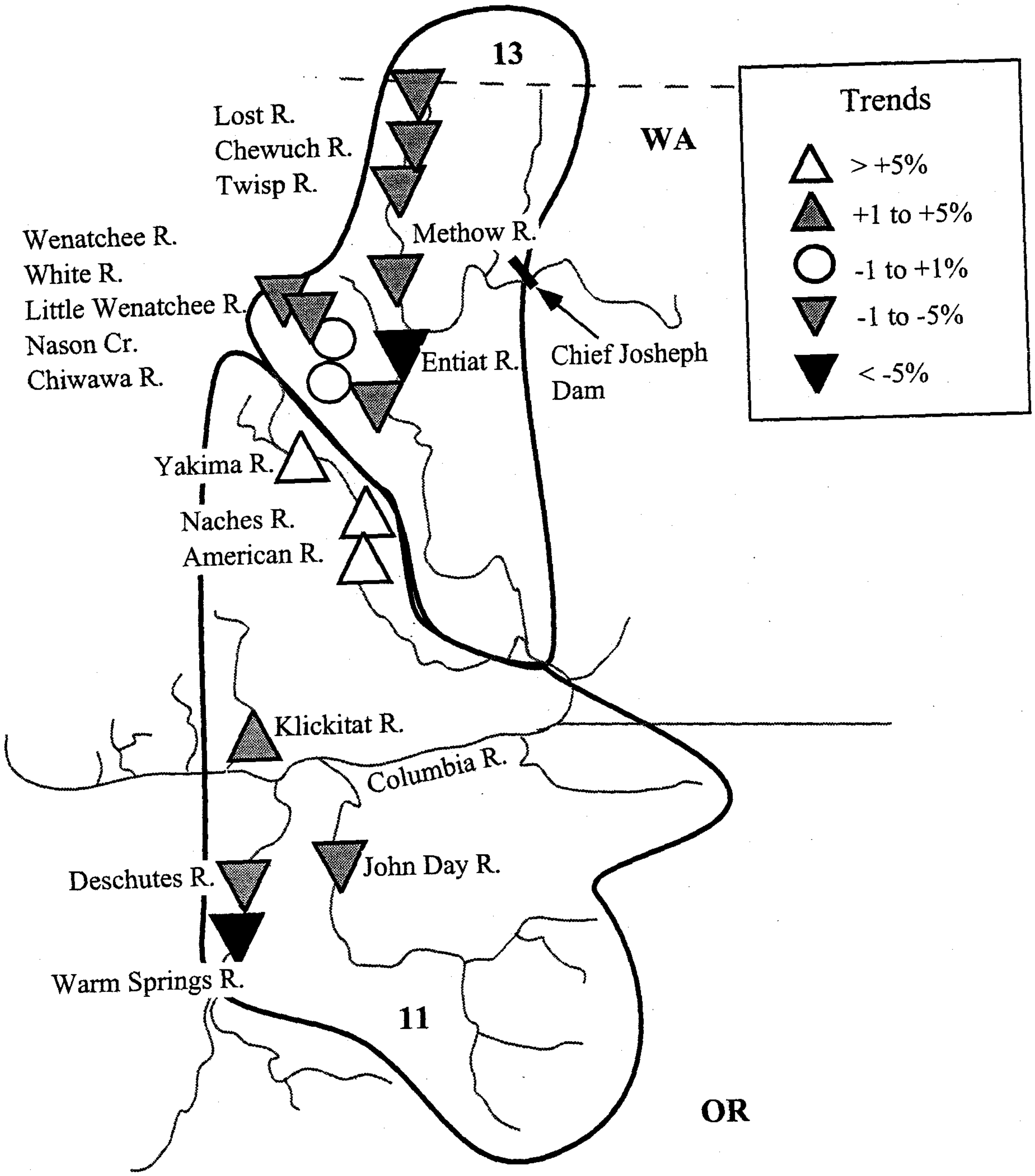

Figure 42. Trends (percent annual change) in abundance for stream-type chinook salmon populations in Middle Columbia River Spring-Run (11) and Upper Columbia River Spring-Run (13) ESUs. All data are for spring run (see Appendix E for details).

than half of all fish released came from outside of the ESU, this estimate is strongly biased by transplants of fish into the Umatilla River Basin. In total, hatchery returns account for 36% of the total escapement to this ESU (ODFW and WDFW 1995).

Stocks in this ESU experience very low ocean harvest rates and only moderate instream harvest. Harvest rates have been declining recently (PSC 1996).

Previous assessments of stocks within this ESU have identified several as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified five stocks as extinct, one as possibly extinct (Klickitat River spring-run chinook salmon), and one as of special concern (John Day River spring-run chinook salmon). Due to the lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered five stocks within the ESU, of which three, all within the Yakima River Basin, were considered to be of native origin and predominantly natural production (Upper Yakima, Naches, and American Rivers). Despite increasing trends in these three stocks, these stocks and the two remaining (not native/natural) stocks were considered to be depressed on the basis of chronically low escapement numbers (WDF et al. 1993). The status of Wind River spring-run chinook salmon was not considered an ESA issue by the BRT (the current stock was not historically present in the watershed or is not representative of historical stock) but was included to give a complete presentation of stocks identified by WDF et al. (1993).

12) Upper Columbia River Summer- and Fall-Run ESU

The status of this ESU was recently reviewed by NMFS (Waknitz et al. 1995), so only a brief summary is provided here. We have no estimates of historical abundance specific to this ESU. Historic estimates of chinook salmon in the upper and middle Columbia River Basin are in the hundreds of thousands, but were declining due to harvest by 1900 (Mullan 1987).

Recent abundance is monitored by a combination of redd counts in tributaries and counts of adult salmon passing dams on the mainstem Columbia River and on tributary rivers. Total recent river runs for the ESU averaged 58,000 adults (geometric mean for 1990-94), estimated from total summer- and fall-run chinook salmon passing McNary Dam, minus fish destined for the Snake River (Ice Harbor Dam counts) and returns to Priest Rapids and Wells Hatcheries. This total represents a large contribution by natural spawning in Hanford Reach (about 51,000 fish) and the Wenatchee River (ave. 9,700 fish in 1987-91), with small spawning populations in the Yakima, Methow, Okanogan, and Similkameen Rivers (Fig. 43, Appendix E). Long-term trends for the three largest populations are positive, while those for the smaller populations are a mix of positive and negative (Fig. 44, Appendix E).

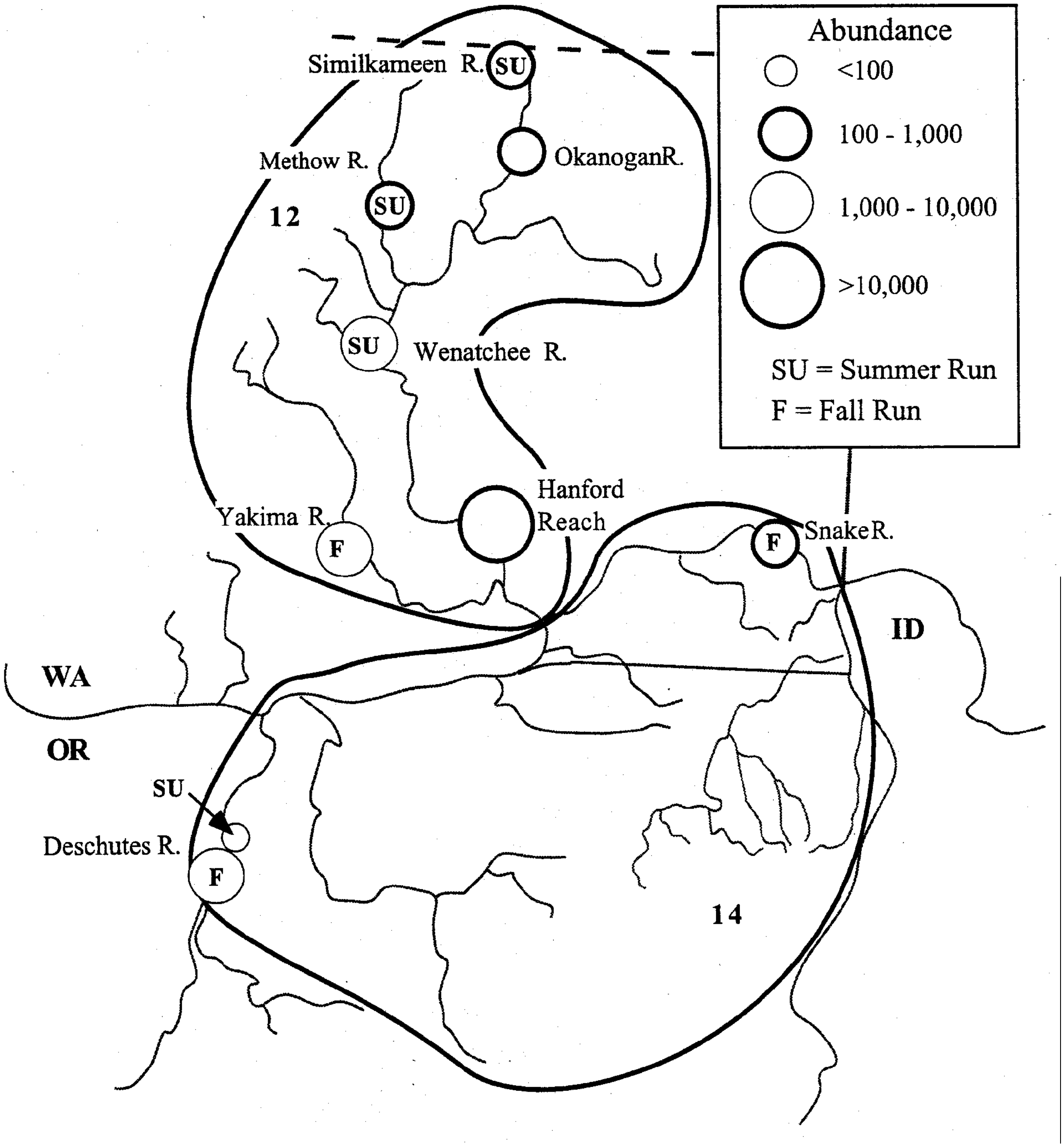

Figure 43. Recent 5-year geometric mean spawning escapement for ocean-type chinook salmon populations in Upper Columbia River Summer- and Fall-Run (12) and Snake River Fall-Run (14) ESUs (see Appendix E for details).

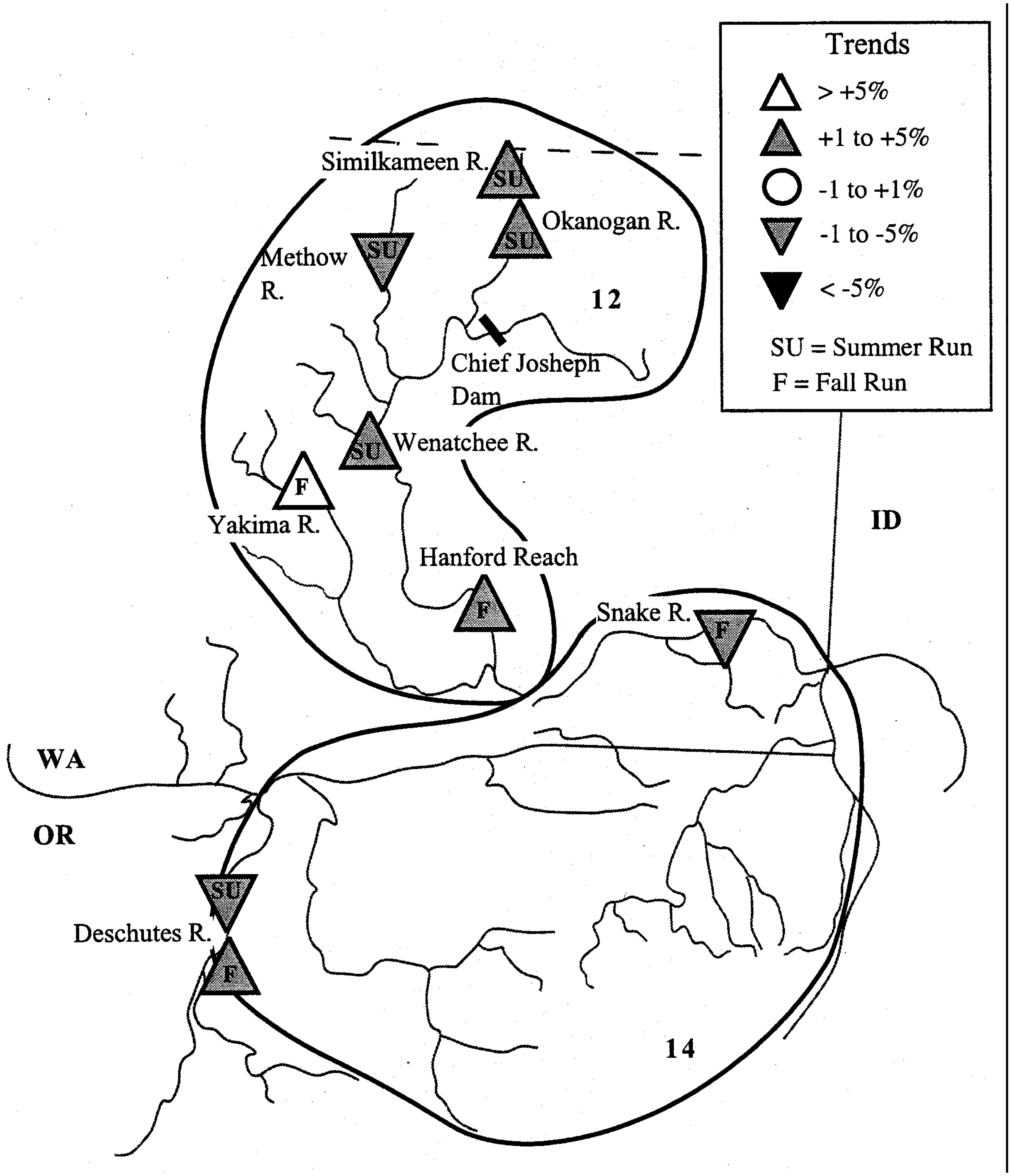

Figure 44. Trends (percent annual change) in abundance for ocean-type chinook salmon populations in Upper Columbia River Summer- and Fall-Run (12) and Snake River Fall Run (14) ESUs see (Appendix E for details).

Access to a substantial portion of historical habitat was blocked by Chief Joseph (RKm 877) and Grand Coulee (RKm 961) Dams. The construction of the Grand Coulee Dam blocked 2830+ kilometers of spawning and rearing habitat (Fish and Hanavan 1948). There are local habitat problems related to irrigation diversions and hydroelectric development, as well as degraded riparian and instream habitat from urbanization and livestock grazing. Mainstem Columbia River hydroelectric development has resulted in a major disruption of migration corridors and affected flow regimes and estuarine habitat.

Artificial propagation activities in this ESU are related to the GCFMP and mainstem dam mitigation. Trapping operations for the GCFMP at Rock Island Dam effectively combined summer- and fall-run chinook salmon destined for the upper Columbia River (Waknitz et al. 1995). Furthermore, there was probably some hybridization between spring- and summer-run fish during the GCFMP (Fish and Hanavan 1948, Mullan 1987), although recent genetic analysis does not indicate the persistence of hybridization effects (Chapman et al 1995).

Nearly 38 million summer-run fish have been released from the Wells Dam Hatchery since 1967 (Table 6, Appendix D). Efforts to establish the Wells Dam summer-run broodstock removed a large proportion of spawners (94% of the run in 1969) destined for the Methow River and other upstream tributaries (Mullan et al. 1992). Additionally, a number of fall-run fish have been incorporated into the summer-run program, especially during the 1980s (Marshall et al. 1995). Large numbers of fall-run chinook salmon have been released into the mainstem Columbia and Yakima Rivers (Table 6, Appendix D). Although no hatcheries operate on the Yakima River, releases of “upriver bright” fall-run chinook salmon into the lower Yakima River (below Prosser Dam) are thought to have overwhelmed local naturally spawning stocks (WDF et al. 1993, Marshall et al. 1995). Fall-run chinook salmon also spawn in the mainstem Columbia River; this occurs primarily in the Hanford Reach portion of the Columbia River, with additional spawning sites in the tailrace areas of mainstem dams. “Upriver bright” fall-run chinook salmon represent a composite of stocks intercepted at various dams. This stock has also been released in large numbers by hatcheries on the mainstem Columbia River. Although the “upriver bright” stocks incorporated representatives from the mainstem spawning populations in the Hanford Reach and those displaced by the construction of Grand Coulee Dam and other mainstem dams, they have also incorporated individuals from the Snake River Fall-Run ESU (Howell et al. 1985). The mixed genetic background of “upriver bright” stocks may result in less accurate homing (McIsaac and Quinn 1988, Chapman et al. 1994); however, the naturally spawning Hanford Reach fall-run population appears to stray at very low levels (Hymer et al. 1992b).

Harvest rates are moderately high, with an average 39% ocean exploitation rate and 68% total exploitation rate (brood years 1982-89) (PSC 1994), although these may be overestimates due to incomplete accounting of escapement.

Previous assessments of stocks within this ESU have identified several as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified six stocks as extinct, one as a moderate extinction risk (Methow River summer-run chinook salmon), and one as of special concern (Okanogan River summer-run chinook salmon). Due to the lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered 10 stocks within the ESU, of which 3 were considered to be of native origin and predominantly natural production. The status of these three stocks was two healthy (Marion Drain and Hanford Reach fall runs) and one depressed (Okanogan River summer run). The status of the remaining (not native/natural) seven stocks was six healthy and one depressed. The Klickitat River fall-run "brights," and Wind and White Salmon River fall-run chinook salmon were not considered an ESA issue by the BRT (stocks were not historically present in the watershed or current stocks are not representative of historical stocks). The BRT could not resolve the affinity of the Marion Drain chinook salmon population, and it is not included in this ESU. These stocks were included to give a complete presentation of stocks identified by WDF et al. (1993). Huntington et al. (1996) identified one healthy Level I stock in their survey (Hanford Reach fall run).

13) Upper Columbia River Spring-Run ESU

We have no estimates of historical abundance specific to this ESU. WDFW monitors nine spring-run chinook salmon stocks geographically located within this ESU. Escapements to most tributaries are monitored by redd counts, which are expanded to total live fish based on counts at mainstem dams.

An estimate of the overall run returning to spawn naturally in this ESU can be obtained from counts of adults at Priest Rapids Dam minus returns to hatcheries above the dam. The 5-year (1990-94) geometric mean of this dam-count-based estimate is approximately 4,880 spawners. This estimate does not account for recreational harvest or prespawning mortality, so it must be viewed as an upper bound on escapement to the ESU. Individual populations within the ESU are all quite small, with none averaging over 150 adults in recent years (Fig. 41, Appendix E).

Sufficient data were available to estimate trends in abundance for ten populations. Long-term trends in estimated abundance are mostly downward, with annual rates of change ranging from -5% to +1% over the full data set. All ten short-term trends were downward, with eight populations exhibiting rates of decline exceeding 20% per year (Fig. 42, Appendix E).

Access to a substantial portion of historical habitat was blocked by Chief Joseph and Grand Coulee Dams. There are local habitat problems related to irrigation diversions and hydroelectric development, as well as degraded riparian and instream habitat from urbanization and livestock grazing. Mainstem Columbia River hydroelectric development has resulted in a major disruption of migration corridors and affected flow regimes and estuarine habitat. Some populations in this ESU must migrate through nine mainstem dams.

Artificial propagation efforts have had a significant impact on spring-run populations in this ESU, either through hatchery-based enhancement or the extensive trapping and transportation activities associated with the GCFMP. Prior to the implementation of the GCFMP, spring-run chinook salmon populations in the Wenatchee, Entiat, and Methow Rivers were at severely depressed levels (Craig and Suomela 1941). Therefore, it is probable that the majority of returning spring-run adults trapped at Rock Island Dam for use in the GCFMP were probably not native to these three rivers (Chapman et al. 1995). All returning adults were either directly transported to river spawning sites or spawned in one of the NFHs built for the GCFMP.

In the years following the GCFMP, several stocks were transferred to the NFHs in this area, most importantly Carson NFH spring-run chinook salmon or other stocks derived from the Carson NFH stock (WDF et al. 1993, Chapman et al. 1995, Marshall et al. 1995). Naturally spawning populations in tributaries upstream of hatchery release sites have apparently undergone limited introgression by hatchery stocks, based on CWT recoveries and genetic analysis (Chapman et al. 1995). Utter et al. (1995) found that the Leavenworth and Winthrop NFH spring runs were genetically indistinguishable from the Carson NFH stock, but distinct from naturally spawning populations in the White and Chiwawa Rivers and Nason Creek. Artificial propagation efforts have recently focused on supplementing naturally spawning populations in this ESU (Bugert 1998), although it should be emphasized that these naturally spawning populations were founded by the same GCFMP homogenized stock. Furthermore, the potential for hatchery-derived non-native stocks to genetically impact naturally spawning populations exists, especially given the recent low numbers of fish returning to rivers in this ESU. The hatchery contribution to escapement has been estimated at greater than 37% in one instance; however, the homing fidelity of spring-run fish may moderate the potential for hybridization (Chapman et al. 1995). For example, the hatchery contribution to naturally spawning escapement was 39% in the mainstem Methow River (where the hatcheries are located), but averaged only 10% in the tributaries—Chewuch, Lost, and Twisp Rivers—that are upstream of the hatcheries (Spotts 1995). In contrast, WDFW (1997a) reports that in 1996 the Chewuch and Twisp runs were 62% and 78% hatchery fish, respectively.

Howell et al. (1985), Mullan et al. (1992), Chapman et al. (1991), and Chapman et al. (1995) have suggested that the prevalence of bacterial kidney disease (BKD) in upper Columbia and Snake River hatcheries is directly responsible for the low survival of hatchery stocks. These authors also suggest that the high incidence of BKD in hatcheries impacts wild populations, and reduces the survival of hatchery fish to such an extent that naturally spawning adults are “mined” to perpetuate hatchery stocks (Chapman et al. 1991). There may also be direct horizontal transmission of BKD between hatchery and wild juveniles during downstream migration (specifically in smolt collection and transportation facilities) or vertical transmission from hatchery-reared females on the spawning grounds.

Harvest rates are low for this ESU, with very low ocean and moderate instream harvest. Harvest rates have been declining recently (ODFW and WDFW 1995).

Previous assessments of stocks within this ESU have identified several as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified six stocks as extinct. Due to lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered nine stocks within the ESU, of which eight were considered to be of native origin and predominantly natural production. The status of all nine stocks was considered depressed. Populations in this ESU have experienced record low returns for the last few years.

14) Snake River Fall-Run ESU

The Snake River portion of this ESU has been extensively reviewed by NMFS (Waples et al. 1991b, NMFS 1995b), and that information is not repeated here. We discuss populations not included in the earlier status review, and have updated abundance information for the Snake River population.

Snake River fall-run chinook salmon adult abundance is monitored at Lower Granite Dam and by redd counts in the mainstem Snake River between Lower Granite and Hells Canyon Dams. Because redd counts are incomplete, we have relied primarily on the dam count data. Deschutes River summer- and fall-run adults are also monitored by dam counts (at Pelton Ladder, RKm 160) and by redd counts in the lower river (Kostow 1995). The introduced Umatilla River stock is also monitored, but we did not include this information in our assessments. In recent years (1992-96), returns of naturally spawning fish to the Deschutes River (about 6,000 adults per year) have been higher than in the Snake River (5-year mean about 1,000 total and 500 natural adults per year) (Fig. 43, Appendix E). However, historically the Snake River populations dominated production in this ESU, with total abundance estimated to be about 72,000 in the 1930s and 1940s and probably substantially higher before that. Trends in escapement are mapped in Figure 44 and listed in Appendix E, and exhibit recent increases in both populations.

Almost all historical spawning habitat in the Snake River was blocked by the Hells Canyon Dam complex. Remaining habitat has been reduced by inundation from lower Snake River reservoirs. Spawning and rearing habitats in the mid-Columbia River region are affected largely by agriculture including water withdrawals, grazing, and riparian vegetation management. Mainstem Columbia and Snake River hydroelectric development has resulted in a major disruption of migration corridors and affected flow regimes and estuarine habitat.

The two components of this ESU, the Snake and Deschutes Rivers, have very different histories of artificial propagation effort. The hatchery contribution to Snake River escapement has been estimated at greater than 47%, although nearly all of the releases into the Snake River have been derived stocks within the ESU. The Lyons Ferry Hatchery has been the primary artificial propagation facility for fall-run fish in the Snake River since 1984. Considerable numbers of hatchery strays from outside of the ESU—upriver bright fall-run chinook salmon from the Umatilla River restoration program and mainstem Columbia River releases—have been observed returning to the Snake River (Lyons Ferry Hatchery and Lower Granite Dam) (Waples et al. 1991b, LaVoy and Mendel 1996). The proportionally high level of hatchery input, small population size, and introgression from non-native hatchery strays pose a significant risk to the genetic integrity and diversity of the Snake River population.

In contrast, there is no hatchery on the Deschutes River and the historical number of releases into the river relative to the naturally spawning component is minimal (Appendix D). A small number of stray hatchery fish are recovered annually in the Deschutes River (Olsen et al. 1992), but the impact of these is probably small based on the number of strays relative to naturally spawning native fish.

Harvest rates on these populations were moderate in 1982-89, with Snake River (Lyons Ferry Hatchery) fall-run chinook salmon averaging 34.9% ocean exploitation, 26% inriver exploitation, and 53% total exploitation (PSC 1994). As a result of the ESA listing, ocean harvest rates for the Snake River fall-run chinook salmon decreased to 11.5% in 1995 and 23.0% in 1996 (PFMC 1997). Harvest rates for Hanford Reach fall-run chinook salmon have averaged 39% ocean exploitation and 64% total exploitation (PSC 1994).

Previous assessments of stocks within this ESU have identified several as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified three stocks as extinct (Umatilla River, Walla Walla River, and Snake River above Hells Canyon Dam) and one as a high risk of extinction (Snake River). Due to lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered one stock within the Snake River ESU, which was considered to be of native origin and predominantly natural production. The status of this stock was considered to be depressed.

15) Snake River Spring- and Summer-Run ESU

This ESU has been extensively reviewed by NMFS (Matthews and Waples 1991, NMFS 1995b), and that information is briefly summarized and updated here.

Recent adult abundance is monitored by a combination of redd counts conducted by IDFG, WDFW, and ODFW (Fig. 45) and counts at mainstem Snake River dams. The most recent

5-year (1992-96) geometric mean abundance (based on counts at Lower Granite Dam adjusted by estimated hatchery:natural ratios) was 3,820 naturally-produced spawners (PFMC 1997). Both short- and long-term trends in abundance are downward for all populations except Asotin Creek (Fig. 46, Appendix E). WDFW (1997a) reported that the Asotin Creek population has recently been extirpated. Historical abundance probably exceeded 1.5 million adults in some years in the 1800s (Matthews and Waples 1991).

Mainstem Columbia and Snake River hydroelectric development has resulted in a major disruption of migration corridors and affected flow regimes and estuarine habitat. There is habitat degradation in many areas related to forest, grazing, and mining practices, with significant factors being lack of pools, high temperatures, low flows, poor overwintering conditions, and high sediment loads. Substantial portions of the Salmon River subbasin are protected in wilderness areas.

Summer- and spring-run chinook salmon are propagated in a number of artificial propagation facilities throughout the Snake River Basin. On average, 61% of the total escapement is hatchery derived. Historically, releases originating from outside of the ESU have constituted a small proportion, 7%, of the total releases (Table 6, Appendix D). The Carson NFH stock has been released into a number of watersheds, most prominently the Grande Ronde River Basin (Matthews and Waples 1991, Keifer et al. 1992). The Rapid River Hatchery stock, initially founded by spring-run chinook salmon from above the Hells Canyon complex, has been released in most of the watersheds in the Snake River Basin. It was a major component of the broodstock used to reestablish chinook salmon runs in the Clearwater River Basin via the Dworshak and Kooskia Hatcheries (Chapman et al. 1991). The Rapid River Hatchery stock was also used to establish the broodstock currently being used at the Lookingglass Hatchery in the Grande Ronde Basin (Matthews and Waples 1991). Since 1986, approximately 75% of the naturally spawning escapement in the Grande Ronde River has consisted of hatchery strays or returns from outplants of non-native stocks (NMFS 1995b). Finally, the high incidence of BKD in many Snake River hatcheries poses many of the same risks described in ESU 13 (Chapman et al. 1991).

Harvest on these populations is low, with very low ocean harvest and moderate instream harvest (PFMC 1996b). Inriver harvest has been substantially restricted since 1991. At present, only tribal fisheries are permitted in the Snake River. The average harvest rate from 1986-90 was estimated to be 10.7%, and the 1995 and 1996 harvests were estimated to be 6.1 and 5.5%, respectively (PFMC 1997).

Previous assessments of stocks within this ESU have identified several stocks as being at risk or of concern (Appendix E). Nehlsen et al. (1991) identified 10 stocks as extinct, 4 as at high risk of extinction, and 2 as at moderate extinction risk (Grande Ronde River spring-run and

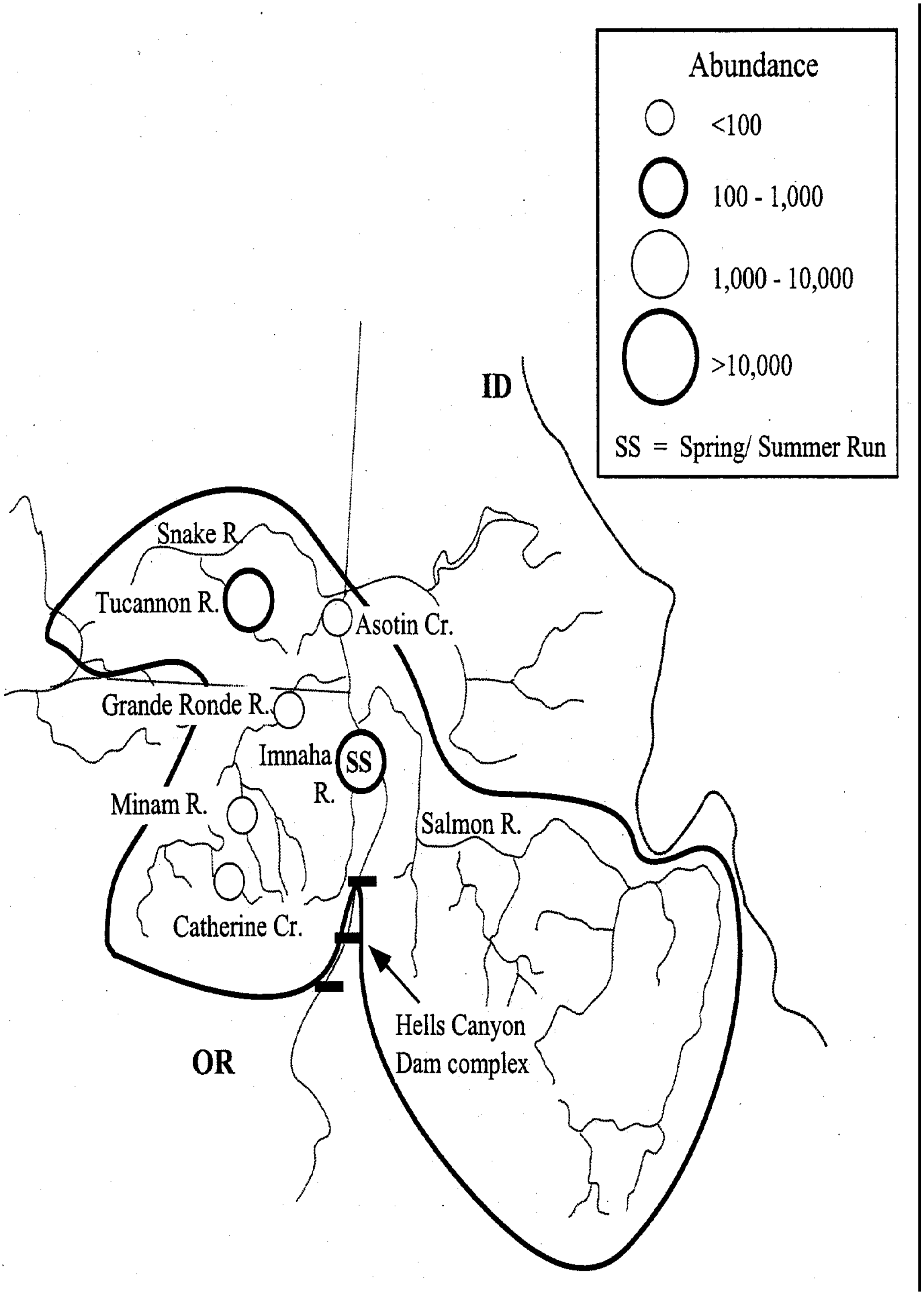

Figure 45. Recent 5-year geometric mean spawning escapement for stream-type chinook salmon populations in Snake River Spring- and Summer-Run (15) ESU. All data are for spring run, except as noted (see Appendix E for details).

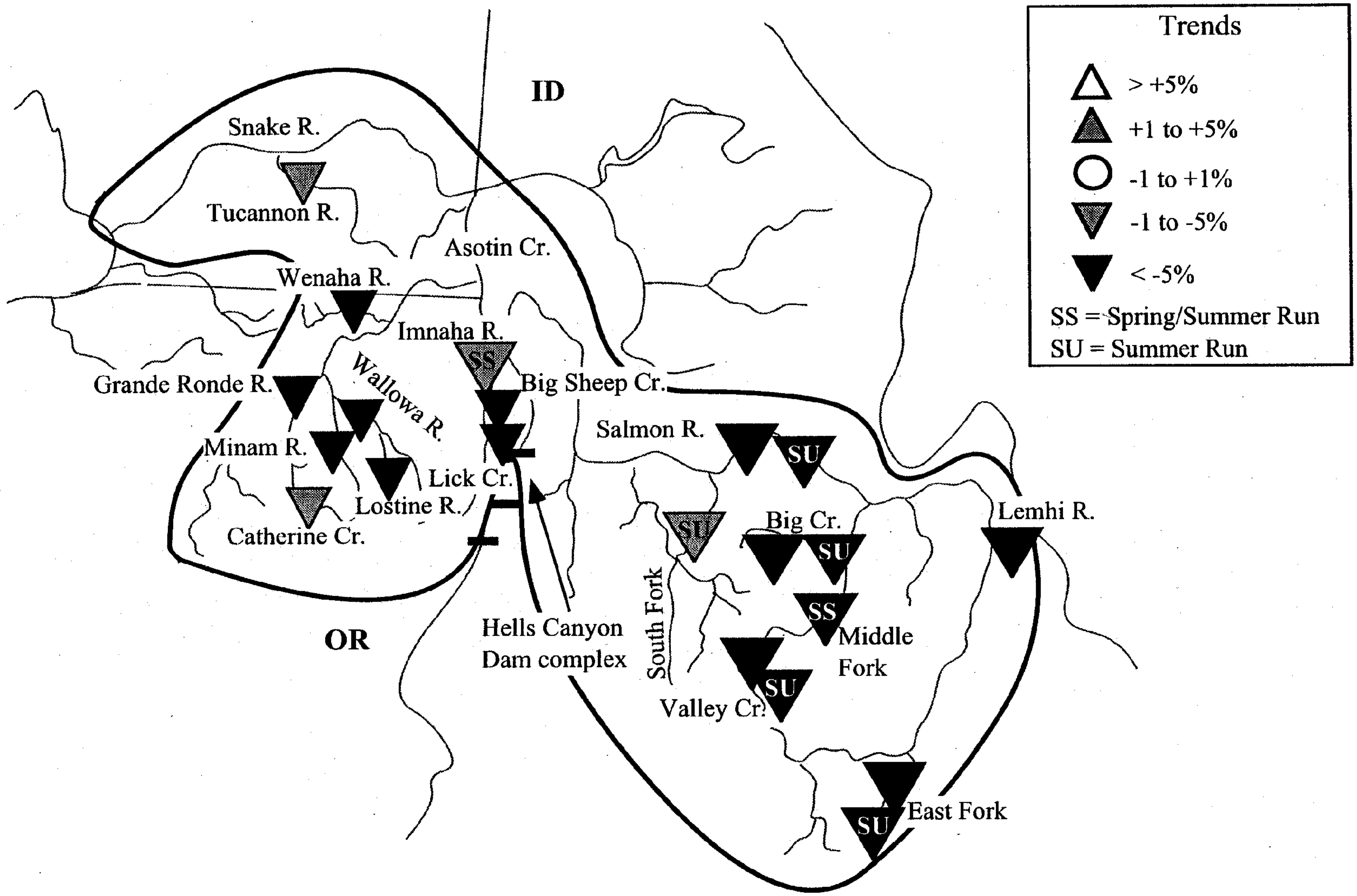

Figure 46. Trends (percent annual change) in abundance for stream-type chinook salmon populations in 15-Snake River Spring- and Summer-Run ESU. All data are for spring run, except as noted (see Appendix E for details).

Imnaha River spring/summer-run). Due to the lack of information on chinook salmon stocks that are presumed to be extinct, the relationship of these stocks to existing ESUs is uncertain. They are listed here based on geography and to give a complete presentation of the stocks identified by Nehlsen et al. (1991). WDF et al. (1993) considered two stocks within the ESU that were considered to be of native origin and predominantly natural production. The status of these stocks was one depressed (Tucannon River spring-run) and one critical (Asotin Creek spring-run), although WDFW (1997a) reported that the Asotin Creek population has since been extirpated.

Discussion and Conclusion on ESU Risk Analysis

The ESA (section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. In this review, we did not evaluate likely or possible effects of conservation measures. Therefore, we do not make recommendations as to whether identified ESUs should be listed as threatened or endangered species, because that determination requires evaluation of factors not considered by us. Rather, we have drawn scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue.

The BRT considered a variety of information in evaluating the level of risk faced by each ESU. Important considerations include 1) absolute numbers of fish and their spatial and temporal distribution; 2) current abundance in relation to historical abundance and carrying capacity of the habitat; 3) trends in abundance, based on indices such as dam or redd counts or on estimates of spawner-recruit ratios; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., selective fisheries and interactions between hatchery and natural fish); and 6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the ESU. Additional risk factors, such as disease prevalence or changes in life-history traits, may also be considered in evaluating risk to populations. The BRT conclusions for each chinook salmon ESU follow.

1) Sacramento River Winter-Run ESU

Presently listed as Endangered under the California and federal Endangered Species Acts; not reviewed further here.

2) Central Valley Spring-Run ESU

The majority of the BRT concluded that chinook salmon in this ESU are in danger of extinction; a minority felt that this ESU is not presently in danger of extinction, but is likely to become so in the foreseeable future. The BRT identified several concerns regarding the status of this ESU. Native spring-run chinook salmon have been extirpated from all tributaries in the San Joaquin River Basin, which represents a large portion of the historic range and abundance. The only streams considered to have wild spring-run chinook salmon are Mill and Deer Creeks, and possibly Butte Creek (tributaries to the Sacramento River), and these are relatively small populations with sharply declining trends. Demographic and genetic risks due to small population sizes are thus considered to be high.

Habitat problems were considered by the BRT to be the most important source of ongoing risk to this ESU. Spring-run fish cannot access most of their historical spawning and rearing habitat in the Sacramento and San Joaquin River Basins (which is now above impassable dams), and current spawning is restricted to the mainstem and a few river tributaries in the Sacramento River. The remaining spawning habitat accessible to fish is severely degraded. Collectively, these habitat problems greatly reduce the resiliency of this ESU to respond to additional stresses in the future. The general degradation of conditions in the Sacramento River Basin (including elevated water temperatures, agricultural and municipal diversions and returns, restricted and regulated flows, entrainment of migrating fish into unscreened or poorly screened diversions, and the poor quality and quantity of remaining habitat) has severely impacted important juvenile rearing habitat and migration corridors.

The BRT also expressed concern for threats to genetic integrity posed by hatchery programs in the Central Valley. Most of the spring-run chinook salmon production in the Central Valley is of hatchery origin, and naturally spawning populations may be interbreeding with both fall- and spring-run hatchery fish. This problem is exacerbated by the increasing production of spring-run chinook salmon from the Feather River and Butte Creek Hatcheries, especially in light of reports suggesting a high degree of mixing between spring- and fall-run broodstock in the hatcheries. In addition, hatchery strays are considered to be an increasing problem due to the management practice of releasing a larger proportion of fish off-station (primarily into the Sacramento River delta and San Francisco Bay).

3) Central Valley Fall-Run ESU

A majority of the BRT concluded that chinook salmon in this ESU are not in danger of extinction but are likely to become so in the foreseeable future. A minority of the BRT felt that chinook salmon in this ESU are not presently at significant risk or were undecided on its status. Although total population abundance in this ESU is relatively high, perhaps near historical levels, the BRT identified several concerns regarding its status. The abundance of natural fall-run chinook salmon in the San Joaquin River Basin is low, leading a number of BRT members to conclude that a large proportion of the historic range of this ESU has been lost or is in danger of extinction. Most of the historical spawning habitat for this ESU is downstream from impassable dams, so habitat blockage is not as severe as for winter- and spring-run chinook salmon in this region. However, there has been a severe degradation of the remaining habitat, especially due to agricultural and municipal water use activities in the Central Valley (which result in point and non-point pollution, elevated water temperatures, diminished flows, and smolt and adult entrainment into poorly screened or unscreened diversions).

Natural runs throughout the ESU are very depressed. Returns to hatcheries account for only about 20% of fall-run chinook salmon spawners in the Central Valley; however, due to high rates of straying by hatchery fish released off-station, production from hatcheries may be responsible for a much larger proportion of natural spawning escapement. A mitigating factor for the overall risk to the ESU is that a few of the Sacramento and San Joaquin River Basin tributaries are showing recent, short-term increases in abundance. However, those streams supporting natural runs considered to be the least influenced by hatchery fish have the lowest abundance and the most consistently negative trends of all populations in the ESU. In general, high hatchery production combined with infrequent monitoring of natural production make assessing the sustainability of natural production problematic, resulting in substantial uncertainty in assessing the status of this ESU.

Other concerns identified by the BRT are the high ocean and freshwater harvest rates in recent years, which may be higher than is sustainable by natural populations given the productivity of the ESU under present habitat conditions.

4) Southern Oregon and California Coastal ESU

The BRT was unanimous in its conclusion that chinook salmon in this ESU are likely to become at risk of extinction in the foreseeable future. Overall abundance of spawners is highly variable among populations, with populations in California and spring-run chinook salmon throughout the ESU being of particular concern. There is a general pattern of downward trends in abundance in most populations for which data are available, with declines being especially pronounced in spring-run populations. The BRT felt that the extremely depressed status of almost all coastal populations south of the Klamath River is an important source of risk to the ESU. There was a general concern expressed by the BRT that no current information was available for many river systems in the southern portion of this ESU, which historically maintained numerous large populations. These populations form a genetically distinct subgroup within the ESU. Although (as discussed above) the majority of the BRT concluded that these California coastal populations do not form a separate ESU, they represent a considerable portion of genetic and ecological diversity within this ESU.

Current hatchery contribution to overall abundance is relatively low except for the Rogue River spring run, which also contains almost all of the documented spring-run abundance in this ESU. Fall-run chinook salmon in the Rogue River represent the only relatively healthy population we could identify in this ESU. The BRT questioned whether there are sustainable populations outside the Rogue River Basin. All river basins have degraded habitats resulting from agricultural and forestry practices, water diversions, urbanization, mining, and severe recent flooding. The BRT was very concerned about the risks to spring-run chinook in this ESU; their stocks are in low abundance and they have continued to decline dramatically in recent years. In addition, the lack of population monitoring, particularly in the California portion of the range, led to a high degree of uncertainty regarding the status of these populations.

5) Upper Klamath and Trinity Rivers ESU

A majority of the BRT concluded that chinook salmon in this ESU are not at significant risk of extinction nor likely to become so in the forseeable future. One minority concluded that the ESU is not presently in danger of extinction but is likely to become so in the foreseeable future, while another minority was undecided about the status of this ESU. The question of overall risk was difficult to evaluate because of the large disparity in the status of spring- and fall-run populations within the ESU.

Spring-run chinook salmon were once the dominant run type in the Klamath-Trinity River Basin. Most spring-run spawning and rearing habitat was blocked by the construction of dams in the late 1800s and early 1900s in the Klamath River Basin and in the 1960s in the Trinity River Basin. As a result of these and other factors, spring-run populations are at less than 10% of their historic levels, and at least 7 spring-run populations that once existed in the basin are now considered extinct. The remaining spring runs have relatively small populations sizes and are isolated in just a few areas of the basin, resulting in genetic and demographic risks.

On a more positive note, trends in abundance for some populations in this ESU are stable or increasing slightly. Substantial numbers of fall-run chinook salmon spawn naturally in many areas of the ESU. However, natural populations have frequently failed to meet modest spawning escapement goals despite active harvest management. In addition to habitat blockages, there continues to be severe degradation of remaining habitat due to mining, agricultural and forestry activities, and water storage and transfer. Furthermore, hatchery production in the basin is substantial, with considerable potential for interbreeding between natural and hatchery fish. The BRT expressed concern that hatchery fish spawning naturally may mask declines in natural populations.

In summary, all BRT members were concerned about the depressed status of spring-run chinook salmon in this ESU, and the loss of access to a large proportion of historical habitat. However, the majority concluded that, because of the relative health of the fall-run populations, the ESU as a whole is not currently at significant risk of extinction.

6) Oregon Coast ESU

The BRT unanimously concluded that chinook salmon in this ESU are neither presently in danger of extinction nor are they likely to become so in the foreseeable future. Abundance of this ESU is relatively high, and fish are well distributed among numerous, relatively small river basins. Some suitable spawning habitat remains blocked, but access of chinook salmon to spawning areas is better than it was at the turn of the century.

Production in this ESU is mostly dependent on naturally-spawning fish, and spring-run chinook salmon in this ESU are in relatively better condition than those in adjacent ESUs. Long-term trends in abundance of chinook salmon within most populations in this ESU are upward.

In spite of a generally positive outlook for this ESU, the BRT identified several concerns regarding its status. First, several populations are exhibiting recent and severe (> 9% per year) short-term declines in abundance. In addition, while hatchery production is not as pervasive as in other ESUs, there are several hatchery programs and Salmon and Trout Enhancement Programs (STEP) releasing chinook salmon throughout the ESU, and many of the fish released are derived from a single stock (Trask River). Most importantly, although hatchery production is thought to be low relative to natural production, there is a lack of clear information on the degree of straying of these hatchery fish into naturally-spawning populations. There are also many populations within the ESU for which there are no abundance data; the BRT expressed concern about the uncertain risk assessment given these data gaps. Third, exploitation rates on chinook salmon from this ESU have been high in the past, and the BRT felt that the level of harvest could be a significant source of risk if it continues at historically high rates. Finally, freshwater habitats are generally in poor condition, with numerous problems such as low summer flows, high temperatures, loss of riparian cover, and streambed changes.

7) Washington Coast ESU

The BRT unanimously concluded that chinook salmon in this ESU are not in danger of extinction nor are they likely to become so in the foreseeable future. Recent abundance has been relatively high, although it is less than estimated peak historical abundance in this region. Chinook salmon in this ESU are distributed among a relatively large number of populations, most of which are large enough to avoid serious genetic and demographic risks associated with small populations.

Long-term trends in population abundance have been predominantly upward for the medium and larger populations but are sharply downward for several of the smaller populations. In addition, the BRT was concerned about significant short-term declines in abundance that have been observed in several populations. In general, abundance and trend indicators are more favorable for stocks in the northern portion of the ESU, and more favorable for fall-run populations than for spring- or summer-run fish. This disparity was a source of concern to the BRT regarding the overall health of the ESU.

Hatchery production is substantial in several basins within the range of the ESU, and several populations are identified as being of composite production. There is considerable potential for hatchery fish to stray into natural populations, especially since some hatcheries are apparently unable to attract returning adults effectively. Hatchery influence is greatest in the southern part of the ESU region, especially in Willapa Bay, where there have been numerous introductions of stocks from outside of the ESU. Furthermore, the use of an exotic spring-run stock at the Sol Duc Hatchery was cited as a concern.

All basins are affected by habitat degradation, largely related to forestry practices. Tributaries inside Olympic National Park are generally in the best condition regarding habitat quality. Special concern was expressed regarding the status of spring-run populations throughout the ESU and fall-run populations in Willapa Bay and parts of the Grays Harbor drainage.

8) Puget Sound ESU

A majority of the BRT concluded that chinook salmon in this ESU are not presently in danger of extinction, but they are likely to become so in the foreseeable future. A minority concluded that this ESU is not presently at significant risk or were uncertain about its status. Overall abundance of chinook salmon in this ESU has declined substantially from historical levels, and many populations are small enough that genetic and demographic risks are likely to be relatively high. Contributing to these reduced abundances are widespread stream blockages, which reduce access to spawning habitat, especially in upper reaches. Both long- and short-term trends in abundance are predominantly downward, and several populations are exhibiting severe short-term declines. Spring-run chinook salmon populations throughout this ESU are all depressed.

Tens of millions of hatchery fish have been released annually throughout the ESU. More than half of the recent total Puget Sound escapement returned to hatcheries. The BRT was concerned that the preponderance of hatchery production throughout the ESU may mask trends in natural populations and makes it difficult to determine whether they are self-sustaining. This difficulty is compounded by the dearth of data pertaining to proportion of naturally spawning fish that are of hatchery origin. There has also been widespread use of a limited number of hatchery stocks, resulting in increased risk of loss of fitness and diversity among populations.

Freshwater habitat throughout the range of the ESU has been blocked or degraded, with upper tributaries widely affected by poor forestry practices and lower tributaries and mainstem rivers affected by agriculture and urbanization. There also is concern that harvest rates of natural stocks in mixed-stock fisheries may be excessive, as evidenced by recent declines in most stocks managed for natural escapement despite curtailed terminal fisheries. Finally, special concern was expressed regarding the status of spring- and summer-run populations.

9) Lower Columbia River ESU

A majority of the BRT concluded that chinook salmon in this ESU are not presently in danger of extinction but are likely to become so in the foreseeable future. A minority felt that this ESU is not presently at significant risk or were uncertain as to its status. Estimated overall abundance of chinook salmon in this ESU is not cause for immediate concern. However, apart from the relatively large and apparently healthy fall-run population in the Lewis River, production in this ESU appears to be predominantly hatchery-driven with few identifiable native, naturally reproducing populations. Long- and short-term trends in abundance of individual populations are mostly negative, some severely so. About half of the populations comprising this ESU are very small, increasing the likelihood that risks due to genetic and demographic processes in small populations will be important. Numbers of naturally spawning spring-run chinook salmon are very low, and native populations in the Sandy and Clackamas Rivers have been supplanted by spring-run fish from the Upper Willamette River. There have been at least six documented extinctions of populations in this ESU, and it is possible that extirpation of other native populations has occurred but has been masked by the presence of naturally spawning hatchery fish. The BRT was particularly concerned about the inability to identify any healthy native spring-run populations.

The large numbers of hatchery fish in this ESU make it difficult to determine the proportion of naturally produced fish. In spite of the heavy impact of hatcheries, genetic and life-history characteristics of populations in this ESU still differ from those in other ESUs. The BRT, however, identified the loss of fitness and diversity within the ESU as an important concern. There was a special concern regarding recent releases of Rogue River fall-run fish at Youngs Bay and their documented straying into many tributaries in the Lower Columbia River.

Freshwater habitat is in poor condition in many basins, with problems related to forestry practices, urbanization, and agriculture. Dam construction on the Cowlitz, Lewis, White Salmon, and Sandy Rivers eliminated access to a substantial portion of the spring-run spawning habitat, with a lesser impact on fall-run habitat.

10) Upper Willamette River ESU

A majority of the BRT concluded that chinook salmon in this ESU are not presently in danger of extinction but are likely to become so in the foreseeable future. A minority felt that this ESU is not presently at significant risk or were uncertain as to its status, and one member considered this ESU to be at risk of extinction. Total abundance has been relatively stable at approximately 20,000 to 30,000 fish; however, recent natural escapement is less than 5,000 fish and has been declining sharply. Furthermore, it is estimated that about two-thirds of the natural spawners are first-generation hatchery fish, suggesting that the natural population is falling far short of replacing itself. The BRT noted a similarity between these population dynamic parameters and those for the upper Columbia River steelhead ESU, which was recently listed as endangered by NMFS.

The introduction of fall-run chinook salmon into the basin and laddering of Willamette Falls have increased the potential for genetic introgression between wild spring- and hatchery fall-run chinook salmon, but there is no direct evidence of hybridization (other than an overlap in spawning times and spawning location) between these two runs.

The proximate sources of risk to chinook salmon in this ESU are habitat blockage of large areas of important spawning and rearing habitat by dam construction. Remaining habitat has been degraded by thermal effects of dams, forestry practices, agriculture, and urbanization. Another concern for this ESU is that commercial and recreational harvest are high relative to the apparent productivity of natural populations.

11) Middle Columbia River Spring-Run ESU

The BRT agreed that chinook salmon in this ESU are not presently in danger of extinction nor likely to become so in the foreseeable future. The majority of the BRT concluded that the ESU is not at significant risk at the present time, although a minority of BRT members felt that the ESU is likely to become at risk of extinction in the foreseeable future. Total abundance of this ESU is low relative to the total basin area, and 1994-96 escapements have been very low. Several historical populations have been extirpated, and the few extant populations in this ESU are not widely distributed geographically. In addition, there are only two populations (John Day and Yakima Rivers) with substantial run-sizes.

Despite of low abundances relative to estimated historical levels, long-term trends in abundance have been relatively stable, with an approximately even mix of upward and downward trends in populations. Two major river basins (John Day and Yakima Rivers) are comprised predominantly of naturally produced fish, and both of these exhibit long-term increasing trends in abundance. Recent analyses done as part of the PATH process indicates that productivity of natural populations in the Deschutes and John Day Rivers has been more robust that most other stream-type chinook salmon in the Columbia River (Schaller et al. 1996).

Hatchery production accounts for a substantial proportion of total escapement to the region. However, screening procedures at the Warm Springs River weir apparently minimize the potential for hatchery-wild introgression in the Deschutes River basin. Although straying is less of a problem with returning spring-run adults, the use of the composite, out-of-ESU Carson Hatchery stock to reestablish the Umatilla River spring run would be a cause for concern if fish from that program stray out of the basin.

Spawning and rearing habitat has been affected by agriculture (water withdrawals, livestock grazing, and agricultural effluents) throughout the range of the ESU, and migration corridors have been affected substantially by hydroelectric development. In addition, lack of agreement between run-size estimates based on dam counts and spawner surveys contribute to the uncertainty in evaluating this ESU.

12) Upper Columbia River Summer- and Fall-Run ESU

In an earlier review, this ESU was determined to be neither at risk of extinction nor likely to become so. Its status is not reviewed in detail here. However, the BRT did express concern regarding new data that show the proportion of naturally spawning summer-run chinook salmon of hatchery origin has been increasingly rapidly in areas above Wells Dam. This raises a question about the sustainability of natural populations in that area and is also a concern because of possible genetic/life-history consequences of the shift in hatchery releases from subyearlings to yearlings.

13) Upper Columbia River Spring-Run ESU

The majority of the BRT concluded that chinook salmon in this ESU are in danger of extinction. A minority concluded that this ESU is not presently in danger of extinction, but it is likely to become so in the foreseeable future. Recent total abundance of this ESU is quite low, and escapements in 1994-96 were the lowest in at least 60 years. At least 6 populations of spring-run chinook salmon in this ESU have become extinct, and almost all remaining naturally-spawning populations have fewer than 100 spawners. The BRT expressed concern about the genetic and demographic risks associated with such small populations. In addition to extremely small population sizes, both recent and long-term trends in abundance are downward, some extremely so.

Hydrosystem development has substantially affected this ESU. Grande Coulee Dam blocked access to important spawning and rearing habitat, and downstream dams are an impediment to migration (both juvenile and adult fish from this ESU must navigate past as many as nine mainstem dams). The BRT also had substantial concerns over degradation of the remaining spawning and rearing habitat.

Risks associated with interactions between wild and hatchery chinook salmon are also a concern, as there continues to be substantial production of the composite, non-native Carson stock for fishery enhancement and hydropower mitigation. For example, estimates of hatchery contribution to natural spawning escapements are 39% in the Methow River Basin.

14) Snake River Fall-Run ESU

Snake River fall-run chinook salmon are currently listed as a threatened species under the ESA. As discussed above, the BRT concluded that the Snake River fall-run ESU also includes fall-run chinook salmon in the Deschutes River and, historically, populations from the John Day, Umatilla, Walla Walla Rivers that have been extirpated in the 20th century.

Assessing extinction risk to the newly configured ESU is difficult because of the geographic discontinuity and the disparity in the status of the two remaining populations. Historically, the Snake River populations dominated production in this ESU; total abundance is estimated to have been about 72,000 in the 1930s and 1940s, and it was probably substantially higher before that. Production from the Deschutes River was presumably only a small fraction of historic production in the ESU. In contrast, recent (1990-96) returns of naturally spawning fish to the Deschutes River (about 6,000 adults per year) have been much higher than in the Snake River (5-year mean about 500 adults per year, including hatchery strays). Long term trends in abundance are mixed—slightly upward in the Deschutes River and downward in the Snake River. On a more positive note, short-term trends in both remaining populations are upward.

In spite of the relative health of the Deschutes River population, a majority of the BRT concluded that the ESU as a whole is likely to be in danger of extinction in the foreseeable future, with the remainder being undecided on its status. The BRT was concerned that almost all historical spawning habitat in the Snake River Basin was blocked by the Hells Canyon Dam complex, and other habitat blockages have occurred in Columbia River tributaries. Hydroelectric development on the mainstem Columbia and Snake Rivers continues to affect juvenile and adult migration. Remaining habitat has been reduced by inundation in the mainstem Snake and Columbia Rivers, and the ESU's range has also been affected by agricultural water withdrawals, grazing, and vegetation management.

An additional source of risk to the Snake River chinook salmon is the continued straying by non-native hatchery fish into natural production areas. The BRT also noted that considerable uncertainty regarding the origins of fall-run chinook salmon in the lower Deschutes River and their relationship to fish in the upper Deschutes River.

15) Snake River Spring- and Summer-Run ESU

This ESU is presently listed as a threatened species under the U.S. ESA and is not reviewed further here.

CITATIONS

Aguilar, B. 1995. Capture and coded-wire tagging of naturally produced chinook salmon in the Trinity River Basin. Chapter II Job II. Calif. Dep. Fish Game, Inland Fish. Div., p. 35-52. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

Aguilar, B., L.D. Davis, L. Hanson, B. Collins, M. Zuspan, W. Sinnen, M. Dean, and R. Reavis. 1996. Annual report: Trinity River basin salmon and steelhead monitoring project. 1993-1994 season. Calif. Dep. Fish Game, Inland Fish. Div., 266 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

Alaska Department of Fish and Game (ADFG). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon by F. Rue, February 1997, 9 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Alderdice, D.F., and F.P.T. Velsen. 1978. Relation between temperature and incubation time for eggs of chinook salmon (*O. tshawytscha*). J. Fish. Res. Board Can. 35:69-75.

Allan, R. 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon: Sol Duc Salmon Hatchery data. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Allendorf, F.W., and N. Ryman. 1987. Genetic management of hatchery stocks. *In* N. Ryman and F. Utter (eds.), Population genetics & fishery management, p. 141-159. Univ. Wash. Press, Seattle.

Allendorf, F.W., D. Bayles, D.L. Bottom, K.P. Currens, C.A. Frissel, D. Hankin, J.A. Lichatowich, W. Nehlsen, P.C. Trotter, and T.H. Williams. 1997. Prioritizing Pacific Salmon Stocks for Conservation. Conserv. Biol. 11(1): 140-152.

Appleby, A., and K. Keown. 1994. History of White River spring chinook broodstocking and captive rearing efforts. Wash. Dep. Fish Wildl., 53 p. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Appleby, A., and K. Keown. 1995. History of White River spring chinook broodstock and captive brood rearing efforts. *In* T. A. Flagg and C. V. W. Mahnaken (eds.), An assessment of the status of captive broodstock technology for Pacific salmon, p. 1-32. Report to the Bonneville Power Administration. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Ashbrook, C., and H.J. Fuss. 1996. Hatchery operation plans and performance summaries, Vol. 11, No. 2 Coast. Annual Report. Wash. Dept. Fish Wild., Assess. Develop. Div., Olympia. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Atkinson, C.E. 1960. Fisheries research: its organization and program within the USSR. U. S. Bur. Fish., Seattle, WA.

Bakun, A. 1973. Coastal upwelling indices, west of North America, 1946-71. NOAA Tech. Rep. NMFS SSRF-671, 163 p. (Available from Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.)

Bakun, A. 1975. Daily and weekly upwelling indices, West Coast of North America, 1967-73. NOAA Tech. Rep. NMFS SSRF-693, 114 p. (Available from Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.)

Banks, M.A., B.A. Baldwin, S.M. Blankenship, and D. Hedgecock. 1996. Unpublished data transmitted to NMFS 30 January 1996 from the Bodega Marine Laboratory, Bodega Bay, California. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Ste. 500, Portland, OR 97232.)

Barnhart, R.A. 1995. Salmon and steelhead populations of the Klamath-Trinity Basin, California. *In* T. J. Hassler (ed.), Klamath Basin Fisheries Symposium, p. 73-97. California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA. (Available from California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA 95521.)

Bartlett, H. 1995. Summary report for Methow Basin spring chinook salmon hatchery program. Wash. Dep. Fish Wildl., H96-03, 46 p. (Available from Douglas County Public Utility District, 1151 Valley Mall Parkway, East Wenatchee, WA 98802-4497.)

Bartlett, H., and B. Bugert. 1994. Methow River Basin spring chinook salmon hatchery program evaluation. 1992 Annual Report. Wash. Dep. Fish Wildl., 35 p. (Available from Douglas Public Utility District, 1151 Valley Mall Parkway, East Wenatchee, WA 98802-4497.)

Bartley, D., B. Bentley, J. Brodziak, R. Gomulkiewicz, M. Mangel, and G.A.E. Gall. 1992. Geographic variation in population genetic structure of chinook salmon from California and Oregon. Fish. Bull., U.S. 90:77-100.

Bartley, D.M., and G.A.E. Gall. 1990. Genetic structure and gene flow in chinook salmon populations of California. Trans. Am. Fish. Soc. 119:55-71.

Bartley, D.M., G.A.E. Gall, and D.B. Bentley. 1990. Biochemical genetic detection of natural and artificial hybridization of chinook and coho salmon in northern California. Trans. Am. Fish. Soc. 119:431-437.

Beacham, T.D., and C.B. Murray. 1985. Effect of female size, egg size, and water temperature on developmental biology of chum salmon (*Oncorhynchus keta*) from the Nitinat River, British Columbia. Can. J. Fish. Aquat. Sci. 42:1755-1765.

Beacham, T.D., and C.B. Murray. 1987. Adaptive variation in body size, age, morphology, egg size, and developmental biology of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Res. 44:244-261.

Beacham, T.D., and C.B. Murray. 1989. Variation in developmental biology of sockeye salmon (*Oncorhynchus nerka*) and chinook salmon (*O. tshawytscha*) in British Columbia. Can. J. Zool. 67:2081-2089.

Beacham, T.D., C.B. Murray, and R.E. Withler. 1989. Age, morphology, and biochemical genetic variation of Yukon River chinook salmon. Trans. Am. Fish. Soc. 118:46-63.

Beacham, T.D., R.E. Withler, and T.A. Stevens. 1996. Stock identification of chinook salmon (*Oncorhynchus tshawytscha*) using minisatellite DNA variation. Can. J. Fish. Aquat. Sci. 53:380-394.

Beamish, R.J., and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. 50:1002-1016.

Beamesderfer, R.C.P., H.P. Schaller, M.P. Zimmerman, C.E. Petrosky, O.P. Langness, and L. LaVoy. 1997. Spawner-recruit data for spring and summer chinook salmon populations in Idaho, Oregon, and Washington. Unpublished draft manuscript dated 6/23/97, 78 p. (Compiled and edited by ESSA Technologies Ltd., Vancouver, B.C.)

Beauchamp, D.A., D.E. Pflug, and G. Lucchetti. 1987. Snohomish River juvenile salmon outmigration study 1987. Tulalip Tribal Fisheries, 126 p. (Available from Tulalip Fisheries, 7615 Totem Beach Rd., Marysville, WA 98271.)

Bennett, D.E. 1988. Willamette River spring chinook run. Oreg. Dep. Fish Wildl., 88-031, 34 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Bennett, D.E. 1994. The 1993 Willamette River spring chinook salmon run, fisheries, and passage at Willamette Falls. Oreg. Dep. Fish Wildl. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Berg, W.J., and S.D. Ferris. 1984. Restriction endoneuclease analysis of salmonid mitochondrial DNA. Can. J. Fish. Aquat. Sci. 41:1041-1047.

Berman, C.H., and T.P. Quinn. 1991. Behavioral thermoregulation and homing by spring chinook salmon, *Oncorhynchus tshawytscha*, in the Yakima River. J. Fish Biol. 39:301-312.

Big Eagle & Associates, and LGL Limited (BE and LGL). 1995. Chinook salmon catch, escapement, and historical abundance data. Report prepared for NOAA, NMFS, Northwest Fisheries Science Center. (Available from Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.)

Bishop, S., and A. Morgan, (eds.). 1996. Critical habitat issues by basin for natural chinook salmon stocks in the coastal and Puget Sound areas of Washington State. Northwest Indian Fisheries Commission, Olympia, WA, 105 p. (Available from Northwest Indian Fisheries Commission, 6730 Martin Way E., Olympia, WA 98506.)

Bishop, S.M. 1995. Distribution of west coast chinook stocks or hatchery groups. Report submitted to the ESA Administrative Record for west coast chinook salmon August 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Bisson, P.A., G.H. Reeves, R.E. Bilby, and R.J. Naiman. 1997. Watershed management and Pacific salmon: desired future conditions. *In* D.J. Stouder, P.A. Bisson, and RJ. Naiman (eds.), Pacific salmon and their ecosystems: status and future options, p. 447-474. Chapman and Hall, New York.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Am. Fish. Soc. 100:423-428.

Bjornn, T.C. 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon. T. Bjornn, 16 February 1997, 3 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Bjornn, T.C., D. Ortmann, D. Corley, and W. Platts. 1964. Salmon and steelhead investigations, Job 3: The gathering and compilation of relevant data for Idaho salmon and steelhead runs (salmon spawning ground surveys-1963). Idaho Dep. Fish Game. (Available from Idaho Department of Fish and Game, 600 South Walnut, Box 25, Boise, ID 83707-0025.)

Bonneville Power Administration (BPA), Washington Department of Fish and Wildlife (WDFW), and Yakama Indian Nation (YIN). 1996. Yakima fisheries project. Final environmental impact statement. DOE/EIS-0169, 152 p. (Available from Bonneville Power Administration, Public Involvement Manager, P.O. Box 12999, Portland, OR 97212.)

Bottom, D.L., P.J. Howell, and J.D. Rodgers. 1985. The effects of stream alterations on salmon and trout habitat in Oregon. Oreg. Dep. Fish Wildl., Portland, OR, 70 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Bouck, G.R., A.V. Nebeker, and D.G. Stevens. 1975. Effects of holding temperatures on reproductive development in adult sockeye salmon (*Oncorhynchus nerka*). Annual Northwest Fish Culture Conference, Otter Rock, OR, 17 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Bowers, G.M. 1900. A Manual of fish culture, based on the methods of the United States Commission of Fish and Fisheries, with chapters on the cultivation of oysters and frogs. U.S. Government Printing Office, Washington, D.C., 340 p.

Bowles, E., and E. Leitzinger. 1991. Salmon supplementation studies in Idaho Rivers. Project No. 899882. Bonn. Power Administration, 167 p. + app. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Bradford, M.J. 1994. Trends in the abundance of Chinook Salmon (*Oncorhynchus tshawytscha*) of the Nechako River, British Columbia. Can. J. Fish. Aquat. Sci. 51:965-973.

Brannon, E.L., and W.K. Hershberger. 1984. Elwha River fall chinook salmon. *In* J.M.Walton and D.B. Houton (eds.), Proceedings of Olympic wild fish conference, p. 169-172. Port Angeles, WA.

Brannon, E.L., and A. Setter. 1987. Marine distribution of a hatchery fall chinook salmon population. *In* E. Brannon and B. Jonsson (eds.), Proceedings of the Salmonid Migration and Distribution Symposium, p. 63-69. Trondheim, Norway.

Britton, E.W., and D.E. Marshall. 1980. Catalogue of salmon streams and spawning escapements of Statistical Areas 9 and 10, (Rivers Inlet and Smith Inlet). Can. Data Rep. Fish. Aquat. Sci. 222:164.

Broddrick, L. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: CDFG memorandum to Ms. D. McKee, Inland Fisheries Division, October 13, 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Bruner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. 1992 52:95-110.

Bryant, F.G. 1949. A survey of the Columbia River and its tributaries with special reference to its fishery resources--Part II. Washington streams from the mouth of the Columbia to and including the Klickitat River (Area I). U.S. Fish Wildl. Serv., Spec. Sci. Rep. 62, 110 p.

Bryant, F.G., and Z.E. Parkhurst. 1950. Survey of the Columbia River and its tributaries--Part IV. Area III Washington streams from the Klickitat and Snake Rivers to Grand Coulee Dam, with notes on the Columbia and its tribuataries above Grand Coulee Dam. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 37, 108 p.

Bugert, R. 1998. Mechanics of supplementation in the Columbia River. Fisheries 23:11-20.

Bugert, R., and B. Hopley. 1989. The Snake River fall chinook salmon egg bank program: The final chapter. Washington Department of Fisheries, 7 p. (Available from Washington Department of Fish and Wildlife, 600 Capital Way N., Olympia WA 98501-1091.)

Burck, W.A. 1967. Mature stream-reared spring chinook salmon. Fish Commission of Oregon, Research Briefs 13:128.

Burck, W.A., and P.E. Reimers. 1978. Temporal and spatial distribution of fall chinook salmon spawning in Elk River. Oreg. Dep. Fish. Wildl., Information Report Series 78-3, 14 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Burck, W.A., R.B. Lindsay, B.J. Smith, and E.A. Olsen. 1979. Spring chinook salmon in the John Day River. Annual progress report. Oreg. Dep. Fish Wildl. DE-AC79-80BP18324, 63 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Burger, C.V., R.L. Wilmot, and D.B. Wangard. 1985. Comparison of spawning areas and times for two runs of chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai River, Alaska. Can. J. Fish. Aquat. Sci. 42: 693-700.

Burgner, R.L. 1991. The life history of sockeye salmon (*Oncorhynchus nerka*). *In* C. Groot and L. Margolis (eds.), Life history of Pacific salmon, p. 3-117. Univ. B.C. Press, Vancouver, B.C.

Busack, C. 1990. Yakima/Klickitat production project genetic risk assessment. Appendix A, Yakima/Klikitat production project preliminary design report, 20 p.

Busack, C.A., and K.P. Currens. 1995. Genetic risks and hazards in hatchery operations: Fundamental concepts and issues. Am. Fish. Soc. Symp. 15:71-80.

Busack, C., and A.R. Marshall. 1995. Defining units of genetic diversity in Washington salmonids. *In* C. Busack and J. B. Shaklee (eds.), Genetic diversity units and major ancestral lineages of salmonid fishes in Washington, p. 1-19. Wash. Dep. Fish Wildl. Tech. Rep. RAD 95-02, 173 p. (Available from Washington Department of Fish and Wildlife, 600 Capital Way N., Olympia WA 98501-1091.)

Busack, C.A., C. Knudsen, A. Marshall, S. Phelps, and D. Seiler. 1991. Yakima hatchery experimental design. Bonneville Power Administration. 89-082, 266 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Busby, M.S. 1991. The abundance of epibenthic and plantonic macrofauna and feeding habits of juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) in the Mattole River estuary/lagoon, Humboldt County, California. M.S. Thesis, Humboldt State University, Arcata, California, 130 p.

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. NOAA Tech. Memo. NMFS-NWFSC-27, 261 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Bush, G., C. McConnell, C. Cloyd, K. Musser, and B. Metzer. 1997. Assessment of the effects of the 1996 flood on the Siuslaw National Forest. Siuslaw Natl. Forest, Draft Tech. Rep. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32: 667-680.

California Advisory Committee on Salmon and Steelhead Trout (CACSST). 1988. Restoring the balance. Calif. Dep. Fish Game, 84 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

California Department of Fish and Game (CDFG). 1965. California fish and wildlife plan. Three volumes. Sacramento, CA. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

California Department of Fish and Game (CDFG). 1984. CDFG memorandum from Fred Meyer to file re: Calaveras River fishery below New Hogan Dam. CDFG Region 2, May 1, 1984. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1995. Klamath River fall chinook salmon run-size, in-river harvest and spawner escapement - 1995 season. Calif. Dep. Fish Game, Klamath-Trinity Program, 8 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

California Department of Fish and Game (CDFG). 1996. Trinity River Basin salmon and steelhead monitoring project annual report: 1994-95 season. CDFG report dated May 1996, 193 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth Street, Sacramento, CA 95814.)

California Department of Fish and Game (CDFG). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by R. Carpenter, 21 March 1997, 12 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon. A. Baracco, 4 April 1997, 16 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1997c. Documents submitted to the ESA Administrative Record for west coast chinook salmon by C. Harvey, 12 September 1997, 3 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1997d. Documents submitted to the ESA Administrative Record for west coast chinook salmon by G. Neillands, 16 September 1997, 5 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1997e. Documents submitted to the ESA Administrative Record for west coast chinook salmon by B. Jong, 18 September 1997, 1 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

California Department of Fish and Game (CDFG). 1997f. San Joaquin River chinook salmon enhancement project: Annual report fiscal year 1995-96. CDFG Report dated April 1997, 104 p. (Available from California Department of Fish and Game, Region 4, 1234 East Shaw Avenue, Fresno, CA 93710.)

California Department of Fish and Game (CDFG). 1997g. Trinity River Basin salmon and steelhead monitoring project annual report: 1996-97 season. CDFG draft report, 27 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth Street, Sacramento, CA 95814.)

California Department of Natural Resources (CDNR). 1931. Thirty-first biennial report, 1928-1930. Div. of Fish and Game, Sacramento, CA, 96 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

California State Lands Commission (CSLC). 1993. California’s rivers, a public trust report, 304 p.

Calkins, R.D., W.F. Durand, and W.H. Rich. 1940. Report of the board of consultants on the fish problem of the upper Sacramento River. Stanford Univ., 34 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Campbell, E.A., and P.B. Moyle. 1990. Historical and recent populations sizes of spring-run chinook salmon in California. *In* T.J. Hassler (ed.), Northeast Pacific chinook and coho salmon workshops and proceeding, p. 155-216. Humbolt State University, Arcata, CA.

Campton, D.E. 1995. Genetic effects of hatchery fish on wild populations of Pacific salmon and steelhead: what do we really know? Am. Fish. So. Symp. 15:337-353.

Carie, D. 1996. Spring and summer chinook salmon spawning ground surveys on the Entiat River, 1996. U.S. Fish and Wildlife Report dated December 1996, 16 p. (Available from U.S. Fish and Wildlife Service, Mid-Columbia River Fisheries Resource Office, 12790 Fish Hatchery Rd., Leavenworth, WA 98826.)

Carl, L.M., and M.C. Healey. 1984. Differences in enzyme frequency and body morphology among three juvenile life history types of chinook salmon (*Oncorhynchus tshawytscha*) in the Nanaimo River, British Columbia. Can. J. Fish. Aquat. Sci. 41:1070-1077.

Casteneda, R. 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Caughley, G. 1994. Directions in conservation biology. J. Anim. Ecol. 63:215-244.

Cavalli-Sforza, L.L., and A.W.F. Edwards. 1967. Phylogenetic analysis: Models and estimation procedures. Evolution 21:550-570.

Chakraborty, R. 1980. Gene diversity analysis in nested subdivided populations. Genetics 96:721-726.

Chapman, D., A. Giorgi, M. Hill, A. Maule, S. McCutcheon, D. Park, W. Platts, K. Prat, J. Seeb, L. Seeb and others. 1991. Status of Snake River chinook salmon. Pacific Northwest Utilities Conference Committee, 531 p. (Available from Don Chapman Consultants, 3653 Rickenbacker, Ste. 200, Boise, ID 83705.)

Chapman, D., A. Giorgi, T. Hillman, D. Deppert, M. Erho, S. Hays, C. Peven, B. Suzumoto, and R. Klinge. 1994. Status of summer/fall chinook salmon in the mid-Columbia region. Report for Chelan, Douglas, and Grant County PUDs. 412 p. + app. (Available from Don Chapman Consultants, 3653 Rickenbacker, Ste. 200, Boise, ID 83705.)

Chapman, D., C. Peven, A. Giorgi, T. Hillman, and F. Utter. 1995. Status of spring chinook salmon in the mid-Columbia River. Don Chapman Consultants, Inc., 477 p. (Available from Don Chapman Consultants, 3653 Rickenbacker, Ste. 200, Boise, ID 83705.)

Chapman, W.M. 1943. The spawning of chinook salmon in the main Columbia River. Copeia(3):168-170.

Cheng, K.M., I.M. McCallum, R.I. McKay, and B.E. March. 1987. A comparison of survival and growth of two strains of chinook salmon (*Oncorhynchus tshawytscha*) and their crosses reared in confinement. Aquaculture 67:301-311.

Clark, G.H. 1929. Sacramento-San Joaquin salmon (*Oncorhynchus tshawytscha*) fishery of California. Calif. Fish Game Bull. 17:73.

Clarke, W.C., R.E. Withler, and J.E. Shelbourn. 1992. Genetic control of juvenile life-history pattern in chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 49:2300-2306.

Cobb, J.N. 1930. Pacific salmon fisheries. Report of the U.S. Commissioner of Fisheries for 1930. Bureau of Fish. Doc. 1092, p. 409-704.

Columbia Basin Fish and Wildlife Authority (CBFWA). 1990a. Integrated system plan for salmon and steelhead production in the Columbia River Basin. Columbia Basin Fish and Wildlife Authority, 449 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Columbia Basin Fish and Wildlife Authority (CBFWA). 1990b. Review of the history, development, and management of anadromous fish production facilities in the Columbia river basin. Columbia Basin Fish and Wildlife Authority, Portland, Oregon, 52 p. (Available from Columbia Basin Fish and Wildlife Authority, 2501 SW First Ave., Suite 200, Portland, OR 97201.)

Columbia Basin Fish and Wildlife Authority (CBFWA). 1996. Impacts of artificial salmon and steelhead production strategies in the Columbia River basin. Draft Programmatic Environmental Impact Statement. (Available from Columbia Basin Fish and Wildlife Authority, 2501 SW First Ave., Suite 200, Portland, OR 97201.)

Conner, W.P., H.L. Burge, and W.H. Miller, 1994. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles. *In* D.W. Rondorf & W.H. Miller (eds.), Identification of the spawning, rearing, and migratory requirements of fall chinook salmon in the Columbia River Basin, p. 92-119. U.S. Department of Energy, Bonneville Power Administration. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Cooney, C.X., and S.E. Jacobs. 1994. Oregon coastal salmon spawning surverys, 1992. Oreg. Dep. Fish Wildl, Fish Div. Info. Rep., No. 94-2, 103 p.

Cope, O.B., and D.W. Slater. 1957. Role of Coleman hatchery in maintaining a king salmon run. U.S. Fish Wildl. Serv. Res. Rep., No. 47, 22 p. (Available from Superintendent of Documents, United States Government Printing Office, Washington, D.C.)

Craig, J. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: completed questionnaires for Klamath River, Wooley Creek, Trinity River, New River, and Blue Creek; age composition of 1991-1994 Klamath and Trinity Rivers fall chinook salmon. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Craig, J.A., and Suomela. 1941. Time of appearance of the runs of salmon and steelhead trout native to the Wenatchee, Entiat, Methow, and Okanogan rivers. U.S. Fish Wildl. Serv. [Reprinted in Mullan et al. 1992.]

Craig, J.A., and L.D. Townsend. 1946. An investigation of fish-maintenance problems in relation to the Willamette Valley Project. U.S. Fish Wildl. Spec. Sci. Rep. 33:74.

Craig, J.L., and T.S. Fletcher. 1994. Klamath River fisheries assessment program. 1992 Annual report. U.S. Fish Wildl. Serv. AFF1-FRO-94-03, 63 p. (Available from U.S. Fish and Wildlife Service, Coastal California Fishery Resource Office, Arcata, California.)

Cramer, S.P. 1987. Abundance of Rogue River fall chinook salmon. Annual progress report. Oreg. Dep. Fish Wildl., Fish Res. Project. AFS 78-1, 166 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Cramer, S.P. [1989]. Contribution of Sacramento Basin hatcheries to ocean catch and river escapement of fall chinook salmon. S.P. Cramer & Associates, 113 p. (Available from S. P. Cramer and Associates, Inc., 300 S.E. Arrow Creek Land, Gresham, OR 97080.)

Cramer, S.P. 1996. The status of late-fall and spring chinook salmon in the Sacramento River Basin in regards to the Endangered Species Act. S.P. Cramer & Associates, 39 p. (Available from S.P. Cramer & Associates, Inc., 300 S.E. Arrow Creek Lane, Gresham, OR 97080.)

Cramer, S. P., C. F. Willis, D. Cramer, M. Smith, T. Downey, and R. Montagne. 1996. Status of Willamette River spring chinook salmon in regards to the Federal Endangered Species Act (Part 2). Portland General Electric Company and Eugene Water and Electric Board, 131 p. (Available from S.P. Cramer & Associates, Inc., 300 S.E. Arrow Creek Lane, Gresham, OR 97080.)

Crateau, E. 1997. Straying of hatchery origin spring/summer-run chinook salmon in the Grande Ronde Basin. *In* W.S. Grant (ed.), Genetic effects of straying of non-native hatchery fish into natural populations: Proceedings of the workshop, p. 9-15. NOAA Tech. Memo. NMFS-NWFSC-30.

Crawford, B.A. 1979. The origin and history of the trout brood stocks of the Washington Department of Game. Washington State Game Dep., Fishery Research Report, 76 p. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Crawford, J. 1894. Fifth annual report of the State Fish Commission of the State of Washington. Dep. Fish., State of Washington, 12 p. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Cross, C.L., L. Lapi, and E.A. Perry. 1991. Production of chinook and coho salmon from British Columbia hatcheries, 1971 through 1989. Can Tech. Rept. Fish Aquat. Sci. 1816, 48 p.

Cuenco, M.L., T.W.H. Backman, and P.R. Mundy. 1993. The use of supplementation to aid in natural stock restoration. *In* J.G. Cloud and G.H. Thorgaard (eds.), Genetic conservation of salmonid fishes, p. 269-293. Plenum Press and NATO Scientific Affairs Division, New York.

Currens, K.P., and C.A. Busack. 1995. A framework for assessing genetic vulnerability. Fisheries. 20(12):24-31.

Currens, K., J. Lannan, B. Riddell, D. Tave, and C. Wood. 1996. Responses of the independent scientific panel to questions about the interpretation of genetic data for spring chinook salmon in Grand Ronde Basin. Report for the US vs. Oregon Dispute Resolution, 43 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Dahl, T.E. 1990. Wetland losses in the United States 1780's to 1980's. Report to Congress, U.S. Fish Wildl. Serv., Washington, D.C., 13 p.

Data Access in Real Time Adult Passage (DARTAP). 1997. Columbia River Basin Research, University of Washington, Seattle, WA. (Available through Online Internet database at http://www.cqs.washington.edu/dart/adult.html.)

Dauble, D.D., R.L. Johnson, R.P. Mueller, and C.S. Abernathy. 1995. Spawning of fall chinook salmon downstream of Lower Snake River hydroelectric projects 1994. U.S. Army Corps of Engineers, 14 p. (Available from U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA 99362.)

Davidson, F.A. 1953. Historical notes on development of Yakima River basin. Yakama Indian Nation Toppenish, WA. Mimeo Report, 22 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Dean, M. 1995. Trinity River Basin salmon and steelhead monitoring project 1992-1993 season: Job VII Life History, distribution, run size, and harvest of spring chinook salmon in the South Fork Trinity River Basin. Calif. Fish and Game, Inland Fish. Div., 187-226 p . (Available from Inland Fisheries Division, 1416 Ninth Street, Sacramento, CA 95814.)

Delarm, M.R., and R.Z. Smith. 1990a. Assessment of present anadromous fish production facilities in the Columbia River Basin Volume 1: U.S. Fish and Wildlife Hatcheries. Bonneville Power Administration. 89-045, 106 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife-PJ, P.O. Box 3621, Portland, OR 97208.)

Delarm, M.R., and R.Z. Smith. 1990b. Assessment of present anadromous fish production facilities in the Columbia River Basin Volume 2: Idaho Department of Fish and Game Hatcheries. Bonneville Power Administration. 89-045, 77 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife-PJ, P.O. Box 3621, Portland, OR 97208.)

Delarm, M.R., and R.Z. Smith. 1990c. Assessment of present anadromous fish production facilities in the Columbia River Basin Volume 3: Oregon Department of Fish and Wildlife Hatcheries. Bonneville Power Administration. 89-045, 177 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife-PJ, P.O. Box 3621, Portland, OR 97208.)

Delarm, M.R., and R Z. Smith. 1990d. Assessment of present anadromous fish production facilities in the Columbia River Basin Volume 4: Washington Department of Fish Hatcheries. Bonneville Power Administration. 89-045, 130 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife-PJ, P.O. Box 3621, Portland, OR 97208.)

Department of Water Resources (DWR). 1988. Water temperature effects on chinook salmon (*Oncorhynchus tshawytscha*) with emphasis on the Sacramento River: A literature review. Calif. Dep. Water Res., Sacramento, CA, 43 p.

Dettman, D.H., D.W. Kelley, and W.T. Mitchell. 1987. The influence of flow on Central Valley salmon. Prepared for the California Dept. of Water Resources. Revised July 1987, 66 p. (Available from D.W. Kelley and Associates, 8955 Langs Hill Rd., P.O. Box 634, Newcastle, CA 95658.)

Dewberry, C., P. Burns, and L. Hood. 1996. The effects of the storms of 1996 on anadromous fish-bearing reaches in the Knowles Creek Watershed. Draft Report for John Hancock Timber Management Group, 15 p. + tables.

Donaldson, L.R., and K. Bonham. 1970. Effects of chronic exposure of chinook salmon eggs and alevins to gamma irradiation. Trans. Am. Fish. Soc. 99:112-119.

Donaldson, L.R., and D. Manasveta. 1961. Selective breeding of chinook salmon. Trans. Am. Fish. Soc. 90:160-164.

Ducey, R. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: data for the American River. (Available from Environmental and Technical Services Division, National Marine Fisheries Service, 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Duker, G.J. 1981. Instream orientation and species recognition by Pacific salmon. *In* E.L. Brannon and E.O. Salo (eds.), Salmon and trout migratory behavior symposium, p. 286-295. Univ. Wash. Press, Seattle, WA.

Dunston, W. 1955. White River downstream migration. Puget Sound stream studies (1953-1956). Wash. Dep. Fish. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

East Bay Municipal Utility District (EBMUD). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon 24 August 1995: data reports for the Mokelumne River. (Available from Environmental and Technical Services Division, National Marine Fisheries Service, 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

East Bay Municipal Utility District (EBMUD). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Miyamoto, 18 September 1997, 3 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Ellis, C.H., and R.E. Noble. 1961. Returns of marked fall chinook salmon to the Deschutes River. Annual report. Wash. State Fish. Dep. 70 (72-75). (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Emlen, J.M. 1995. Population viability of the Snake River chinook salmon. Can. J. Fish. Aquat. Sci. 52:1442-1448.

Environment Canada. 1977. Water temperatures: British Columbia and Yukon Territory. Inland Waters Directorate, Vancouver, Canada, 1874 p.

Environment Canada. 1991. HYDAT: Surface water data to 1990. Version CD Rom 3.0. Ottawa: Environment Canada, Inland Waters Directorate, Water Resources Branch.

Evermann, B.W. 1896. A preliminary report on salmon investigations in Idaho in 1894. Bull. U.S. Fish. Comm. 15:253-284.

Fagen, R., and W.W. Smoker. 1989. How large-capacity hatcheries can alter interannual variability of salmon production. Fish. Res. 8:1-11.

Fast, D., J. Hubble, M. Kohn, and B. Watson. 1991. Yakima River spring chinook salmon enhancement study. Final report. Bonneville Power Administration. Project No. 82-16. App. (Available from Bonneville Power Administration, Div. Fish Wildl., P.O. Box 3621, Portland, OR 97208.)

Fast, D., M. Hubble, and B. Watson. 1986. Yakima River spring chinook enhancement study. Annual report FY 1996. Yakama Indian Nation, Fisheries Resource Management. Project No. 82-16. (Available from Bonneville Power Administration, P.O. Box 3621, Portland, OR 97208.)

Fish, F.F., and M.G. Hanavan. 1948. A report on the Grand Coulee Fish Maintenance. Project 1939-1947. U.S. Fish Wildl. Serv. Spec. Sci. Rep 55.

Fisher, F.W. 1994. Past and present status of Central Valley chinook salmon. Conserv. Biol. 8:870-873.

Fisher, F.W. 1995. Central Valley coded-wire tag recoveries from hatcheries and inland waters, 1975 through 1994. Draft report. Calif. Dep. Fish Game, Inland Fish. Div., 49 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

Flagg, T.A., F.W. Waknitz, and C.V.W. Mahnken. 1995a. The captive broodstock concept: Application to rearing Pacific salmon. *In* T.A. Flagg and C.V.W. Mahnken (preparers), An Assessment of the status of captive broodstock technology for Pacific salmon. Final Report to the Bonneville Power Administration, Portland, OR, p. 1-60. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Flagg, T.A., F.W. Waknitz, D.J. Maynard, G.B. Milner, and C.V. Mahnken. 1995b. 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.

Fleming, I.A., and M.R. Gross. 1990. Latitudinal clines a trade-off between egg number and size in Pacific salmon. Ecology 71:1-11.

Foerster, R.E. 1968. The Sockeye Salmon. Fish. Res. Board Can. Bull. 162, 422 p.

Foote, C.J. 1990. An experimental comparison of male and female spawning territoriality in Pacific salmon. Behavior 115:283-314.

Foote, C.J., W.C. Clarke, and J. Blackburn. 1991. Inhibition of smolting in precocious male chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Zool. 69:1848-1852.

Forbes, G.F. 1992. Coleman National Fish Hatchery winter chinook salmon brood year 1991 production report. USFWS report submitted to the administrative record for coastal chinook salmon. (Available from USFWS, Fisheries Assistance Office, P.O. Box 667, Red Bluff, CA 96080.)

Forest Ecosystem Management Assessment Team (FEMAT). 1993. Forest ecosystem management: an ecological, economic, and social assessment. U.S. Forest Service, Natl. Mar. Fish. Serv., Bureau of Land Management, U.S. Fish and Wildlife Service, National Park Service, U.S. Environmental Protection Agency. Portland, Oregon, and Washington D.C. 843 p. + app.

Fowler, L.G. 1972. Growth and mortality of fingerling chinook salmon as affected by egg size. Prog. Fish-Cult. 34:66-69.

Fraser, F.J., P.J. Starr, and A.Y. Fedorenko. 1982. A review of the chinook and coho salmon of the Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. 1126:130.

French, R.R., and RJ. Wahle. 1959. Biology of chinook and blueback salmon and steelhead in the Wenatchee River system. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 304, 17 p.

Fryer, J.K., and M. Schwartzberg. 1990. Experiments in identifying hatchery and naturally spawning stocks of Columbia Basin spring chinook salmon using scale pattern analyses. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 90-3, 29 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fryer, J.K., and M. Schwartzberg. 1991a. Age and length composition of Columbia Basin spring chinook salmon at Bonneville dam in 1990. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 91-1, 22 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fryer, J.K., and M. Schwartzberg. 1991b. Age and length composition of Columiba Basin summer chinook salmon at Bonneville dam in 1990. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 91-4, 21 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fryer, J.K., and M. Schwartzberg. 1992. Age and length composition of Columbia Basin summer chinook salmon at Bonneville dam in 1991. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 92-4, 14 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fryer, J.K., and M. Schwartzberg. 1993. Age and length composition of Columbia Basin spring and summer chinook salmon at Bonneville dam in 1992. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 93-3, 29 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR, 97232.)

Fryer, J.K., and M. Schwartzberg. 1994. Age and length composition of Columbia Basin spring and summer chinook salmon at Bonneville dam in 1993. Columbia River Inter-Tribal Fish Commission Portland, Technical Report 94-1, 30 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fryer, J.K., C. Pearson, and M. Schwartzberg. 1992. Age and length composition of Columbia Basin spring chinook salmon at Bonneville dam in 1991. Columbia River Inter-Tribal Fish Commission Portland. Technical Report 92-1, 29 p. (Available from Columbia River Inter-Tribal Fish Commission, 729 N.E. Oregon St., Portland, OR 97232.)

Fulton, L.A. 1968. Spawning areas and abundance of chinook salmon, *Oncorhynchus tshawytscha*, in the Columbia River Basin-Past and present. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Fish. 571:26.

Fuss, H.J., and C. Ashbrook. 1995. Hatchery operation plans and performance summaries. Volume I (2). Puget Sound. Annual Report. Washington Department of Fish Wild., Assessment and Develop. Div., Olympia. (Available from Washington Dept. of Fish and Wildlife, 600 Capital Way N., Olympia, WA 98501-1091.)

Galbreath, J.L. 1965. Timing of Willamette River spring chinook salmon through the lower Columbia River. Fish Comm. Oreg., Research Briefs 11:29-41.

Galbreath, J.L. 1966. Timing of tributary races of chinook salmon through the lower Columbia River based on analysis of tag recoveries. Fish Comm. Oreg., Res. Briefs 12, 58-80 p.

Galbreath, J.L., and R. L. Ridenhour. 1964. Fecundity of Columbia River chinook salmon. Fish Comm. Oreg., Research Briefs 10, 16-27 p.

Gall, G.A.E. 1975. Genetics of reproduction in rainbow trout. J. Anim. Sci. 40:19-28.

Garcia, A.P., W.P. Connor, R.D. Nelle, C. Eaton, R.S. Bowen, P.W. Bigelow, E.A. Rockhold, and R.H. Taylor. 1996. Fall chinook salmon spawning ground surveys in the Snake

River, 1994. *In* D.W. Rondorf and K.F. Tiffan (eds.), Identification of the spawning, rearing, and migratory requirements of fall chinook salmon in the Columbia River Basin, p. 1-15. U.S. Department of Energy, Bonneville Power Administration. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Gard, M. 1995. Upper Sacramento River IFIM study scoping report. U.S. Fish Wildl. Serv., 14 p.

Gebhards, S.V. 1960. Biological notes on precocious male chinook salmon parr in the Salmon River drainage, Idaho. Prog. Fish-Cult. 22:121-123.

Gharrett, A.J., and W.W. Smoker. 1993. Genetic components in life-history traits contribute to population structure. *In* J. G. Cloud and G. H. Thorgaard (eds.), Genetic Conservation of Salmonid Fishes, p. 197-201. Plenum Press, London.

Gharrett, A.J., S.M. Shirley, and G.R. Tromble. 1987. Genetic relationships among populations of Alaskan chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 44:765-774.

Gharrett, A.J., C. Smoot, and A.J. McGregor. 1988. Genetic relationships of even-year northwestern Alaskan pink salmon. Trans. Am. Fish. Soc. 117: 536-545.

Gilbert, C.H. 1912. Age at maturity of Pacific coast salmon of the genus *Oncorhynchus*. Bull. U.S. Fish Comm. 32:57-70.

Gilbert, C.H. 1922. The salmon of the Yukon River. U.S. Bur. Fish., Bull. 38:317-332.

Gilpin, M.E., and M.E. Soule. 1986. Minimum viable populations: Processes of species extinction. *In* M.E. Soule (ed.), Conservation Biology: The science of scarcity and diversity, p. 19-34. Sinauer Associates, Sunderland, MA.

Godfrey, H. 1968. Ages and physical characteristics of maturing chinook salmon on the Nass, Skeena, and Fraser Rivers in 1964, 1965, and 1966. Fish. Res. Board Can. Manuscript Report 967.

Goodman, D. In press. Population viability analysis: the risk assessment paradigm. *In* A. D. MacCall and T. C. Wainwright (eds.), Assessing Extinction Risk for West Coast Salmon: Proceedings of the Workshop. NOAA Tech. Memo. NMFS-NWFSC.

Grant, S. (ed.). 1997. Genetic effects of straying of non-native hatchery fish into natural populations. Proceedings of the NOAA workshop, June 1-2, 1995, Seattle, WA. NOAA Tech. Memo. NMFS-NWFSC-30.

Grass, A. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: questionaire for the Noyo River. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Gray, P.L. 1965. Fecundity of the chinook salmon (*Oncorhynchus tshawytscha*) related to size, age, and egg diameter. M.S. Thesis, Univ. Wash., Seattle, WA, 65 p.

Gregory, S.V., and P.A. Bisson. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. *In* D. J. Stouder, P. A. Bisson, and R.J. Naiman (eds.), Pacific salmon and their ecosystems: status and future options, p. 277-314. Chapman and Hall, New York

Gross, M.R. 1987. Evolution of Diadromy in Fishes. Am. Fish. Soc. Symp. 1:14-25.

Gunter, J.E.R. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: data for the Russian River. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Hallock, R.J., and F. Fisher. 1985. Status of winter-run chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento River. Calif. Dept. Fish and Fame, Anad. Fish. Branch Report, 28 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

Hallock, R.J., and D.H. Fry, Jr. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game 53:5-22.

Hallock, R.J. and W.F. Vanwoert. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. Calif. Fish Game 45(4): 227-267.

Halupka, K.C., J.K. Troyer, M.F. Wilson, and F.H. Everest. 1993. Identification of unique and sensitive salmonid stocks of Southeast Alaska. U.S. Dep. Agriculture, 92 p. (Available from U.S. Department of Agriculture, 2770 Sherwood Lane 2A, Juneau, AK 99801-8545.)

Hancock, M.J., A.J. Leaney-East, and D.E. Marshall. 1983a. Catalogue of salmon streams and spawning escapements of Statistical Areas 4 (Lower Skeena River) including coastal streams. Can. Data Rep. Fish. Aquat. Sci. 395, 422 p.

Hancock, M.J., A J. Leaney-East, and D.E. Marshall. 1983b. Catalogue of salmon streams and spawing escapements of Statistical Area 4, (Upper Skeena River). Can. Data Rep. Fish. Aquat. Sci. 394, 324 p.

Hankin, D. 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon. D. Hankin, 19 March 1997, 135 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Hankin, D., and R. McKelvey. 1985. Comment on fecundity of chinook salmon and its relevance to life history theory. Can. J. Fish. Aquat. Sci. 42:393-394.

Hankin, D.G., J.W. Nicholas, and T.W. Downey. 1993. Evidence for inheritance of age of maturity in chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 50:347-358.

Hanson, H.A., O.R. Smith, and P.R. Needham. 1940. An investigation of fish-salvage problems in relation to Shasta Dam. U.S. Dep. Interior, Bureau of Fish., Special Scientific Report 10, 200 p.

Hard, J.J. 1995. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. Am. Fish. Soc. Symp. 15:212-225.

Hard, J.J., and W.K. Hershberger. 1995. Quantitative genetic consequences of captive broodstock programs for anadromous Pacific salmon (*Oncorhynchus* spp.). *In* T.A. Flagg and C.V.W. Mahnken (eds.), An assessment of the status of captive broodstock technology for Pacific salmon, p. 2-1 through 2-75. (Available from Bonneville Power Administration (Project No. 93-56), P.O. Box 3621, Portland, OR 92708-3621.)

Hard, J.J., R.P. Jones, Jr., M.R. Delarm, and R.S. Waples. 1992. Pacific salmon and artificial propagation under the Endangered Species Act. NOAA Tech. Memo., NMFS-NWFSC-2, 56 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Hard, J.J., R.G. Kope, W.S. Grant, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1996. Status review of pink salmon from Washington, Oregon, and California. NOAA Tech. Memo. NMFS-NWFSC-25, 131 p. (Available from Conservation Biology Division, Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

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 Columiba. *In* W.R. Meehan,T.R.

Merrill, Jr., and T.A. Hanley (eds.), Fish and wildlife relationships in old-growth forests, p. 141-149. Am. Instit. Fish. Biologists.

Healey, M.C. 1982. Catch, escapement, and stock-recruitment for British Columbia chinook salmon since 1951. Can. Tech. Rep. Fish. Aquat. Sci. 1107:77.

Healey, M.C. 1983. Coastwide distribution and ocean migration patterns of stream- and ocean-type chinook salmon, *Oncorhynchus tshawytscha*. Can. Field-Nat. 97:427-433.

Healey, M.C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. Can. Spec. Publ. Fish. Aquat. Sci. 89:39-52.

Healey, M.C. 1991. The life history of chinook salmon (*Oncorhynchus tshawytscha*). *In* C. Groot and L. Margolis (eds.), Life history of Pacific salmon, p. 311-393. Univ. B.C. Press, Vancouver, B.C.

Healey, M.C., and C. Groot. 1987. Marine migration and orientation of ocean-type chinook and sockeye-salmon. Am. Fish. Soc. Symp. 1:298-312.

Healey, M.C., and W.R. Heard. 1984. Inter- and intra-population variation in the fecundity of chinook salmon (*Oncorhynchus tshawytscha*) and its relevance to life history theory. Can. J. Fish. Aquat. Sci. 41:476-483.

Heard, W.R. 1985. Chinook salmon fisheries and enhancement in Alaska: a 1982 overview. NOAA Tech. Report NMFS F/NWC 27:21-28.

Heard, W.R. 1996. Sequential imprinting in chinook salmon: is it essential for homing fidelity? Bull. Nat. Res. Inst. Aquacult. Suppl. 2:59-64.

Heard, W.R., R. Burkett, F. Thrower, and S. McGee. 1995. A review of chinook salmon resources in Southeast Alaska and development of an enhancement program designed for minimal hatchery-wild stock interaction. Am. Fish. Soc. Symp., Bethesda, MD. 15:21-37.

Heath, D.D., N.J. Bernier, and T.A. Mousseau. 1995. A single-locus minisatellite discriminates chinook salmon (*Oncorhynchus tshawytscha*) populations. Mol. Ecol. 4:389-393.

Heath, D.D., R.H. Devlin, J.W. Heath, and G.K. Iwama. 1994. Genetic, environmental, and interaction effects on the incidence of jacking in *Oncorhynchus tshawytscha* (chinook salmon). Heredity 72:146-154.

Hedgecock, D., M.A. Banks, S.M. Blankenship, and M.J. Calavetta. 1995. Genetic evidence for admixture and hybridization of spring- and winter-run chinook salmon in an artificial propagation program. Unpublished manuscript, 23 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Ste. 500, Portland, OR 97232.)

Hedrick, P.W., D. Hedgecock, and S. Hamelberg. 1995. Estimation of effective population size in winter-run chinook salmon. Conserv. Biol. 9:615-624.

Hershberger, W.K., and R.N. Iwamoto. 1984. Genetics of age at maturity in chinook salmon. 1984 International Conference on Biology of Pacific Salmon, Victoria/Aggassiz, British Columbia.

Hickey, P.L. 1983. Analysis of the genetic variability in the times to hatching and yolk absorption among chinook salmon (*Oncorhynchus tshawytscha*) eggs and alevins. M.S. Thesis, Univ. Wash., Seattle, WA, 97 p.

Higgins, P., S. Dobush, and D. Fuller. 1992. Factors in northern California threatening stocks with extinction. Humboldt Chapter of the American Fisheries Society, Arcata, CA, 24 p.

Hillis, D.M., C. Mortiz, and B.K. Mable, (eds.). 1996. Molecular systematics. Second edition. Sinauer Assoc., Sunderland, MA.

Hillman, T.W., and D.W. Chapman. 1989. Abundance, growth and movement of juvenile chinook salmon and steelhead. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final report. Chelan County PUD, Washington.

Hillman, T.W., J.S. Griffith, and W.S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Trans. Am. Fish. Soc. 116:185-195.

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquatic Sci. 48:945-957.

Hockersmith, E., J. Vella, L. Stuehrenberg, R.N. Iwamoto, and G. Swan. 1994. Yakima River radio-telemetry study: spring chinook salmon, 1991-1992. Natl. Mar. Fish. Serv. report to Bonneville Power Administration. Project No. 89-089, 98 p.

Hoh Indian Tribe (HIT). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Jorgensen, August 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

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, p. 159-174. Pacific Biological Station, Nanaimo, B.C.

Holtby, L.B., and M.C. Healey. 1986. Selection for adult size in female coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 43:1946-1959.

Hoopa Valley Tribal Council (HVTC). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon. M. Orcutt, 31 March 1997 response to the November 22 1996 co-manager's draft of the the west coast chinook salmon status review, 4 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Howell, P., J. Hutchinson, and R. Hooton. 1988. McKenzie subbasin fish management plan. Oreg. Dep. Fish Wildl. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Knedra, and D. Orrmann. 1985. Stock assessment of Columbia River anadromous salmonids. Vol: I. U.S. Dep. Energy, Bonneville Power Administration. Project No. 83-335, 558 p.

Hughes, R.M., E. Rexstad, and C.E. Bond. 1987. The relationship of aquatic ecoregions, river basins, and physiographic provinces to the icthyogeographic regions of Oregon. Copeia 1987:423-432.

Huntington, C., W. Nehlsen, and J. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. Fisheries 21(3):6-14.

Huttunen, D.C. 1985. Abundance, age, sex, and size of salmon (*Oncorhynchus* sp.) catches and escapements in the Kuskokwim area, 1983. Alaska Dept. Of Fish and Game, Technical Report No. 133, 94 p. (Available from Alaska Dept. Of Fish and Game, P.O. Box 3-2000, Juneau, Alaska 99802.)

Hydrosphere Data Products, Inc. 1993. Hydrodata Regional CD-ROMs: U.S. Geological Survey daily values, Vols. West 1, West 2. (Available from Hydrosphere Data Products, Inc., 1002 Walnut, Suite 200, Boulder, CO 80302.)

Hymer, J., R. Pettit, M. Wastel, P. Hahn, and K. Hatch. 1992a. Stock summary reports for Columbia River anadromous salmonids. Volume III: Washington subbasins below McNary Dam. Bonneville Power Administration. Project No. 88-108, 1077 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, Public Information Officer - PJ, P.O. Box 3621, Portland, OR, 97208.)

Hymer, J., R. Pettit, M. Wastel, P. Hahn, and K. Hatch. 1992b. Stock summary reports for Columbia River anadromous salmonids. Vol. IV: Washington subbasins above McNary Dam. Bonneville Power Administration. Project No. 88-108, 375 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, Public Information Officer - PJ, P.O. Box 3621, Portland, OR, 97208.)

Hynes, J.D., J.E.H. Brown, J.H. Helle, N. Ryman, and D.A. Webster. 1981. Guidelines for the culture of fish stocks for resource management. Can. J. Fish. Aquatic Sci. 38:1867-1876.

Idaho Department of Fish and Game (IDFG). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon. S. Huffaker, 15 January 1997, 6 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Ivankov, V.N. 1983. Causes of variation in fecundity and age of sexual maturation in moncylic fishes with examples from salmon, genus *Oncorhynchus*. J. Ichthyol. 23:84-92.

Iwamoto, R.N. 1982. Strain-photoperiod-temperature interactions in coho salmon: freshwater growth, smoltification, and seawater adaptation. Ph.D. Dissertation, Univ. Wash., Seattle, WA, 380 p.

Johnson, O.W. 1988a. Induced triploidy in Pacific salmon. Ph.D. Dissertation, Univ. Wash., Seattle, WA, 137 p.

Johnson, R.R., D.C. Weigand, and F.W. Fisher. 1992b. Use of growth data to determine the spatial and temporal distribution of four runs of juvenile chinook salmon in the Sacramento River, California. U.S. Fish Wildl. Serv. AFF1/FRO-92-15. (Available from U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, CA 96080.)

Johnson, S., T. Richardson, J. Campbell, S. Parry, V. Segarich, and B. Hodges. 1973. Tehama-Colusa fish production facilities spawning channel production report. U.S. Fish Wildl. Serv., 44 p. (Available from Fish and Wildlife Service, 10950 Tyler Road, Red Bluff, CA, 96080.)

Johnson, S.L. 1988b. 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.W., J.F. Thedinga, and K.V. Koski. 1992a. Life history of juvenile ocean-type chinook salmon (*Oncorhynchus tshawytscha*) in the Situk River, Alaska. Can. J. Fish. Aquat. Sci. 49:2621-2629.

Jonasson, B.C., and R.B. Lindsay. 1988. Fall chinook salmon in the Deschutes River, Oregon. Oreg. Dep. Fish Wildl. Info. Rep. 88-6, 57 p.

Jones, R.N., and R.B. Roseburg. 1995. Adult spring chinook salmon returns to Dworshak-Kooskia NFH complex in 1995 and prognosis for 1996. U.S. Fish Wildl. Serv., 12 p.

Kaczynski, V.W., and J.F. Palmisano. 1993. Oregon's wild salmon and steelhead trout: a review of the impact of management and environmental factors. Oregon Forest Industries Council, 328 p. (Available from Oregon Forest Resources Institute, 1440 SW Third Avenue, Suite 305, Portland, Oregon 97201.)

Kaev, A.M., and V.E. Kaeva. 1987. Variability in fecundity and egg size in chum salmon, *Oncorhynchus keta*, and pink salmon, *Oncorhynchus gorbuscha*, in relation to the size-age structure of spawning populations. J. Ichthyol. 27:76-86.

Keifer, S., M. Rowe, and K. Hatch. 1992. Stock summary reports for Columbia River anadromous salmonids Volume V: Idaho. Project report. U.S. Dep. Energy, Bonneville Power Administration, Div. Fish Wildl. Project No. 88-108. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, Oregon 97208.)

Kelly, M.D., P.O. McMillan, and W.J. Wilson. 1990. North Pacific salmonid enhancement programs and genetic resources: Issues and concerns. U.S. Dept. Int., Nat. Park Serv. Tech. Rep. NPS/NRARO/NRTR-90/03, 232 p.

Kirk, S.V. 1994. Historical Information on Redwood Creek. National Park Service, U.S. Dep. Interior, 32 p.

Kissner, P.D. 1982. A study of chinook salmon in Southeast Alaska. Alaska Dep. Fish Game, Div. Sport Fish., Anadromous Fish Studies 41-10, 53 p. (Available from Alaska Department of Fish and Game, Division of Sport Fish., Juneau, AK.)

Kissner, P.D. 1985. A study of chinook salmon in Southeast Alaska. Alaska Dep. Fish Game. Anadromous Fish Studies 41-12. (Available from Alaska Department of Fish and Game, Division of Sport Fish, Juneau, AK.)

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1982. Life history of fall-run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary, California. *In* V. S. Kennedy (ed.), Estuarine Comparisons, p. 393-411. Academic Press, New York, NY.

Klamath River Basin Fisheries Task Force (KRBFTF). 1991. Long range plan for the Klamath River Basin Conservation Area Fishery Restoration Program. 339 p. + app. (Available from U.S. Fish and Wildlife Service, Klamath River Fishery Resource Office, P.O. Box 1006, Yreka, CA 96097.)

Kondzela, C.M., C.M. Guthrie, S.L. Hawkins, C.D. Russell, J.H. Helle, and A.J. Gharett. 1994. Genetic relationships among populations of chum salmon in southeastern Alaska and Northern British Columbia. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):50-64.

Konovalov, S.M. 1980. U. S. S. R. *In* J.E. Thorpe (ed.). Salmon Ranching, p. 63-89. Academic Press, New York.

Koo, T.S.Y., and A. Isarankura. 1967. Objective studies of scales of Columbia River chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). Fish. Bull. 66:165-180.

Kostow, K. 1995. Biennial Report on the Status of Wild Fish in Oregon. Oreg. Dep. Fish Wildl. Rep., 217 p. + app. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Kostow, K. 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon by K. Kostow, 23 December 1996, 9 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Kreeger, K.Y. 1995. Differences in the onset of salinity tolerance between juvenile chinook salmon from two coastal Oregon river systems. Can. J. Fish. Aquat. Sci. 52: 623-630.

Krisiansson, A.C., and J.D. McIntyre. 1976. Genetic variation in chinook salmon (*Oncorhynchus tshawytscha*) from the Columbia River and three Oregon coastal rivers. Trans. Am. Fish. Soc. 105:620-623.

Kruskal, J.B. 1964. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychrometrika 29:1-27.

Kurras, K. 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Kutkuhn, J. H. 1963. Estimating absolute age composition of California salmon landings. Calif. Dep. Fish Game, Fish Bulletin 120, 47 p. (Available from California Department of Fish and Game, Sacramento, CA.)

Kuznetzov, I.I. 1928. Some observations on spawning of the Amur and Kamchatka salmons. Bull. Pacific Scientific Fishery Research Station, Vladivostock 2:1-196.

LaVoy, L., and G. Mendel. 1996. Stock composition of fall chinook at Lower Granite Dam in 1995. Washington Department of Fish and Wildlife, Columbia River Progress Report No. 96-13.

Lawson, P.W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries 18(8):6-10.

Leach, G.C. 1924. Propagation and distribution of food fishes for the fiscal year 1923. *In* H. O'Malley (ed.), Report of the United States Commissioner of Fisheries for the fiscal year 1924. Appendix XIII, p. 108.

Leach, G.C. 1928. Propagation and distribution of food fishes for the fiscal year 1927. *In* H. O'Malley (ed.), Report of the United States Commissioner of Fisheries for the fiscal year 1927, p. 683-736.

Leach, G.C. 1932. Propagation and distribution of food fishes, 1931. *In* H. O'Malley (ed.), Report of the United States Commissioner of Fisheries for the fiscal year 1931, p. 627-696.

Leach, G.C. 1941. Propagation and distribution of food fishes, 1939. *In* H. O'Malley (ed.), Report of the United States Commissioner of Fisheries for the fiscal year 1939, p. 555-528.

Leider, S.A., P.L. Hulett, and T.H. Johnson. 1995. Preliminary assessment of genetic conservation management units for Washington steelhead. Progress report, Wash. Dep. Fish Wildl., 21 p. (Available from Washington Department of Fish and Wildlife, Fish Management Program, 600 Capital Way, Olympia, WA 98501-1091.)

Leidy, R.A., and G.R. Leidy. 1984. Life stage periodicities of anadromous salmonids in the Klamath River Basin, northwestern California. U.S. Fish Wildl. Serv., 38 p.

Leitritz, E., and R.C. Lewis. 1980. Trout and Salmon Culture. Univ. Calif., Berkeley, 197 p.

Lessa, E.P. 1990. Multidimensional analysis of geographic genetic structure. Syst. Zool. 39:242-252.

Lever, C. 1996. Naturalized Fishes of the World. Academic Press, New York, 408 p.

Levings, C.D. 1993. Requirements for genetic data on adaptations to environment and habitats of salmonids. *In* J. G. Cloud and G. H. Thorgaard (eds.), Genetic Conservation of Salmonid Fishes, p. 49-66, Plenum Press.

Levings, C.D., and R. Lauzier. 1989. Migration patterns of wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*) in the Nicola River, British Columbia. *In* B. G. Shepherd (ed.), Proceedings of the 1988 Northeast Pacific chinook and coho salmon workshop, p. 267-275. BC Ministry of Environment, 3547 Skaha Lake Road, Penticton, B.C. V2A 7K2.

Levy, D.A., and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Lewis, R.R. 1992. Coastal ecosystems. Restor. Manage. News. 10(1):18-20.

Lichatowich, J.A., and J.D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. Am. Fish. Soc. Symp.(1):131-136.

Lindsay, R.B., W.J. Knox, M.W. Flesher, B.J. Smith, E.A. Olsen, and W.S. Lutz. 1986. Study of wild spring chinook in the John Day River System. Report of the Oregon Department of Fish and Wildlife to Bonneville Power Administration.

Lindsay, R.B., J.S. Ziller, R.K. Schroeder. 1982. An ecological and fish cultural study of Deschutes River salmonids. Annual progress report of the Oregon Department of Fish and Wildlife. Fish Research Project F-88-R-13, 32 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Lindsay, R.C., B.C. Jonasson, R.K. Schroeder, and B.C. Cates. 1989. Spring chinook in the Deschutes River, Oregon. Oreg. Dep. Fish Wildl. No. 89-4, 92 p.

Lindsey, C.C., and J.D. McPhail. 1986. Zoogeography of fishes of the Yukon and Mackenzie Basins. *In* C.H. Hocutt and E.O. Wiley (eds.), The zoogeography of North American freshwater fishes, p. 639-674. Wiley Interscience Publication, New York.

Linley, T.J. 1993. Patterns of life history variation among sockeye salmon (*Oncorhynchus nerka*) in the Fraser River, British Columbia. Thesis, Univ. Wash., Seattle, WA, 162 p.

Lister, D.B. 1990. Egg size and fecundity as indicators of life-history patterns in southern British Columbia chinook stocks. *In* T.J. Hassler (ed.), Northeast Pacific chinook and coho salmon workshops and proceedings, p. 393-411, Humbolt State University, Arata, CA.

Lister, D.B., C.E. Walker, and M.A. Giles. 1971. Cowichan River chinook salmon escapements and juvenile production 1965-1967. Can. Fish. Serv. 1971-3, 8 p.

Lummi Indian Business Council, (LIBC). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon. M. Jefferson, 11 January 1997, 3 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Mahnken, C., G. Ruggerone, W. Waknitz, and T. Flagg. In press. A Historical Perspective on Salmonid Production from Pacific Rim Hatcheries. Proceedings of the NPAFC, Bulletin No.1, "Assessment and Status of Pacific Rim Salmonid Stocks."

Major, R.L., and J.L. Mighell. 1969. Egg-to-migrant survival of spring chinook salmon (*Oncorhynchus tshawytscha*) in the Yakima River, Washington. Fish. Bull. 67:347-359.

Manzon, C.I., and D.E. Marshall. 1980. Catalogue of salmon streams and spawning escapements of Statistical Area 8. Can. Data Rep. Fish. Aquat. Sci. 1980:1980.

Marshall, A.R., C. Smith, R. Brix, W. Dammers, J. Hymer, and L. LaVoy. 1995. Genetic diversity units and major ancestral lineages for chinook salmon in Washington. *In* C. Busack and J. B. Shaklee (eds.), Genetic diversity units and major ancestral lineages of salmonid fishes in Washington, p. 111-173. Wash. Dep. Fish Wildl. Tech. Rep. RAD 95-02. (Available from Washington Department of Fish and Wildlife, 600 Capital Way N., Olympia WA 98501-1091.)

Mathews, S.B., and T.K. Meekin. 1971. Fecundity of fall chinook salmon from the upper Columbia River. Wash. Dep. Fish. Tech. Rep. 6, 29-37 p. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, Washington, 98501-1091.)

Matthews, G.M., and R.S. Waples. 1991. Status review for Snake River spring and summer chinook salmon. NOAA Tech. Memo. NMFS F/NWC-200, 75 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Mattson, C.R. 1948. Spawning ground studies of Willamette River spring chinook salmon. Fish Comm. Oreg. 1(2):21-32.

Mattson, C.R. 1955. Sandy River and its anadromous salmonids. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Mattson, C.R. 1962. Early life history of Willamette river spring chinook salmon. Fish Comm. Oreg., 50 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Mattson, C.R. 1963. An investigation of adult spring chinook salmon of the Willamette River system. Fish Comm. Oreg. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Mayhall, L.E. 1925. Review of hatchery operations in Washington. Thirty-Fourth and Thirty-Fifth annual reports of the State Supervisors of Fisheries, 17-32 p. (Available from Washington Department of Fish and Wildlife, 600 Capital Way N., Olympia, WA 98501-1091.)

McBride, D.N., H.H. Hamner, and L.S. Buklis. 1983. Age, sex, and size of Yukon River salmon catch and escapement, 1982. Alaska Dep. Fish Game. No. 90, 1-141 p. (Available from Alaska Department of Fish and Game, CFMD Division - Publications Section, P.O. Box 25526, Juneau, AK 99802-5526.)

McDowall, R.M. 1994. The origin of New Zealand's chinook salmon, *Oncorhynchus tshawytscha*. Mar. Fish. Rev. 56:1-7.

McGie, A.M. 1980. Analysis of relationships between hatchery coho salmon transplants and adult escapement in Oregon coastal watersheds. Oreg. Dep. Fish Wildl. Info. Rep. 80-6, Portland, OR. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

McGregor, E.A. 1922. Observations of the egg yield of Klamath River king salmon. Calif. Fish Game 8:161-164.

McGregor, E.A. 1923a. A possible separation of the river races of king salmon in ocean-caught fish by means of anatomical characters. Calif. Fish Game 9:138-150.

McGregor, E.A. 1923b. Notes on the egg yield of Sacramento River king salmon. Calif. Fish Game 9:134-138.

McIsaac, D.O. 1990. Factors affecting the abundance of 1977-1979 brood wild fall chinook salmon (*Oncorhynchus tshawytscha*) in the Lewis River, Washington. Ph.D. Dissertation, Univ. Wash., Seattle, WA.

McIsaac, D.O., and T.P. Quinn. 1988. Evidence for a hereditary component in homing behavior of chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 45:2201-2205.

McLain, D.R. 1984. Coastal ocean warming in the Northeast Pacific, 1976-1983. *In* W. G. Pearcy (ed.), The influence of ocean conditions on the production of salmonids in the North Pacific, p. 61-86. Oreg. State Univ. Sea Grant, Corvallis, Oregon.

McLeod, D. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: data for southern Oregon and northern California coastal rivers.

(Available from Environmental and Technical Services Division, National Marine Fisheries Service, 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

McNair, M. 1996. Alaska fisheries enhancement program 1995 annual report. Alaska Dept. Fish Game Reg. Info. Rep. 5J96-08, 43 p.

McNeil, W.J. 1977. Artificial recruitment of Pacific salmon in Japan, Republic of Korea, and the Soviet Union. NWAFC Processed Report, January, 1977. (Available from Northwest Fisheries Science Center, Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.)

McPhail, J.D., and C.C. Lindsey. 1970. Freshwater fishes of Northwestern Canada and Alaska. Bull. Fish. Res. Board Can. 173:381.

McPhail, J.D., and C.C. Lindsey. 1986. Zoogeography of freshwater fishes Cascadia (the Columbia Sytem and river north to the Stikine). *In* C. H. Hocutt and E. O. Wiley (eds.), The zoogeography of North American Freshwater Fishes, p. 615-637. Wiley Interscience Publication, New York.

Meehan, W.R., and D.B. Sniff. 1962. A study of downstream migrations of anadromous fishes in the Taku River, Alaska. Trans. Am. Fish. Soc. 91:399-407.

Mendel, G., J. Bumgarner, D. Milks, L. Ross, and J. Dedloff. 1996. Lyons Ferry Hatchery evaluation: fall chinook. Washington Department of Fish and Wildlife Report, H96-09, 60 p. (Available from Washington Department of Fish and Wildlife, 600 Capital Way N., Olympia, WA 98501-1091.)

Mighetto, L., and W.J. Ebel. 1994. Saving the Salmon: a history of the U. S. Army Corps of Engineers' efforts to protect anadromous fish in the Columbia and Snake rivers. Historical Research Associates, Seattle, WA, 262 p. + app. (Available from Historical Research Associates Inc., 119 Pine St., Suite 207, Seattle, WA 98101.)

Miller, R.J., and E.L. Brannon. 1982. The origin and development of life-history patterns in Pacific salmon. *In* E.L. Brannon and E.O. Salo (eds.), Proceedings of the Salmon and Trout Migratory Behavior Symposium, p. 296-309. Univ. Wash. Press, Seattle, WA.

Miller, W.H., T.C. Coley, H.L. Burge, and T.T. Kisanuki. 1990. Part 2: emphasis on unpublished reports and present programs. *In* W. H. Miller (preparer), Analysis of Salmon and Steelhead Supplementation. Final Report (Project 88-100) to the Bonneville Power Administration. (Available from Bonneville Power Administration, Division of Fish and Wildlife, Public Information Officer - PJ, P.O. Box 3621, Portland, OR 97208.)

Milner, A.M., and R.G. Bailey. 1989. Salmonid colonization of new streams in Glacier Bay National Park, Alaska. Aquacult. Fish. Manage. 20:179-192.

Mitchell, W.T. 1987. Evaluation of the frequency and duration of exposure of downstream migrant chinook salmon to high water temperatures in the Sacramento River. Prepared for the California Department of Water Resources, DWR 563. D.W. Kelley and Associates, Newcastle, CA, 10 p.

Moffett, J.W. 1949. The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California. Calif. Fish Game 35:77-102.

Moffett, J.W., and S.H. Smith. 1950. Biological investigations of the fishery resources of Trinity River, California. U.S. Fish Wildl. Spec. Sci. Rep. Fish. 12, 71 p.

Moffit, S.D., C. Rich, and J.A. Wilcock. 1994. Salmon catch and escapement statistics for Copper River, Bering River, and Prince William Sound, 1990. Alaska Dept. of Fish and Game, Technical Fishery Report 94-08, 164 p. (Available from Alaska Dept. of Fish and Game, P.O. Box 25526, Juneau, AK 99802-5526.)

Moore, K. and K. Jones. 1997. Assessment of 1996 flood impacts: Channel morphology and fish habitat. Oreg. Dep. Fish Wildl., Research Sect., Draft Report, 16 p.

Moore, M., K. McLeod, and D. Reed. 1960. Fisheries, fish farming, fisheries management. Wash. Dep. Fish., Olympia, 349 p.

Mosser, D. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: questionaire response and additional data for the Little River. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Mullan, J.W. 1987. Status and propagation of chinook salmon in the mid-Columbia River through 1985. U.S. Fish Wildl. Serv. Biol. Rep. 87:111.

Mullan, J.W., A. Rockhold, and C.R. Chrisman. 1992. Life histories and precocity of chinook salmon in the mid-Columiba River. Prog. Fish-Cult. 54:25-28.

Myers, K.W., C.K. Harris, C.M. Knudsen, R.V. Walker, N.D. Davis, and D.E. Rogers. 1987. Stock origins of chinook salmon in the area of the Japanese mothership salmon fishery. N. Am. J. Fish. Manage. 7:459-474.

Myers, K.W., D.E. Rogers, C.K. Harris, C.M. Knudsen, R.V. Walker, and N.D. Davis. 1984. Origins of chinook salmon in the area of the Japanese mothership and landbased driftnet salmon fisheries in 1975-1981. Fisheries Research Institute, 204 p. (Available from Fisheries Research Institute, University of Washington, Seattle, WA 98195.)

National Marine Fisheries Service (NMFS). 1987. Endangered and threatened species; winter-run chinook salmon. Federal Register [Docket No. 27 Febuary 1986] 52(39):6041-6048.

National Marine Fisheries Service (NMFS). 1988. Endangered and threatened species; winter-run chinook salmon. Federal Register [December 8, 1988 - 49722] Vol 53(237).

National Marine Fisheries Service (NMFS). 1989. Endangered and threatened species; critical habitat; winter-run chinook salmon. Federal Register [Docket No. 90778-9178] 54(149):32085-32088.

National Marine Fisheries Service (NMFS). 1990a. Endangered and threatened species; winter-run chinook salmon. Federal Register [Docket No. 90778-0079] 55(63):12191-12193.

National Marine Fisheries Service (NMFS). 1990b. Endangered and threatened species; Sacramento River winter-run chinook salmon. Federal Register [Docket No. 90778-0275, 5 November 1990] 55(214):46515-46523.

National Marine Fisheries Service (NMFS). 1991. Policy of applying the definition of species under the Endangered Species Act to Pacific salmon. Federal Register [Docket No. 9120248-1255, 20 November 1991] 56(224):58612-58616.

National Marine Fisheries Service (NMFS). 1992. Endangered and threatened species; threatened status for Snake River spring/summer chinook salmon, threatened status for Snake River fall chinook salmon. Federal Register [Docket No. 910647-2043, 22 April 1992] 57(78):14653-14662.

National Marine Fisheries Service (NMFS). 1993. Interim policy on artificial propagation of Pacific salmon under the Endangered Species Act. Federal Register [Docket No. 921186-2286, 5 April 1993] 58(63):17573-17576.

National Marine Fisheries Service (NMFS). 1994a. Endangered and threatened species; Mid-Columbia River summer chinook salmon. Federal Register [Docket No. 940947-4247, 23 September 1994] 59(184):48855-48859.

National Marine Fisheries Service (NMFS). 1994b. Endangered and threatened species: Status of Sacramento River winter-run chinook salmon. Federal Register [Docket No. 930779-930779-3330; I.D. 051192B January 4, 1994] 59(2):440-450.

National Marine Fisheries Service (NMFS). 1994c. Endangered and threatened species; status of Snake River spring/summer chinook salmon and Snake River fall chinook salmon.

Emergency interim rule. Federal Register [Docket No. 940822-4222 I.D. 07594B, 18 August 1994].

National Marine Fisheries Service (NMFS). 1994d. Listing endangered and threatened species and designating critical habitat: Initiation of status reviews for pink salmon, chum salmon, chinook salmon, and sea-run cutthroat trout populations in Washington, Oregon, Idaho, and California. Federal Register [I.D. 081694D, 12 September 1994] 59(175):46808-46810.

National Marine Fisheries Service (NMFS). 1995a. Endangered and threatened species; status of Snake River spring/summer chinook salmon and Snake River fall chinook salmon. Final Rule. Federal Register [Docket No. 950412102-5102-01; I.D. 072594B] 60(73): 19341-19342.

National Marine Fisheries Service (NMFS). 1995b. Proposed recovery plan for Snake River Salmon. 364 p. + app. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

National Marine Fisheries Service (NMFS). 1996a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Harmon, January 1996. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

National Marine Fisheries Service (NMFS). 1996b. Factors for decline: A supplement to the Notice of Determination for West Coast Steelhead under the Endangered Species Act. NMFS Protected Species Branch, Portland, OR, 82 p. + app.

National Marine Fisheries Service (NMFS). 1996c. Recommendations for the recovery of the Sacramento River winter-run chinook salmon. NMFS Southwest Region, Long Beach, CA, 228 p. + app.

National Marine Fisheries Service (NMFS). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon by M. Dahlberg, 12 February 1997, 4 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Portland, OR 97232.)

National Research Council Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (NRCC). 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington, DC, 452 p.

Natural Resources Consultants (NRC). 1996. Artificial propagation of anadromous Pacific salmonids, 1950 to present. Chinook salmon. Contract report to U.S. Dept Comm., NOAA, NMFS, February 1996. Includes electronic database. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Portland, OR 97232.)

Neave, F. 1958. The origin and speciation of *Oncorhynchus*. Trans. Royal Soc. Can. 52:25-39.

Needham, P.R., O.R. Smith, and H.A. Hanson. 1940. Salmon salvage problems in relation to Shasta Dam, California, and notes on the biology of the Sacramento River salmon. Trans. Am. Fish. Soc. 70:55-69.

Nehlsen, W. 1995. Historical salmon and steelhead runs of the upper Deschutes River and their environments, 65 p. (Available from Portland General Electric Company, Hydro Licensing Department, Attn: Mary May, 3WTCR04, 121 SW Salmon St, Portland, OR 97204.)

Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Nei, M. 1972. Genetic distance between populations. Am. Nat. 106:283-292.

Nei, M. 1973. Analysis of gene diversity in subdivided populations. Proc. Nat. Acad. Sci. U.S. 70:3321-3323.

Nei, M. 1978. Estimation of average heterozygosity and genetic distance from a small number of individuals. Genetics 89:583-590.

Neillands, G.W. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: responses to questionnaires for the Merced, San Joaquin, Stanislaus, and Tuolumne Rivers. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Nelson, K., and M. Soulé. 1987. Genetical conservation of exploited fishes. *In* N. Ryman and F. Utter (eds.), Population genetics & fishery management, p. 345-368. University of Washington Press, Seattle, WA.

Nelson, W.R., and J. Bodle. 1990. Ninety years of salmon culture at the Little White Salmon National Fish Hatchery. U.S. Fish Wildl. Serv. Biol. Rep. 90:22.

Netboy, A. 1958. Salmon of the Pacific Northwest. Fish vs. Dams. Binfords & Mort, Portland, OR, 119 p.

Nicholas, J. 1995. Status of Willamette spring-run chinook salmon relative to Federal Endangered Species Act. Report to the Natl. Mar. Fish. Serv. Oreg. Dep. Wildl., 44 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Nicholas, J.W., and D.G. Hankin. 1988. Chinook salmon populations in Oregon coastal river basins: Description of life histories and assessment of recent trends in run strengths. Oreg. Dep. Fish Wildl., Fish. Div. Info. Rep., No. 88-1, 359 p.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D. H. Peterson. 1986. The modification of an estuary. Science 231:567-573.

Nickelson, T.E., J.W. Nicholas, A.M. McGie, R.B. Lindsay, D.L. Bottom, R.J. Kaiser, and S.E. Jacobs. 1992. Status of anadromous salmonids in Oregon coastal basins. Oreg. Dep. Fish Wildl., Research and Development Section and Ocean Salmon Management. Unpubl. manuscr., 83 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207.)

Nielsen, J. 1997. Mitochondrial DNA and nuclear microsatellite polymorphisms in chinook salmon from the Sacramento-San Joaquin Basin 1991-1995. Report to California Division of Fish and Game, 29 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth St., Sacramento, CA 95814.)

Nielsen, J.L. 1995. Mitochondrial DNA frequency distributions in chinook salmon from the Sacramento-San Joaquin Basin and Guadalupe River 1992-1994. Hopkins Marine Station, Stanford University.

Nielson, J.L., C. Gan, and W.K. Thomas. 1994. Differences in genetic diversity for mitochondrial DNA between hatchery and wild populations of *Oncorhynchus*. Can. J. Fish. Aquat. Sci. 51:290-297.

Nooksack Technical Group (NTG). [1987]. Nooksack River spring chinook report. 101 p. Unpublished draft. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Northwest Indian Fisheries Commission (NWIFC). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Anderson, 7 February 1997, 22 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Northwest Indian Fisheries Commission (NWIFC). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by M. Messenger, 19 September

1997, 1 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Olsen, D.E. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon on November 3, 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Olsen, M.A. 1992. Abundance, age, sex, and size of chinook salmon catches and escapement in Southeast Alaska in 1987. Alaska Dep. Fish Game Tech. Fish. Rep. 92-07, 126 p. (Available from Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 25526, Juneau, AK 99802-5526.)

Olsen, E., P. Pierce, M. McLean, and K. Hatch. 1992. Stock Summary Reports for Columbia River Anadromous Salmonids Volume I: Oregon. U.S. Dep. Energy., Bonneville Power Administration. Project No. 88-108. (Available from Bonneville Power Administration, Division of Fish and Wildlife, Public Information Officer - PJ, P.O. Box 3621, Portland, OR 97208.)

Olsen, E.A., P.M.P. Beamesderfer, M.L. McLean, and E.S. Tinus. 1994a. Salmon and steelhead stock summaries for the Deschutes River Basin: an interim report. Oreg. Dep. Fish Wildl., 204 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Olsen, E.A., P.M.P. Beamesderfer, M.L. McLean, and E.S. Tinus. 1994b. Salmon and steelhead stock summaries for the Grande Ronde Basin: an interim report. Oreg. Dep. Fish Wildl. Proj. Rep. 88-108, 132 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Olsen, E.A., P.M.P. Beamesderfer, M.L. McLean, and E.S. Tinus. 1994c. Salmon and steelhead stock summaries for the Imnaha River Basin: an interim report. Oreg. Dep. Fish Wildl. Proj. Rep. 88-108, 93 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Olsen, E.A., P.M.P. Beamesderfer, M.L. McLean, and E.S. Tinus. 1994d. Salmon and steelhead stock summaries for the John Day River Basin: an interim report. Oreg. Dep. Fish Wildl. Proj. Rep. 88-108, 66 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Ann. Assoc. Am. Geographers 77:118-125.

Omernik, J.M., and A.L. Gallant. 1986. Ecoregions of the Pacific Northwest. U.S. Environ. Protec. Agen. Rep. EA/600/3-86/033, 39 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Oregon Department of Fish and Wildlife (ODFW). 1954. Annual report. Fishery Division 1954. Oreg. State Game Comm., 184 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Oregon Department of Fish and Wildlife (ODFW). 1990. Effects of Lost Creek Dam on the distribution and time of chinook salmon spawning in the Rogue River upstream of Gold Ray Dam. Oreg. Dep. Fish Wildl., 39 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Street, P.O. Box 59, Portland, OR 97207.)

Oregon Department of Fish and Wildlife (ODFW). 1991. Documents submitted to the ESA Administrative Record for Snake River fall chinook salmon. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1993. Oregon salmon and steelhead catch data, 1980-92. Oreg. Dep. Fish Wildl., Fish Div., 22 p.

Oregon Department of Fish and Wildlife (ODFW). 1995. Letter to M. Schiewe regarding west coast chinook salmon status review by D. McIsaac, 9 October 1997, 9 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by R. Berry, 17 January 1997, 5 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Swartz, 23 April 1997, 10 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1997c. Documents submitted to the ESA Administrative Record for west coast chinook salmon by K. Braun, 18 September 1997, 10 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1997d. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Liscia, 19 September 1997, 1 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). 1997e. Electronic data and documents submitted to the ESA Administrative Record for west coast chinook salmon by S. Jacobs, 16 and 19 September 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Oregon Department of Fish and Wildlife (ODFW). Unpublished. Details of egg and fry for Oregon hatcheries. Preliminary report for brood year 1993, 94, and 95. 3 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Avenue, PO Box 59, Portland, OR 97207.)

Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW). 1995. Status report: Columbia River fish runs and fisheries 1938-94. Oreg. Dep. Fish Wildl., Wash. Dep. Fish Wildl., 291 p.

Oregon Natural Resources Council (ONRC), and R.K. Nawa. 1995. Petition for a rule to list chinook salmon as threatened or endangered under the endangered Speices Act and to designate critical habitat. Unpublished manuscr., 319 p. (Available from Oregon Natural Resources Council, 522 SW 5th, Suite 1050, Portland, OR 97204.)

Orrell, R. 1976. Skagit chinook race differentiation study. NMFS Proj. Rep. 1-98-R, 53 p. (Available from Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98122.)

Orsi, J.A., and Jaenicke, H.W. 1996. Marine distribution and origin of prerecruit chinook salmon, *Oncorhynchus tshawytscha*, in southeastern Alaska. Fish. Bulletin 94(3):482-497.

Pacific Fishery Management Council (PFMC). 1994. Klamath River fall chinook report: An assessment of the status of the Klamath River fall chinook stock as required under the salmon fishery management plan. Pacific Fishery Management Council, 20 p. + app. (Available from Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.)

Pacific Fishery Management Council (PFMC). 1995. Vital habitat concerns. Pacific Fishery Management Council, Portland, OR, 19 p. + app. (Available from Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.)

Pacific Fishery Management Council (PFMC). 1996a. Preseason report I: Stock abundance analysis for 1996 ocean salmon fisheries. Pacific Fishery Management Council, 50 p. + app. (Available from Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.)

Pacific Fishery Management Council (PFMC). 1996b. Review of the 1995 ocean salmon fisheries. Pacific Fishery Management Council, 115 p. + app. (Available from Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.)

Pacific Fishery Management Council (PFMC). 1997. Review of the 1996 ocean salmon fisheries. PFMC, 275 p. (Available from Pacific Fishery Management Council, 2130 SW Fifth Ave., Suite 224, Portland, OR 97201.)

Pacific Northwest River Basins Commission (PNRBC). 1969. Columbia-North Pacific region comprehensive framework study of water and related lands. Appendix II. The Region. Pacific Northwest River Basins Commission, 147 p. (Available from Pacific Northwest River Basins Commission, 1 Columbia River, Vancouver, Washington..)

Pacific Salmon Commission (PSC). 1994. Pacific Salmon Commission Joint Chinook Technical Committee 1993 annual report. Pacific Salmon Commission. Report Chinook (94)-1, 121 p. + app. (Available from Pacific Salmon Commission, 600-1155 Robson St., Vancouver, B.C. V6E 1B5.)

Pacific Salmon Commission (PSC). 1996. Pacific Salmon Commission Joint Chinook Technical Committee 1994 annual report. (96)-1, 65 p. + app. (Available from Pacific Salmon Commission, 600-1155 Robson St., Vancouver, B.C. V6E 1B5.)

Pacific States Marine Fisheries Commission (PSMFC). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by G. Christofferson, 9 June 1997, 4 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Pacific States Marine Fisheries Commission (PSMFC). 1997b. Streamnet Microsoft Access computerized database submitted to the ESA Administrative Record for west coast chinook salmon by D. Anderson, May 1997. (Available from Pacific States Marine Fisheries Commission, 45 SE 82nd Drive, Suite 100, Gladstone, OR 97027.)

Pacific Watershed Associates. Undated. Post-storm aerial reconnaissance of the middle Oregon Cascades and middle Coast Range. Preliminary executive summary, 5 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Page, W.H. 1888. The most recent methods of hatching fish eggs. Bull. U.S. Fish Comm. 8:207-218.

Pascual, M.A., and T.P. Quinn. 1994. Homing and straying in salmon. Aquacult. Fish. Manage. 25:17-30.

Pearcy, W. 1992. Ocean ecology of North Pacific salmonids. Univ. Wash. Press, Seattle, WA.

Peven, C.M. 1994. Spring and summer chinook spawning ground surveys on the Wenatchee River basin, 1993. Chelan Co. PUD, Fish Wildl. Oper., 30 p. + app. (Available from Chelan Co. PUD, Fish Wild. Opert., P.O. Box 1321, Wenatchee, WA 98801.)

Peven, C.M. and T.R. Mosey. 1996. Spring and summer chinook spawning ground surveys on the Wenatchee River Basin, 1996. Chelan County Public Utility District. 29 p. + app. (Available from Chelan Co. PUD, Fish Wild. Oper., P.O. Box 1321, Wenatchee, WA 98801.)

Peven, C.M., and K.B. Truscott. 1995. Spring and summer chinook spawning ground surveys on the Wenatchee River basin, 1994. Chelan County Public Utility District. 30 p. + app. (Available from Chelan Co. PUD, Fish Wild. Oper., P.O. Box 1321, Wenatchee, WA 98801.)

Phelps, S.R., L.L. LeClair, S. Young, and H.L. Blankenship. 1994. Chum salmon genetic diversity patterns in Washington and southern British Columbia. Can. J. Fish. Aquat. Sci. 51:65-83.

Pisano, M. 1993. Final performance report. Salmon and steelhead research, management and enhancement project: Study 2. Klamath River project. Report submitted to NMFS, Southwest Region. Project No: NA26FA0244-01, 20 p.

Pisano, M. 1995. Final performance report: Salmon and steelhead research, management and enhancement project, Klamath River Project, July 1, 1994-June 30, 1995. U.S. Fish Wildl. Serv. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Pisarevsky, G. 1978. How the USSR improves on nature and spreads salmon from the Pacific to the Arctic. Russian ranching: billion fry is far east target. Fish. News Int. 17(9): 22-23.

Point No Point Treaty Council (PNPTC). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by N. Lampsakis, September 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Professional Resource Organization-Salmon (PRO-Salmon). 1994. Petition for a rule to list nine Puget Sound salmon populations as threatened or endangered under the Endangered Species Act and to designate critical habitat. Unpublished manuscr., 86 p. (Available from PRO-Salmon, Washington Public Employees Association, 124 10th Ave. S.W., Olympia, WA 98501.)

Puget Sound Salmon Stock Review Group (PSSSRG). 1997. An assessment of the status of Puget Sound chinook and Strait of Juan de Fuca coho stocks as required under the Salmon Fishery Management Plan. Pacific Fishery Management Council Review Draft, 78 p. (Available from the Pacific Fishery Management Council, 2130 Fifth Ave, Ste. 224, Portland, OR 97201.)

Quileute Tribe Natural Resources (QTNR). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by S. Haymes, October 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Quinault Fisheries Division (QFD). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by S. Chitwood, October 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Quinn, T.P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fish. Res. 18:29-44.

Quinn, T.P., and S. Bloomberg. 1992. Fecundity of chinook salmon (*Oncorhynchus tshawytscha*) from the Waitaki and Rakaia rivers, New Zealand. New Z. J. Mar. and Freshwater Res. 26:429-434.

Quinn, T.P., and K. Fresh. 1984. Homing and straying in chinook salmon (*Oncorhynchus tshawytscha*) from Cowilitz River Hatchery, Washington. Can. J. Fish. Aquat. Sci. 41:1078-1082.

Quinn, T.P., R.S. Nemeth, and D.O. McIsaac. 1991. Homing and straying patterns of fall chinook salmon in the lower Columbia River. Trans. Am. Fish. Soc. 120:150-156.

Randall, R.G., M.C. Healey, and J.B. Dempson. 1987. Variability in length of freshwater residence of salmon, trout, and char. Am. Fish. Soc. Symp. 1:27-41.

Ratner, S., R. Lande, and B.B. Roper. 1997. Population viability analysis of spring chinook salmon in the South Umpqua River, Oregon. Conserv. Biol. 11:879-889.

Ravenel, W. de C. 1899. Report on the propagation and distribution of food-fishes. *In* U.S. Commissioner of Fish and Fisheries (ed.), Report of the Commissioner of Fisheries for the year ending June 30, 1898, p. 6-72.

Reavis, R. 1984. Annual report: Chinook salmon spawning stocks in California's central valley, 1983. Draft. Calif. Dep. Fish Game, Anadromous Fisheries Branch Administrative Report, 38 p.

Reavis, R. 1985. Annual report: Chinook salmon spawning stocks in California's central valley, 1984. Draft. Calif. Dep. Fish Game, Anadromous Fisheries Branch Administrative Report, 51 p.

Refalt, W. 1985. Wetland in extremis: A nationwide survey. Wilderness Winter 1985:28-41.

Reimers, P.E. 1971. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Ph.D., Oreg. State Univ., Corvallis, OR, 99 p.

Reimers, P.E. 1973. The length of residence of juvenile fall chinook salmon in the Sixes River, Oregon. Oreg. Fish Comm. 4, 2-43 p.

Reimers, P.E., and R.E. Loeffel. 1967. The length of residence of juvenile fall chinook salmon in selected Columbia River tributaries. Fish Comm. Oreg. 13, 5-19 p.

Reisenbichler, R.R. 1986. Use of spawner-recruit relations to evaluate the effect of degraded environment and increased fishing on the abundance of fall-run chinook salmon, *Oncorhynchus tshawytscha*, in several California streams. Thesis, Univ. Wash., Seattle, WA, 175 p.

Reisenbichler, R.R. 1997. Genetic factors contributing to declines of anadromous salmonids in the Pacific Northwest. *In* D.J. Stouder, P.A. Bisson, and R.J. Naiman (eds.), Pacific salmon & their ecosystems: status and future options, p. 223-244. Chapman Hall, New York.

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steel head trout, *Salmo gairdneri*. J. Fish. Res. Board Can. 34:123-128.

Reisenbichler, R.R., and S.R. Phelps. 1987. Genetic variation in chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, from the north coast of Washington. Fish. Bull., U.S. 85:681-701.

Reynolds, F.L., T.J. Mills, R. Benthin, and A. Low. 1993. Restoring central valley streams: A plan for action. Calif. Dep. Fish Game, Sacramento, CA, 184 p.

Rich, W.H. 1920a. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. U.S. Bur. Fish., Bull. 37:74.

Rich, W.H. 1920b. Racial differences in salmon. Unpublished manuscript, 8 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Rich, W.H. 1921. The relative maturity of the chinook salmon taken in the ocean along the Pacific coast. Calif. Fish Game 7:13-22.

Rich, W.H. 1925. Growth and degree of maturity of chinook salmon in the ocean. U.S. Bur. Fish., Bull. 41:15-89.

Rich, W.H. 1940a. The future of the Columbia River salmon fisheries. Stanford Icthyol. Bull. 2:37-47.

Rich, W.H. 1940b. Seasonal variations in weight of Columbia River chinook salmon. Copeia. 1: 34-43.

Rich, W.H., and H.B. Holmes. 1928. Experiments in marking young chinook salmon on the Columbia River 1916 to 1927. U.S. Bur. Fish., Bull. 44:215-264.

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. MacMillan Lectures in Fisheries, p. 27-160. Univ. B.C., Vancouver, B.C.

Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. Can. J. Fish. Aquat. Sci. 38:1636-1656.

Riggs, L.A. 1990. Principles for genetic conservation and production quality. Report to Northwest Power Planning Council. GENREC/Genetic Resource Consulting, Berkeley, CA.

Rivers, C.M. 1963. Rogue River fisheres, volume 1: History and development of the Rogue River Basin as related to its fishery prior to 1941. Oreg. State Game Comm. Portland, OR. Unpubl. manuscr., 264 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Roff, D.A., and P. Bentzen. 1989. The statistical analysis of mitochondrial DNA polymorphisms: C^2 and the problem of small samples. Mol. Biol. Evol. 6:539-545.

Rogers, J.S. 1972. Measures of genetic similarity and genetic distance. Studies in Genetics VII. Univ. Tex. Publication 7213:145-153.

Rogers, J.S. 1991. A comparison of the suitability of the Rogers, modified Rogers, Manhattan, and Cavalli-Sforza and Edwards distances for inferring phylogenetic trees from allele frequencies. Syst. Zool. 40:63-73.

Roni, P. 1992. Life history and spawning habitat in four stocks of large-bodied chinook salmon (*Oncorhynchus tshawytscha*.) M.S. Thesis, Univ. Wash., Seattle, WA, 96 p.

Roni, P., and T.P. Quinn. 1995. Geographic variation in size and age of North American chinook salmon. N. Am. J. Fish. Manage. 15:325-345.

Roppel, P. 1982. Alaska's Salmon Hatcheries, 1891-1959. Alaska Historical Commission Studies in History No. 20. Alaska Historical Commission, Juneau, 299 p.

Roseburg, R.B. 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon: Dworshak spring chinook salmon egg size. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Rutter, C. 1904. Natural history of the quinnat salmon. Investigation on Sacramento River, 1896-1901. Bull. U.S. Fish Comm. 22: 65-141.

Ryman, N. 1983. Patterns of distribution of biochemical genetic variation in salmonids: Differences between species. Aquaculture 33:1-21.

Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective populations size. Conserv. Biol. 5:325-329.

Saitou, N, and M. Nei. 1987. The neighbor-joining method: a new method for reconstructing phylogenetic trees. Mol. Biol. Evol. 4:406-425.

Sankovich, P., and M.L. Keefe. 1996. Salmon exhibit alternative life styles. Fish News and Views 2(1):7.

Schaller, H.A., C.E. Petrosky, and O.P. Langness. 1996. Contrasts in stock-recruitment patterns of Snake and Columbia River spring and summer chinook populations. *In* D.R. Marmorek (ed.), Plan for analyzing and testing hypotheses (PATH): Final report on retrospective analyses for fiscal year 1996, Chapter 3, p. 1-24. (Available from ESSA Technologies Ltd., Vancouver, B.C.)

Schluchter, M.D., and J.A. Lichatowich. 1977. Juvenile life histories of Rogue River spring chinook salmon *Oncorhynchus tshawytscha* (Walbaum), as determined by scale analysis. Oregon Dept. of Fish Wildl. Info. Rep. Fish. 77-5, 24 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Street, P.O. Box 59, Portland, OR 97207.)

Schneirderhan, D.J. 1993. Origins of chinook salmon in the Yukon River fisheries, 1990. Alaska Dep. Fish Game, Tech. Fish. Rep. 92-11, 34 p. (Available from Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 25526, Juneau, AK 99802-5526.)

Schreck, C.B., H.W. Li, C.S. Sharpe, K.P. Currens, P.L. Hulett, S.L. Stone, and S.B. Yamada. 1986. Stock identification of Columbia River chinook salmon and steelhead trout. U.S. Dep. Energy, Bonneville Power Administration. Project No. 83-45, 184 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, Public Information Officer-PJ, P.O. Box 3621, Portland, OR 97208.)

Schubert, N.D., M.K. Farwell, and L.W. Kalnin. 1993. Enumeration of the 1992 Harrison River chinook salmon escapement. Dep. Fish. Oceans., Can. Manusc. Rep., Fish. Aquat. Sci. 2200, 33 p.

Sedell, J.R., and J.L. Froggatt. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S. from its flood plain by snagging and streamside forest removal. Int. Ver. Theo. Angew. Limnol. Verh. 22:1828-1834.

Seiler, D., P. Hanratty, S. Neuhauser, P. Topping, M. Ackley, and L. E. Kishimoto. 1995. Wild salmon production and survival evaluation. U.S. Fish Wildl. Serv., Prog. Rep. F-112-R-2, 113 p. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA, 98501-1091.)

Shebley, W.H. 1915. Hatchery and fishery notes. Calif. Fish Game 3:187-189.

Shebley, W.H. 1922. A history of fishcultural [sic] operations in California. Calif. Fish Game 8:62-98.

Shepard, M.P., C.D. Shepard, and A.W. Argue. 1985. Historical statistics of salmon production around the Pacific Rim. Can. Manusc. Rep. Fish. Aquat. Sci. No. 1819, 303 p.

Shepherd, B.G., J.E. Hillaby, and R.J. Hutton. 1986. Studies on Pacific salmon (*Oncorhynchus* spp.) in phase I of the salmonid enhancement program. Volume II: Data Appendices. Can. Tech. Rep. Fish. Aqaut. Sci. 1482:1-180.

Simon, R.C., J.D. McIntyre, and A.R. Hemingsen. 1986. Family size and effective population size in a hatchery stock of coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 43:2434-2442.

Siuslaw National Forest. 1996. '96 Floods. A workshop on watershed restoration presented by Siuslaw National Forest, Feb. 4, 1997, Corvalis Public Library, 7 p.

Skagit Cooperative Council (SCC). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by R. Hayman, October 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Skaugstad, C., and B. McKracken. 1991. Fecundity of chinook salmon, Tanana River, Alaska. Alaska Dep. Fish Game. 91-8, 23 p.

Slater, D.W. 1963. Winter-run chinook salmon in the Sacramento River, California, with notes on water temperature requirements at spawning. Fish Wildlife Service Special Science Report Fisheries 461:9.

Smirnov, A.I. 1975. Biologiya, razmozhenie i razivitie tikhookikh lososei. [The biology, reproduction and development of the Pacific Salmon.] Izd. Mosk. Univ., 333 p. [Fisheries and Marine Service Translation No. 3861.] Department of the Environment, Fisheries and Marine Service, Pacific Biological Station, Nanaimo, B.C.

Smirnov, B.P., V.V. Chebanova, and T.V. Vvedenskaya. 1994. Adaptation of hatchery-raised chum salmon, *Oncorhynchus keta*, and chinook salmon, *O. tshawytscha*, to natural feeding and effects of starvation. J. Ichthyol. 34:96-106.

Smith, C.J., and B. Sele. 1995a. Introduction. *In* C. J. Smith and P. Wampler (eds.), Dungeness River Chinook Salmon Rebuilding Project Progress Report 1992-1993, p. 1-3. Northwest Fishery Resource Bulletin Project Report Series Project Report Series 3. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA, 98501-1091.)

Smith, C.J., and B. Sele. 1995b. Stock assessment. *In* C. J. Smith and P. Wampler (eds.), Dungeness River Chinook Salmon Rebuilding Project Progress Report 1992-1993, p. 4-14. (Available from Washington Dept. of Fish and Wildlife, 600 Capitol Way N., Olympia, WA, 98501-1091.)

Smith, E.M. 1966. A study to identify the race of fall chinook whose spawning grounds will be inundated by the John Day Impoundment on the Columbia River. Fish Comm. Oreg. DA-

45-164-CCIVENG-66-5, 53 p. (Available from U.S. Army Corps of Engineers, Walla Walla District.)

Sneath, P.H.A., and R.R. Sokal. 1963. Numerical taxomony. W.H. Freeman, San Francisco, 573 p.

Snyder, J.O. 1931. Salmon of the Klamath River, California. Calif. Fish Game Fish. Bull. 34:130.

Spotts, J. 1995. Chinook salmon stocks/population status analysis. Submitted to the Administrative Record 16 Nov. 1995, 21 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Steiner Environmental Consulting (SEC). 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Ebert, August 1997, 8 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Stevens, T.A., R.E. Withler, S.H. Goh, and T.D. Beacham. 1993. A multilocus probe for DNA fingerprinting in chinook salmon (*Oncorhynchus tshawytscha*), and comparisons with a single-locus probe. Can. J. Fish. Aquat. Sci. 50:1559-1567.

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

Stone, L. 1874. Report of operations during 1872 at the U.S. salmon-hatching establishment on the McCloud River, and on the California salmonidae generally; with a list of specimens collected. Report of U.S. Commissioner of Fisheries for 1872-1873 2:168-215.

Stone, L. 1897. Artificial propagation of salmon on the Pacific Coast of the United States with notes on the natural history of the quinnat salmon. Bull. U.S. Fish Comm. for 1896 16:203-235.

Stuehrenberg, L.C., G.A. Swan, L.K. Timme, P.A. Ocker, M.B. Eppard, R.N. Iwamoto, B.L. Iverson, and B.P. Sanford. 1995. Migrational characteristics of adult spring, summer, and fall chinook salmon passing through reservoirs and dams of the mid-Columbia River. Final report. CZES Division, NWFSC, NMFS, Seattle, WA, 115 p.

Sullivan, C. 1989. Juvenile life history and age composition of mature fall chinook salmon to the Klamath River, 1984-1986. M.S. Thesis, Humboldt State Univ. Arcata, CA, 69 p.

Swan, G.A., E.M. Dawley, R.D. Ledgerwood, W.T. Norman, W.F. Cobb, and D.T. Hartman. 1988. Distribution and relative abundance of deep-water redds for spawning fall chinook salmon at selected study sites in the Hanford Reach of the Columbia River. Natl. Mar. Fish. Serv., 59 p. (Available from Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.)

Taft, A.C. 1941. Report of the Bureau of Fish Conservation. Thirty-Sixth Biennial Report of the Division of Fish and Game for the Years 1938-1940:14-27. (Available from the California Department of Fish and Game, Sacramento, CA.)

Tallman, R.F. 1986. Genetic differentiation among seasonally distinct spawning populations of chum salmon, *Oncorhynchus keta*. Aquaculture 57:211-217.

Taylor, E.B. 1988. Adaptive Variation in reheotactic and agonistic behavior in newly emerged fry of chinook salmon, *Oncorhynchus tshawytscha*, from ocean- and stream-type populations. Can. J. Fish. Aquat. Sci. 45:237-243.

Taylor, E.B. 1989. Precocial male maturation in laboratory-reared populations of chinook salmon, *Oncorhynchus tshawytscha*. Can. J. Zool. 67:1665-1669.

Taylor, E.B. 1990a. Environmental correlates of life-history variation in juvenile chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). J. Fish Biol. 37:1-17.

Taylor, E.B. 1990b. Phenotypic correlates of life-history variation in juvenile chinook salmon *Oncorhynchus tshawytscha*. J. Anim. Ecol. 59:455-468.

Taylor, E.B. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic Salmon. Aquaculture 98:185-207.

Taylor, E.B., and P.A. Larkin. 1986. Current response and agonistic behavior in newly emerged fry of chinook salmon, *Oncorhynchus tshawytscha*, from ocean- and stream-type populations. Can. J. Fish. Aquat. Sci. 43:565-573.

Theis, L., and K. Melcher. 1995. Oregon Lower Columbia River fall and winter chinook spawning ground surveys, 1948-1994. Oreg. Dep. Fish Wildl., 13 p. (Available from Oregon Department of Fish and Wildlife, 2501 SW First Ave., PO Box 59, Portland, OR 97207.)

Thomas, W.K., R.E. Withler, and A.T. Beckenback. 1986. Mitochondrial DNA analysis of Pacific salmonids evolution. Can. J. Zool. 64:1058-1064.

Thompson, G.G. 1991. Determining minimum viable populations under the Endangered Species Act. NOAA Tech. Memo. NMFS F/NWC-198, 78 p.

Thorpe, J.E. 1993. Impacts of fishing on genetic structure of salmonid populations. *In* J.G. Cloud and G.H. Thorgaard (eds.), Genetic conservation of salmonid fishes, p. 67-80. Plenum Press and NATO Scientific Affairs Division, New York.

Titcomb, J.W. 1904. Report on the propagation and distribution of food-fishes. *In* G. M. Bower (ed.), Report of the Commissioner of Fisheries for the year ending June 30, 1902, p. 22-110.

Titcomb, J.W. 1905. Report on the propagation and distribution of food fishes. *In* G. M. Bowers (ed.), Report of the Bureau of Fisheries, 1904, p. 25-80.

Titcomb, J.W. 1917. The distribution of fish and fish eggs during the fiscal year 1915. *In* H. M. Smith (ed.), Report of the United States Commissioner of Fisheries for the fiscal year 1915, p. 138.

Tuss, C., T. Kisanuki, J. Larson, J. Polos, and T. Frazer. 1987. Klamath River fisheries investigation program. Annual report. U.S. Fish Wildl. Serv., 93 p. (Available from U.S. Fish and Wildlife Service, Fisheries Assistance Office, Arcata, California.)

Unwin, M.J. 1997. Fry-to-adult survival of natural and hatchery-produced chinook salmon (*Oncorhynchus tshawytscha*) from a common origin. Can. J. Fish. Aquat. Sci. 54:1246-1254.

U.S. Commissioner for Fish and Fisheries (USCFF). 1893. Report of the Commissioner for 1889-1891. Department of Commerce and Labour, 1-96 p.

U.S. Department of Commerce. 1968. Climate Atlas of the United States. Natl. Climatic Data Center [N.O.A.A. reprint 1983], Asheville, NC, 80 p.

U.S. Fish and Wildlife Service (USFWS). 1978. Tehama-Colusa Fish Facilities Spawning Channel Production Report 1977-1978 Season, 30 p. (Available from the U.S. Fish and Wildlife Service, 10950 Tyler Road, Red Bluff, CA, 96080.)

U.S. Fish and Wildlife Service (USFWS). 1994. Annual Report: Klamath River Fisheries Investigation Program, 1992. Coastal California Fishery Resource Office, 63 p. (Available from U.S. Fish and Wildlife Service Office, Fisheries Assistance Office, Arcata, CA 95521.)

U.S. Fish and Wildlife Service (USFWS). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: annual reports of Klamath River fisheries investigation program. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

U.S. Fish and Wildlife Service (USFWS). 1996a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by S. Hamelberg, April 1996. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

U.S. Fish and Wildlife Service (USFWS). 1996b. Escapement of hatchery-origin winter chinook salmon (*Oncorhynchus tshawytscha*) to the Sacramento River, California in 1995, with notes on spring chinook salmon in Battle Creek. U.S. Fish Wildl. Serv., 18 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

U.S. Fish and Wildlife Service (USFWS). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Finberg, 26 February 1997, 4 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

U.S. Fish and Wildlife Service (USFWS). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Lang, June 1997, 5 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

U.S. Forest Service (USFS). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by J. Lowe, November 1995. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

U.S. Forest Service (USFS). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by M. McCain, 16 September 1997, 19 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

U.S. Forest Service (USFS). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by A. Olson, 18 and 25 September 1997, 9 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

U.S. Forest Service and U.S. Bureau of Land Management (USFS and USBLM). 1996. Storms and floods of the winter of 1995-96. USDA Forest Service Pacific Northwest Region and Pacific Northwest Forest and Range experiment station and USDI BLM Oregon state office.

U.S. Geological Survey (USGS). 1990. National Water Summary 1987. Hydologic events and water supply and use. U.S. Dep. Interior, U.S. Geological Survery Paper 235, 553 p. (Available from U.S. Goverment Printing Office, Washington D.C.)

U.S. Geological Survey (USGS). 1993. National Water Summary 1990-91. Hydologic events and stream water quality. U.S. Dep. Interior, U.S. Geological Survery Paper 2400, 590 p. (Available from U.S. Goverment Printing Office, Washington D.C.)

Uremovich, B. 1977. Straying of fall chinook salmon from Elk River hatchery into Sixes River, 1970-1976. Oreg. Dep. Fish Wildl. Info. Rep. 77-6, 7 p. (Available from Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97027.)

Utter, F., G. Milner, G. Stahl, and D. Teel. 1989. Genetic population structure of chinook salmon (*Oncorhynchus tshawytscha*), in the Pacific Northwest. Fish. Bull. 87:239-264.

Utter, F., D. Teel, G. Milner, and D. McIsaac. 1987. Genetic estimates of stock compositions of 1983 chinook salmon, *Oncorhynchus tshawytscha*, harvests off the Washington coast and Columbia River. Fish. Bull. 85:13-23.

Utter, F.M. 1996. Review of co-manager's draft of the west coast chinook salmon status review submitted to the ESA Administrative Record for west coast chinook salmon by F. Utter, 31 December 1996, 10 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Utter, F.M., D.W. Chapman, and A.R. Marshall. 1995. Genetic population structure and history of chinook salmon of the Upper Columbia River. Am. Fish. Soc. Symp. 17:149-165.

Utter, F.M., W.J. Ebel, G.B. Milner, and D.J. Teel. 1982. Population structures of fall chinook salmon, *Oncorhynchus tshawytscha*, of the mid-Columbia and Snake Rivers. U.S. Dep. Commer., N.O.A.A., Northwest and Alsaka Fisheries Center. Processed Report 82-10, 14 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

Utter, F.M., R.S. Waples, and D.J. Teel. 1992. Genetic isolation of previously indistinguishable chinook salmon populations of the Snake and Klamath Rivers: limitations of negative data. Fish. Bull. 90:770-777.

Vilkitis, J., C. Poly, K. Jones, and S. Kocher. 1994. Population genetics of chinook salmon in the Salmon River system. Unpublished report. 14 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Vreeland, R.R. 1989. Evaluation of the contribution of fall chinook salmon reared at Columbia River hatcheries to the Pacific salmon fisheries. Final report. Bonneville Power Admin., Div. Fish. Wildl. Portland, 113 p. (Available from Bonneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208.)

Vronskiy, B.B. 1972. Reproductive biology of the Kamchatka River chinook salmon (*Oncorhynchus tshawytscha* (Walbaum).) J. Icthyol. 12:259-273.

Wagner, H.H., F.P. Conte, and J.L. Fessler. 1969. Development of osmotic and ionic regulation in two races of chinook salmon *Oncorhynchus tshawytscha*. Comp. Biochem. Physiol. 29:325-341.

Wahle, R.J., and R.E. Peterson. 1987. A listing of Pacific Coast spawning streams and hatcheries producing chinook and coho spawners. NOAA Tech. Memo. NMFS F/NWC-122, 32 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Wahle, R.J., and R.Z. Smith. 1979. A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and a summary of their releases by region, 1960-1976. NOAA Tech. Rep. NMFS SSRF-736, 40 p.

Waknitz, F.W., G.M. Matthews, T. Wainwright, and G.A. Winans. 1995. Status review for Mid-Columbia River summer chinook salmon. NOAA Tech. Mem. NMFS-NWFSC-22, 80 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Waldvogel, J. 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon: responses to questionnaire and additional data for the Smith River and west branch Mill Creek, California. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Waldvogel, J. 1997. Documents submitted to the ESA Administrative Record for west coast chinook salmon 16 September 1997, 4 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Waples, R.S. 1991a. Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. 48(Suppl. 1):124-133.

Waples, R.S. 1991b. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Marine Fisheries Review 53:11-22.

Waples, R.S., and C. Do. 1994. Genetic risk associated with supplementation of Pacific salmonids: Captive broodstock programs. Can. J. Fish. Aquat. Sci. 51 (Suppl. 1):310-329.

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

Waples, R.S., O.W. Johnson, P.B. Aebersold, C.K. Shiflett, D.M. VanDoornik, D.J. Teel, and A.E. Cook. 1993. A genetic monitoring and evaluation program for supplemented populations of salmon and steelhead in the Snake River Basin. Annual report. Bonneville Power Administration. DE-A179-89BP0091.

Waples, R.S., D.J. Teel, and P.B. Aebersold. 1991a. A genetic monitoring and evaluation program for supplemented populations of salmon and steelhead in the Snake River Basin. Annual report. Bonneville Power Administration, 50 p.

Waples, R.S., J. Robert, P. Jones, B.R. Beckman, and G.A. Swan. 1991b. Status review for Snake River fall chinook salmon. NOAA Tech. Memo. NMFS F/NWC-201, 73 p. (Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Ware, D.M., and R.E. Thomson. 1991. Link between long-term variability in upwelling and fish production in the Northeast Pacific Ocean. Can. J. Fish. Aquat. Sci. 48:2296-2306.

Washington Department of Fisheries (WDF). 1934. Forty-second and forty-fifth inclusive annual reports of the State Department of Fisheries for the period from April 1, 1931-March 31, 1935, fiscal years of 1931 to 1934 inclusive. Wash. Dep. Fish., 78 p.

Washington Department of Fisheries (WDF). 1936. Annual bulletin. Dep. Fish., State of Washington. No. 36, 31 p.

Washington Department of Fisheries (WDF). 1937. Annual bulletin. Dep. Fish., State of Washington. No. 37, 37 p.

Washington Department of Fisheries (WDF). 1938. Annual bulletin. Dep. Fish., State of Washington. No. 39, 39 p.

Washington Department of Fisheries (WDF). 1939. Annual bulletin. Dep. Fish., State of Washington. No. 39, 39 p.

Washington Department of Fisheries (WDF). 1940. Annual bulletin. Dep. Fish., State of Washington. No. 40, 51 p.

Washington Department of Fisheries (WDF). 1991. Revised stock transfer guidlines. Memo, 28 May 1991, Salmon Culture Division Olympia, WA, 10 p.

Washington Department of Fisheries (WDF), Washington Department of Game, and U.S. Bureau of Fisheries. 1938. Report of the preliminary investigations into the possible methods of preserve in the Columbia River salmon and steelhead at the Grand Coulee Dam. Washington Department of Fisheries, 121 p. (Available from Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Washington Department of Fisheries (WDF), Washington Department of Wildlife (WDW), and Western Washington Treaty Indian Tribes (WWTIT). 1993. 1992 Washington State salmon and steelhead stock inventory (SASSI). Wash. Dep. Fish Wildl., Olympia, 212 p. + 5 regional volumes. (Available from Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Washington Department of Fisheries and Game (WDFG). 1902. Thirteenth annual report of the State Fish Commission to the Governor of the State of Washington. Dep. Fish. Game, State of Washington, 92 p.

Washington Department of Fisheries and Game (WDFG). 1914. Twenty-second and twenty-third annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1911 to March 31, 1913. Dep. Fish. Game, State of Washington, 124 p.

Washington Department of Fisheries and Game (WDFG). 1916. Twenty-fourth and twenty-fifth annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1913 to March 31, 1915. Dep. Fish. Game, State of Washington, 171 p.

Washington Department of Fisheries and Game (WDFG). 1917. Twenty-Sixth and twenty-seventh annual reports to the State Fisheries Commissioners, Olympia.

Washington Department of Fisheries and Game (WDFG). 1920. Twenty-eighth and twenty-ninth annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1917 to March 31, 1919. Dep. Fish. Game, State of Washington, 171 p.

Washington Department of Fisheries and Game (WDFG). 1921. Thirtieth and thirty-first annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1919 to March 31, 1921. Dep. Fish. Game, State of Washington, 302 p.

Washington Department of Fisheries and Game (WDFG). 1925. Thirty-fourth and thirty-fifth annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1923 to March 31, 1925. Dep. Fish. Game, State of Washington, 140 p.

Washington Department of Fisheries and Game (WDFG). 1928. Thirty-sixth and thirty-seventh annual reports of the State Fish Commission to the Governor of the State of Washington from April 1, 1925 to March 31, 1927. Fiscal years of 1925 and 1926. Dep. Fish. Game, State of Washington, 213 p.

Washington Department of Fish and Wildlife (WDFW). 1995. Documents submitted to the ESA Administrative Record for west coast chinook salmon by B. Tweit. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon on May 1996. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by B.Crawford, 28 January 1997, 34 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by C. Smith, January, March, and September 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997c. Documents submitted to the ESA Administrative Record for west coast chinook salmon by C. Busack, February 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997d. Documents submitted to the ESA Administrative Record for west coast chinook salmon by A. Blakley, May, June, and September 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997e. Electronic data and documents submitted to the ESA Administrative Record for west coast chinook salmon by R.

Woodard, 5 May and 26 September 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1997f. Documents submitted to the ESA Administrative Record for west coast chinook salmon by R. Brix, 18 September 1997. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW), and Oregon Department of Fish and Wildlife (ODFW). 1994. Status report: Columbia River fish runs and fisheries 1938-1993. Wash. Dep. Fish Wildl., Oreg. Dep. Fish and Wildl., 271 p.

Washington Department of Fish and Wildlife (WDFW), Puyallup Indian Tribe, and Muckleshoot Indian Tribe. 1996. Recovery plan for White River spring chinook salmon. Wash. Dep. Fish Wildl., 81 p. (Available from Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Wehrhahn, C.F., and R. Powell. 1987. Electrophoretic variation, regional differences, and gene flow in the coho salmon (*Oncorhynchus kisutch*) of southern British Columbia. Can. J. Fish. Aquat. Sci. 44:822-831.

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. NOAA Tech. Memo. NMFS-NWFSC-24, 258 p. (Available from Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Wertheimer, A.C., and J.R. Winton. 1982. Differences in susceptibility among three stocks of chinook salmon, *Oncorhynchus tshawytscha*, to two isolates of infectious hematopoietic necrosis virus. NMFS Tech. Rep. 22, 11 p. (Available from Northwest and Alaska Fisheries Center Auke Bay Laboratory, Natl. Mar. Fish. Serv., NOAA, P.O. Box 155, Auke Bay, AK, 99821.)

Wilderness Society. 1993. The living landscape, Vol. 2: Pacific salmon and federal lands. Bolle Center for Forest Ecosystem Management, Washington, DC, 87 p. (Available from The Wilderness Society, 900 Seventeenth Street, N.W., Washington, DC 20406-2596.)

Williams, R.W., R.M. Laramie, and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization. Volume 1. Puget Sound Region. Wash. Dep. Fish. (Available from Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.)

Willis, C.F., S.P. Cramer, D. Cramer, M. Smith, T. Downey, and R. Montagne. 1995. Status of Willamette River spring chinook salmon in regards to the Federal Endangered Species Act. Part 1. Portland General Electric Company and Eugene Water and Electric Board, 74 p. (Available from S.P. Cramer & Associates, Inc. 300 S.E. Arrow Creek Lane, Gesham, OR 97080.)

Wilson, G.M., W.K. Thomas, and A.T. Beckenbach. 1987. Mitochondrial DNA analysis of Pacific Northwest Populations of *Oncorhynchus tshawytscha*. Can. J. Fish. Aquat. Sci. 44:1301-1305.

Winans, G.A. 1989. Genetic variability in chinook salmon stocks from the Columbia River Basin. N. Am. J. Fish. Manage. 9:47-52.

Winans, G.A., P.B. Aebersold, S. Urawa, and N.V. Varnavskaya. 1994. Determining continent of origin of chum salmon (*Oncorhynchus keta*) using genetic stock identification techniques: Status of allozyme baseline in Asia. Can. J. Fish. Aquat. Sci. 51 (Suppl.1): 96-113.

Winans, G.A., P.B. Aebersold, and R.S. Waples. 1996. Allozyme variability of *Oncorhynchus nerka* in the Pacific Northwest, with special consideration to populations of Redfish Lake, Idaho. Trans. Am. Fish. Soc. 125:645-663.

Winton, J., and R. Hilborn. 1994. Lessons from supplementation of chinook salmon in British Columbia. N. Amer. J. Fish. Man. 14:1-14.

Withler, R.E. 1988. Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. Aquaculture 68:15-25.

Withler, R.E., W.C. Clarke, B.E. Ridell, and H. Kreiberg. 1987. Genetic variation in freshwater survival and growth of chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture 64:85-96.

Wixom, L.H., J. Pisciotto, and C. Lake. 1995. Final performance report as required by Federal Aid in Sport Fish Restoration Act, Inland and Anadromous Sport Fish Management and Research. Federal Aid Project F-51-R. Project 27. Sacramento River Systems Sport Fish Catch, 76 p.

Wood, C., B. Riddell, B.T. Rutherford, and R.E. Withler. 1994. Biochemical genetic survey of sockeye salmon (*Oncorhynchus nerka*) in Canada. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):114-131.

Yakama Indian Nation (YIN). 1996. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Fast, June 1996. (Available from Environmental and

Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Yip, G.M. 1994. Genetic differentiation of chinook salmon (*Oncorhynchus tshawytscha*) runs at Trinity River Hatchery, California. M.S. Thesis, Humboldt State Univ., Eureka, CA.

Yip, G.M., T. J. Hassler, S. Riley, E.J. Loudenslager. 1996. Genetic variation, differentiation, and relationships of spring- and fall-run chinook salmon (*Oncorhynchus tshawytscha*) at Trinity River Hatchery, California. Final Report RWO 30, National Biological Service, California Cooperative Fishery Research Unit, Eureka, California.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 1996. Historical and present distribution of chinook salmon in the Central Valley drainage of California. Dep. Wildl., Fish, and Conservation Biology, 54 p. (Available from Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, CA 95616.)

Young, D.A. 1987. Juvenile chinook salmon abundance, growth, production, and food habits in the Mattole River lagoon, California. M.S. Thesis, Humboldt State University, Arcata, CA, 73 p.

Young, F. R., and W. L. Robinson. 1974. Age, size, and sex of Columbia River chinook, 1960-1969. Fish Comm. Oreg., Data Report Series 4, 31 p.

Yurok Tribal Fisheries Program (YTFP). 1997a. Documents submitted to the ESA Administrative Record for west coast chinook salmon by Yurok Tribal Fisheries Program, 31 January 1997, 27 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon St., Suite 500, Portland, OR 97232.)

Yurok Tribal Fisheries Program (YTFP). 1997b. Documents submitted to the ESA Administrative Record for west coast chinook salmon by D. Gale, 17 and 19 September 1997, 11 p. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Suite 500, Portland, OR 97232.)

Zinn, J. L., K. A. Johnson, J. E. Sanders, and J. L. Fryer. 1977. Susceptibiility of salmonid species and hatchery stocks of chinook salmon (*Oncorhynchus tshawytscha*) infections by *Ceratomyxa shasta*. J. Fish. Res. Board Can. 34:933-936.

APPENDIX A:

AGE AT SMOLTIFICATION

Appendix A: Comparative percentages of returning adults that emigrated to the ocean as subyearlings, yearlings, and 2-year-olds. Run designations are Sp-spring, Su-summer, F-fall, and W-winter. "Time" designates the timing of outmigration. Age at smoltification is based on growth patterns from scales of returning adults. Under "Age", numbers represent percent adults that emigrated as subyearlings (0) and yearlings (1), and 2-year-old smolts (2), respectively. An "X" under "Age" designates the prevalent age at smoltification. "*N*" designates the number of individuals sampled to estimate population smolt profile, and "Year" designates the year(s) the samples were collected.

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Asia								
Kamchatka R.	Su			X				Smirnov 1975
Paratunka R.	Su			X				Smirnov 1975
Bol'shaya R.	Su			X				Smirnov 1975
Alaskan Coast								
Kenai R.	Sp/Su		0	97	3	313	1989-91	Roni 1992
Farragut R.	Sp/Su		3	96	1	152	1983-85	Halupka et al. 1993
Situk R.	Sp/Su	July/Aug	98	2	0	250	1988-89	Johnson et al. 1992b
Yukon River								
Yukon R.	Su		0	100	0		1920	Gilbert 1922
Yukon R.	Su		0	100	0		1987	Beacham et al. 1989
Big Salmon R.	Su		0	96	4		1985-87	Beacham et al. 1989
Nisutlin R.	Su		0	95	5		1986-87	Beacham et al. 1989
Whitehorse R.	Su		0	17	83		1986-87	Beacham et al. 1989
British Columbian Coast								
Nass R.	Su	May/June	58	42	0		1964-66	Godfrey 1968 Healey 1983
Kitsumkalum R.	Su	May	1	99	0	73	1989-91	Roni 1992
Skeena R.	Su		52	48	0		1964-66	Godfrey 1968 Healey 1983
Taku R.	Su	May	<1	99	0	2527	1984-91	Meehan and Sniff 1962, Halupka et al. 1993
Kitimat R.	Su	Apr	88	12	0			Healey 1983, Shepherd et al. 1986
Atnarko R.	Su	June	86	14	0			Healey 1982
Wannock R.	Su	June	99	1	0	97	1989-91	Roni 1992
Qualicum R.	Su	Mar/Apr	100	0	0			Healey 1983, Shepherd et al. 1986
Quinsam R.	Su		99	1	0			Healey 1982
Nanaimo R.	Su		95	5	0			Healey 1983
East Coast V.I.	Su		100	0	0			Shepherd et al. 1986
Fraser River								

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Bowron R.	Su	May				136	1980	Shepherd et al. 1986
Chilcotin R.	Su							Bradford 1994
Cottonwood R.	Su							Bradford 1994
Upper Fraser R.	Su							Bradford 1994
Holmes R.	Su	Apr						Shepherd et al. 1986, Bradford 1994
McGregor R.	Su							Bradford 1994
Nechako R.	Early Su							Bradford 1994
Quesnel R.	Su	Aug				380	1980	Shepherd et al. 1986
Slim R.	Su	Apr						Bradford 1994
Torpy R.	Su	May				54	1981	Shepherd et al. 1986
West R.	Su							Bradford 1994
Willow R.	Su	May						Bradford 1994
N.F. Thompson R.	Su	Apr	4	96	0	400	1981	Shepherd et al. 1986
S.F. Thompson R.	Mid Su		34	67	0	817	1981	Fraser et al. 1982, Shepherd et al. 1986
Lower Fraser R.	Su	May	X					Fraser et al. 1982
Harrison R.	Late Su							Fraser et al. 1982
Puget Sound								
N.F. Nooksack R.	Su/Sp		91	9	0	1425	1986-91	WDFW 1995
S.F. Nooksack R.	Su/Sp		31	69	0	81	1993-94	WDFW 1995
S.F. Nooksack R.	Su/Sp		84	16	0	73		NTG (unpubl.)
Upper Skagit R.	Su			X				WDF et al. 1993, Seiler et al. 1995
Suiattle R.	Sp	May/June	18-53	47-82	0			Williams et al. 1975, Orrell 1976, WDF et al. 1993
Upper Cascade R.	Sp	May/June						WDF et al. 1993
Sauk R.	Sp	May/June	55	45	0	142		WDF 1995
Stillaguamish R.	Su/F	Mar/June	97	3	0	484	1980-93	WDF et al. 1993, WDFW 1995
Snohomish R.	Su (Sp?)	Apr/July (May/June)						WDF et al. 1993, Williams et al. 1975, Beauchamp et al. 1987
Wallace R.	Su/F	Apr/July						Williams et al. 1975, WDF et al. 1993
Snohomish/ Snoqualmie R.	F	Apr/July	67	33	0	97	1993-94	Williams et al. 1975, WDFW 1995
Bridal Veil Cr.	F	Apr/July						Williams et al. 1975, WDF et al. 1993

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Cedar R.	Su/F	Mar/July						Williams et al. 1975, WDF et al. 1993
Issaquah Cr.	Su/F	Mar/July	99	<1	0	1518	1990-93	Williams et al. 1975, WDF et al. 1993, WDF 1995
White R.	Sp		80	20	0			Dunston 1955, WDF et al. 1993
White R.	Su/F	Feb/Aug						Williams et al. 1975, WDF et al. 1993
Puyallup R.	F		97	3	0	100		WDF et al. 1993
Nisqually R.	Su/F	Feb/June	99	1	0	508		Williams et al. 1975
South Sound	Su/F	Feb/July	99	<1	0	2602		WDFW 1995
Hood Canal								
Skokomish R.	Su/F	May/June	98	2	0	159		Williams et al. 1975
San Juan de Fuca								
Hoko R.	F	Mar/Aug	100	0	0	1415		Williams et al. 1975
Dungeness R.	Su/Sp	Summer/Fall	>95					WDF et al. 1993, Smith and Sele 1995a
Dungeness R.	Sp ?		98	2	0	117	1986-94	WDFW 1995
Elwha R.	Su/Fa		17-55	45-83	0	2480	1988-91	Roni 1992
Washington Coast								
Ozette R.	F	Mar/Aug						Williams et al. 1975
Quillayute R.(gen)	Sp		44	56	0	4410	1989-94	QTNR 1995
Quillayute R.(gen)	Su		73	27	0	1272	1989-94	QTNR 1995
Quillayute R.(gen)	F	Mar/Aug	92	8	0	1723	1984-94	QTNR 1995
Hoh R.	F	Mar/Aug	X					Williams et al. 1975
Queets R.	F	Mar/Aug	99	1	0		1977-93	Williams et al. 1975, QFD 1995
Quinault R.	Su/Sp		96	4	0		1977-94	QFD 1995
Quinault R.	F	Mar/Aug	99	1	0		1984-94	Williams et al. 1975, QFD 1995
Chehalis R.	Sp		96	4	0		1987	QFD 1995
Humtulips R.	F	Apr/June	99	1	0		1976-93	Williams et al. 1975
Chehalis R.	F	Apr/June					1983-93	Williams et al. 1975, QFD 1995
Lower Columbia River								
Cowlitz R.	Sp			X			1978-84	Howell et al. 1985, Hymer et al. 1992a
Kalama R.	Sp		4	96	0	540	1982-86	Hymer et al. 1992a
Lewis R.	Sp		12	88	0	373	1982-86	Hymer et al. 1992a

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Wind R./Carson NFH	Sp	Spring	0	100	0	4389		Howell et al. 1985, Hymer et al. 1992a
Klickitat R.	Sp	Spring		X				Howell et al. 1985, Hymer et al. 1992a
Lewis & Clark R.	F	Summer/Fall	100	0	0	39	1990-91	Olsen et al. 1992
Klaskanine R.	F	Summer/Fall	97	3	0	29	1988	Olsen et al. 1992
Bear Cr.	F	Summer/Fall	100	0	0	188	1987-91	Olsen et al. 1992
Big Cr.	F	Summer/Fall	99	<1	0	334	1987-91	Olsen et al. 1992
Gnat Cr.	F	Summer/Fall	100	0	0	93	1987-91	Olsen et al. 1992
Plympton Cr.	F	Summer/Fall	100	0	0	192	1987-91	Olsen et al. 1992
Grays R.	F	Summer/Fall	99	1	0	2425	1981-84	Hymer et al. 1992a
Elochoman R.	F	Summer/Fall	100	0	0	272	1981-84	Hymer et al. 1992a
Abernathy Cr.	F	Summer/Fall	>90					Hymer et al. 1992a
Cowlitz R.	F	Summer/Fall	98	2	0	1487	1981-84	Hymer et al. 1992a
Coweeman R.	F	Summer/Fall	100	0	0	118	1981-84	Hymer et al. 1992a
S. Fork Toutle R.	F	Summer/Fall	>90					Hymer et al. 1992a
N. Fork Toutle R.	F	Summer/Fall	>90					Hymer et al. 1992a
Kalama R.	F	Summer/Fall	94	6	0	1355	1981-84	Hymer et al. 1992a
Lewis R.	F	Aug (Estuary)	97	3	0	2560	1981-84	Hymer et al. 1992a, Howell et al. 1985, WDFW 1995
E. Fork Lewis R.	F	Aug (Estuary)	99	1	0	308	1981-88	Hymer et al. 1992a
Washougal R.	F	Summer/Fall	99	<1	0	500	1981-84	WDF et al. 1991
Sandy R.	F (late)		27	73	0	11	1980	Howell et al. 1985
White Salmon R. (Tule)	F		100	0	0	45	1979-83	Hymer et al. 1992C
Willamette River								
Clackamas R.	Sp	Summer/Fall		X				Olsen et al. 1992
Santiam R.	Sp		0	100	0	12863		Olsen et al. 1992
Willamette R.	Sp		15	85	0	590	1946-51	Mattson 1963, Wagner et al. 1969, Howell et al. 1985
Clackamas R.	F	Summer/Fall	X					Olsen et al. 1992
Mollalla R.	F	Summer	X					Olsen et al. 1992
Up. Willamette R.	F	Summer/Fall	100	0	0		1983-86	Olsen et al. 1992
Upper Columbia River								
Deschutes R.	Sp	May	0	100	0	738	1978-87	Lindsay et al. 1982, Howell et al. 1985, Lindsay et al. 1989

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Deschutes R.	Sp		0	100	0	194	1989	Fryer and Schwartzberg 1990
N.F. John Day R.	Sp	Apr/Aug	0	100	0	232	1978-88	Howell et al. 1985, Olsen et al. 1992, Olsen et al. 1994c
M.F. John Day R.	Sp	Apr/Aug	0	100	0	448	1978-88	Howell et al. 1985, Olsen et al. 1992, Olsen 1994c
Upper Yakima R.	Sp	Apr	0	100	0	589	1989-92	Howell et al. 1985, WDFW 1995
Naches R.	Sp	Apr	0	100	0	729	1989-93	Howell et al. 1985, Hymer et al. 1992b, Chapman et al. 1995
American R.	Sp	Apr/May	0	100	0	443	1989-93	Hymer et al. 1992b, Chapman et al. 1995
Chiwawa R.	Sp	May	0	100	0	287	1986-93	French and Wahle 1959, Chapman et al. 1995, WDFW 1995
Nason Cr.	Sp		0	100	0	269	1986-93	Hymer et al. 1992b, Chapman et al. 1995
Little Wenatchee R.	Sp	May	0	100	0	20	1986-93	French and Wahle 1959, Chapman et al. 1995, WDFW 1995
Wenatchee R.	Sp		0	100	0	180	1989	Fryer and Schwartzberg 1990
White R.	Sp	May	0	100	0	207	1986-93	French and Wahle 1959, Chapman et al. 1995, WDFW 1995
Entiat R.	Sp	May	0	100	0			Hymer et al. 1992b, Chapman et al. 1995
Methow R.	Sp	May	0	100	0	20		Hymer et al. 1992b, Chapman et al. 1995
Twisp R.	Sp	May	0	100	0	29	1986-93	Hymer et al. 1992b, Chapman et al. 1995
Chewuch R.	Sp		0	100	0	69	1986-93	Hymer et al. 1992b, Chapman et al. 1995
Lost R.	Sp		0	100	0			Hymer et al. 1992b, Chapman et al. 1995
Wenatchee R.	Su	June-Oct	88	12	0	1162		Chapman et al. 1994, Peven and Truscott 1995

Appendix A (Cont.).

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Wenatchee R.	Su		66	34	0	65	1990	Fryer and Schwartzberg 1993
Methow R.	Su	Throughout year	71	29	0	137		Hymer et al. 1992b, French and Wahle 1959, Chapman et al. 1994
Similkameen R.	Su		58	42	0	227		Chapman et al. 1994
Deschutes R.	F	June	96	4	0	2644		Jonasson and Lindsay 1988
Yakima R. (Bright)	F		95	5	0	300	1989-91	Hymer et al. 1992b, WDFW 1995
Marion Drain- Yakima R.	F		100	0	0	319	1989-93	Hymer et al. 1992b, WDFW 1995
Hanford Reach	F	June/July	97	3	0	5601	1981-88	Hymer et al. 1992b
Snake River								
Tucannon R.	Sp	Apr/May	0	100	0	487	1998-94	Hymer et al. 1992b, WDFW 1995
M.S. Snake R.	Sp	May						Healey 1991
Grande Ronde R.	Sp	May/June	0	100	0			Olsen et al. 1992, Olsen et al. 1994b
Lookingglass Cr.	Sp	May/June	0	100	0	216	1989	Fryer and Schwartzberg 1990, Olsen et al. 1992, Olsen et al. 1994b
Imnaha R.	Sp	Apr/May	0	100	0	105	1989	Fryer and Schwartzberg 1990, Olsen et al. 1992, Olsen et al. 1994c
Rapid R.	Sp	May		X				Keifer et al. 1992
Salmon R.	Sp	Spring	0	100	0			Bjornn et al. 1964
M.F. Salmon R.	Sp	Spring	0	100	0	658	1961-62	Keifer et al. 1992
S.F. Salmon R.	Sp	Spring	0	100	0	361		Keifer et al. 1992
Rapid R.	Su	Spring	0	100	0	437	196569	Howell et al. 1985
S.F. Salmon R.	Su		0	100	0	56	1990	Fryer and Schwartzberg 1993
S.F. Salmon R.	Su		0	100	0	363	1961-62	Keifer et al. 1992
Snake R.	F	June/July	X					Chapman et al. 1991, Hymer et al. 1992b
Snake R.	F	Summer	X				1991-92	Connor et al. 1994
Oregon Coast								
Rogue R.	Sp		93	7	0		1974-86	Nicholas and Hankin 1988

Appendix A (Cont.).

			Age at Smoltification					
River	Run	Time	0	1	2	*N*	Year	Reference
Trask R.	Sp		X					Nicholas and Hankin 1988
Umpqua R.	Sp	Fall/Spring	60	40	0		1986	Nicholas and Hankin 1988
Alsea R.	F	June/Sept.						Nicholas and Hankin 1988
Chetco R.	F		100	0	0	30	1970	Nicholas and Hankin 1988
Coos R.	F		100	0	0	168	1980	Nicholas and Hankin 1988
Coquille R.	F	June	99	1	0	759	1978-86	Nicholas and Hankin 1988
Elk R.	F/W	July	97	3	0	5414	1968-85	Nicholas and Hankin 1988
Hunter Cr.	F		X				1973-74	Nicholas and Hankin 1988
Miami R.	F		X					Nicholas and Hankin 1988
Nehalem R.	Su/F	Fall	99	1	0	127	1985-86	Nicholas and Hankin 1988
Nestucca R.	F		94	6	0	80	1978-87	Nicholas and Hankin 1988
Nestucca R.	Early F		100	0	0	87	1957-58	Nicholas and Hankin 1988
Rogue R.	F	July-Sept.	87	13	0		1974-86	Nicholas and Hankin 1988, Schlutcher and Lichatowich 1977
Salmon R.	F	July/Aug. (Estuary)	100	0	0	812	1975-77	Nicholas and Hankin 1988
Siletz R.	F		99	1	0	235	1986	Nicholas and Hankin 1988
Siuslaw R.	F		100	0	0	283	1980-86	Nicholas and Hankin 1988
Sixes R.	F	June/July	97	3	0	378	1965, 1985	Nicholas and Hankin 1988, Reimers 1971
Tillamook R.	F		X				1980-85	Nicholas and Hankin 1988
Trask R.	F		97	3	0	76	1986	Nicholas and Hankin 1988
Umpqua R.	F	June/July	X					Nicholas and Hankin 1988
Wilson R.	F		99	1	0	233	1982-86	Nicholas and Hankin 1988

Appendix A (Cont.).

River	Run	Time	Age at Smoltification			*N*	Year	Reference
			0	1	2			
Yaquina R.	F	Sp/Su	100	0	0	374	1981-82	Nicholas and Hankin 1988
Klamath River								
Klamath R.	F	Late Summer/Fall	87	13	0	5591	1919-23	Snyder 1931
Klamath R.	Sp		83	17	0	35	1920	Snyder 1931
S.F. Trinity	Sp		90	10	0	69	1992	Dean 1995
Central Valley								
Sacramento and San Joaquin R.	All		89	11	0	1747	1919, 1921	Clark 1929
Sacramento R.	W	Sept-Dec	X					Gard 1995
Sacramento R.	Sp	Dec-Mar	X					Gard 1995
Up. Sacramento R.	Sp	Spring	87	13	0	68	1939	Calkins et al. 1940
Sacramento R.	Early F	Dec-June	X					Clark 1929, Kjelson et al. 1982, Gard 1995
Up. Sacramento R.	F	Feb-June & Sept/Dec.	90	10	0	857	1939	Calkins et al. 1940

APPENDIX B:

AGE AT MATURATION

Appendix B. Comparative percentages of age at maturation for selected West Coast stocks of chinook salmon. Stocks are generally arranged from north to south by geographic area. Run designations are Sp-spring, Su-summer, and F-fall, and W-winter. Numbers in bold indicate the most common age-class. Most age determinations are based on scale analysis. Where discrepancies in the age structure reported by different sources were observed, average values were calculated.

		Age at maturation						
River	Run	2	3	4	5	6+	Year	Reference
Alaska Coast								
Kuskokwim	Sp/Su		1	20	15	59/4 (6/7+)	1983	Huttunen 1985
Kenai R.	Early Su	<1	4	13	76	7		Burger et al. 1985, Roni 1992
Copper R.	Sp/Su	<1	6	27	56	11	1990	Moffitt et al. 1994
Situk R.	Sp/Su		19	22	59			Johnson et al. 1992a, Olsen 1992
Farragut R.		6	11	34	41	6	1983-85	Halupka et al. 1993
Yukon River Basin								
Yukon R.			<1	23	41	32/4 (6/7)	1982	McBride et al. 1983
Upper Yukon R.	Su					78/22 (6/7)	1987	Gilbert 1922, Beacham et al. 1989, Healey 1991
Big Salmon R.	Su			3	24	56/18 (6/7)	1985-87	Beacham et al. 1989, Healey 1991, Schneirderhan 1993
Nisutlin R.	Su				3	22/75 (6/7)	1986	Beacham et al. 1989, Schneirderhan 1993
Whitehorse R.	Su			8	27	57/9 (6/7)	1986-87	Beacham et al. 1989, Schneirderhan 1993
British Columbia Coast								
Kitsumkalum R.	Su		3	23	58	16	1991	Hancock et al. 1983a, Roni 1992
Skeena R.	Su	4	7	35	34	20		Healey 1982, Hancock et al. 1983b, Healey 1991
Stikine R.	Su							Kissner 1982
Taku R.	Su	11	27	37	24	2		Kissner 1982
Kitimat R.	Su		35	49	16			Healey 1982
Bella-Coola/Atnarko R.	Su	1	8	50	39	2		Manzon and Marshall 1980, Healey 1982, Healey 1991
Wannock R.	Su		6	22	72		1991	Britton and Marshall 1980, Roni 1992
Qualicum R.	Su	45	25	29	1			Healey 1982, Lister 1990

Appendix B (Continued).

River	Run	2	3	4	5	6+	Year	Reference
Robertson Cr.	Su	38	25	16	21			Healey 1982, Lister 1990
Quinsam R.	Su	1	5	37	46	11		Healey 1982
Fraser River Basin								
Bowron R.	Su			11	89		1979-91	Shepherd et al. 1986, Bradford 1994
Chilko R.	Early Su		12	48	38		1979-91	Healey 1982, Bradford 1994
Nechako R.	Su		9	40	51		1974-91	Shepherd et al. 1986, Bradford 1994
Quesnel R.	Su		8	17	70	5	1974-91	Shepherd et al. 1986, Bradford 1994
Slim R.	Su			28	72		1974-91	Shepherd et al. 1986, Bradford 1994
Torpy R.	Su			14	84	2	1974-91	Shepherd et al. 1986, Bradford 1994
Willow R.	Su		2	18	79	2	1974-91	Shepherd et al. 1986, Bradford 1994
SF Thompson R.	Su	<1	1	51	44	4		Fraser et al. 1982, Shepherd et al. 1986
Harrison R.	Su		24	74	2		1982	Fraser et al. 1982, Schubert et al. 1993
Puget Sound								
Nooksack R.	Sp	5	34	51	9	<1	1980-94	WDFW 1995
NF Nooksack R.	Sp	<1	4	75	20		1986-94	WDF et al. 1993, WDFW 1995
SF Nooksack R.	Sp	1	10	61	28		1993-94	WDF et al. 1993, WDFW 1995
Suiattle R.	Sp	1	8	43	47	35	1986-90	Orrell 1976, WDF et al 1993, WDFW 1995
Stillaguamish R.	Su	4	30	59	7		1980-93	WDF et al. 1993, WDFW 1995
Skagit R. (gen)	F/Su/Sp		10	73	2	1	1965-72	Orrell 1976
Snoqualmie R.	F	6	20	46	28		1993-94	WDF et al. 1993, WDFW 1995
Puyallup R.	F	2	16	76	6		1992-93	WDF et al. 1993, WDFW 1995
Issaquah Cr.	Su/F	2	47	48	3		1990-93	WDF et al 1993
Green R.	Su/F	1	26	62	11	<1	1984-94	WDF et al. 1993, WDFW 1995
Puyallup/White R.	Sp(?)		9	55	36		1993	WDF et al. 1993, WDFW 1995
Nisqually R.	Su/F	24	45	31	1		1992-93	WDF et al. 1993, WDFW 1995
Deschutes R.	Su/F	3	32	56	5	<1	1990-93	WDFW 1995
South Sound	Su/F	7	46	42	4		1992-93	WDF et al. 1993, WDFW 1995
Skokomish R.	Su/F	20	33	43	4	<1	1992-94	PNPTC 1995, WDFW 1995

Appendix B (Continued).

River	Run	2	3	4	5	6+	Year	Reference
Strait of Juan de Fuca								
Dungeness R.	Sp		10	63	25	2	1986-94	PNPTC 1995, WDFW 1995
Elwha R.	Su/F	1	13	57	29	1	1992-94	WDF et al. 1993, PNPTC 1995, WDFW 1995
Hoko R.	F	2	9	43	40	7	1984-93	WDF et al. 1993, WDFW 1995
Washington Coast								
Quillayute R. (gen)	Sp		6	35	50	10	1987-94	QTNR 1995
Hoh R.	Sp/Su		6	25	54	15	1974-94	WDF et al. 1993, HIT 1995
Queets R.	Sp/Su	<1	14	21	49	16	1974-93	WDF et al. 1993, QNTR 1995
Quillayute R. (gen)	Su		2	28	52	18	1989-94	QNTR 1995
Quillayute R.	F	1	2	14	62	21	1984-89	QNTR 1995
Queets R.	F	<1	17	30	43	10	1977-93	WDF et al. 1993, QNTR 1995
Quinault R.	Sp/Su		8	25	52	14	1977-93	WDF et al. 1993, QNTR 1995
Quinault R.	F	<1	17	40	35	8	1975-93	WDF et al. 1993, QNTR 1995
Humptulips R.	F	<1	13	25	46	16	1976-93	QNTR 1995
Humptulips R.	F	7	20	31	39	8	1970-93	WDF et al. 1993
Chehalis R.	F	<1	17	24	50	10	1977-93	QNTR 1995
Chehalis R.	F	7	21	31	39	7	1970-93	WDF et al. 1993
Chehalis R.	F	2	16	27	45	9	1970-94	QNTR 1995
John-Elk R.	F							WDF et al. 1993
Willapa Bay	F	1	21	41	34	4	1970-94	WDF et al. 1993
Lower Columbia River								
Cowlitz R.	Sp		32	35	33		1982	Howell et al. 1985, Schreck et al. 1986, WDF et al. 1993
Grays R.	F	5	39	54	1		1978-83	Howell et al. 1985, Hymer et al. 1992a, WDF et al. 1993
Elochoman R.	F	2	47	49	1		1978-83	Howell et al. 1985, Hymer et al. 1992a, WDF et

Appendix B (Continued).

River	Run	2	3	4	5	6+	Year	Reference
								al. 1993
Cowlitz R.	F	14	28	46	12		1982	Howell et al. 1985, Hymer et al. 1992a
Kalama R.	F		34	55	11		1982	Howell et al. 1985, Hymer et al. 1992a
Lewis R.	F	14	16	41	28	2	1978-88	Howell et al. 1985, Schreck et al. 1986, Hymer et al. 1992a, WDFW 1995
E.F. Lewis R.	F	22	19	45	15	<1	1970-1984	Howell et al. 1985, Hymer et al. 1992a
Lewis & Clark R.	F	7	28	63	2		1985	Howell et al 1985, Olsen et al. 1992
Big Cr.	F		10	76	14		1985	Howell et al. 1985, Olsen et al. 1992
Gnat Cr.	F	9	21	59	12		1985	Howell et al. 1985, Olsen et al. 1992
Plympton Cr.	F		19	79	2		1985	Howell et al. 1985
Willamette River								
Clackamas R.	Sp		5	67	29	<1	1978-87	Galbreath 1965, Howell et al. 1985
Upper Willamette R.	F	4	60	34	1		1982	Howell et al. 1985
N. Santiam R.	Sp		4	54	42		1964-69	Galbreath 1965, Howell et al. 1985, Olsen et al. 1992
M.F. Willamette R.	Sp		2	56	41	1	1978-87	Galbreath 1965, Howell et al. 1985, Bennett 1988
Mid-Columbia River								
Hood River BPH	F	23	67	10			1981-82	Howell et al. 1985
Wind/L. White Salmon R.	Sp		5	54	41	<1	1971-84	Howell et al 1985, Schreck et al 1986, Hymer et al. 1992a
Wind R.	F (bright)	34	24	35	8		1970-84	Howell et al. 1985, Hymer et al. 1992a
Klickitat R.	Sp	na	16	75	9		1980	Howell et al. 1985, Hymer et al. 1992a
Klickitat R.	F (tule)	5	32	45	22		1981-82	Howell et al. 1985, Hymer et al. 1992a
Deschutes R.	Sp		3	57	43		1974-82	Lindsay et al. 1989
Warm Springs R.	Sp		5	77	18		1975-95	Olsen 1995
Deschutes R.	Sp		2	86	12		1989	Fryer and Schwartzberg 1990
Deschutes R.	F/Su ??	34	30	32	5	<1	1975-80	Howell et al 1985, Jonasson and Lindsay 1988
N.F. John Day R.	Sp		3	76	22		1978-84	Burck et al. 1979

Appendix B (Continued).

River	Run	2	3	4	5	6+	Year	Reference
M.F. John Day R.	Sp		2	81	17		1975-80	Burck et al. 1979, Olsen 1994d
M.S. John Day R.	Sp		4	77	19			Burck et al. 1979, Olsen 1994d
Snake River								
Tucannon R.	Sp		1	67	32		1992	Howell et al. 1985, Hymer et al. 1992b, WDFW 1995
Lyons Ferry	Sp		2	67	32	<1	1985-94	WDFW 1995
Snake R.	F	26	19	50	5		1985	Howell et al. 1985, Hymer et al. 1992b, WDF et al. 1993
M.S. Snake R.	Sp		9	59	32		1983-86	Keifer et al. 1992
Grande Ronde R.	Sp		4	79	17	<1	1961-76	Howell et al. 1985
Wenaha R.	Sp		0	55	45		1986-88	Chapman et al. 1991
Minam R.	Sp	0	10	65	26	<1	1961-76	Howell et al. 1985
Imnaha R.	Sp		5	40	50		1961-76	Howell et al. 1985
M.F. Clearwater R.	Sp		7	66	27		1969-86	Keifer et al. 1992
Rapid R.	Sp		11	71	19			Howell et al. 1985, Schreck et al. 1986
Big Sheep Cr.	Sp		<1	29	71		1986-88	Chapman et al. 1991
M.F. Salmon R.	Sp		3	38	59		1957-62	Keifer et al. 1992
Salmon R.	Sp		11	43	50		1957-62	Keifer et al. 1992
Upper Salmon R.	Sp		18	29	54			Keifer et al. 1992
Little Salmon R.	Su		23	73	5			Keifer et al. 1992
Salmon R.	Su		28	61	11		1980-86	Keifer et al. 1992
Pahsimeroi R.	Su		17	54	29			Keifer et al. 1992
Upper Columbia River Basin								
Upper Yakima R.	Sp		14	83	3			Howell et al. 1985, Hymer et al. 1992b
Upper Yakima R.	Sp		3	94	3	<1	1989-92	WDFW 1995
Naches R.	Sp		6	63	31			Howell et al. 1985, Hymer et al. 1992b

Appendix B (Continued).

Naches R.	Sp		2	52	47	<1	1989-93	Major and Mighell 1969, WDFW 1995
American R.	Sp		2	24	74	<1		Major and Mighell 1969, Hymer et al. 1992b, WDFW 1995
Yakima R.	F	2	23	64	11		1991-93	Howell et al. 1985, Hymer et al. 1992b, WDFW 1995
Marion Drain (Yak.)	F	20	51	22	5		1989-93	Howell et al. 1985, Hymer et al. 1992b, WDFW 1995
Hanford Reach	F	16	27	35	22		1981-82	Howell et al. 1985, Hymer et al. 1992b
Chiwawa R.	Sp		1	56	43			WDF et al. 1993, Chapman et al. 1995
Nason Cr.	Sp		4	63	37			French and Wahle 1959, Hymer et al. 1992b, Chapman et al. 1995
Little Wenatchee R.	Sp		3	44	53			French and Wahle 1959, Hymer et al. 1992b, Chapman et al. 1995
Wenatchee R.	Sp		5	76	19		1989	Fryer and Schwartzberg 1990
White R.	Sp		<1	63	37			French and Wahle 1959, Hymer et al. 1992b, Chapman et al. 1995
Wenatchee R.	Su	<1	8	34	46	3		French and Wahle 1959, Hymer et al. 1992b, Chapman et al. 1995
Wenatchee R.	Su	<1	3	44	54	<1	1993	Howell et al. 1985, Hymer et al. 1992b, Peven and Truscott 1995
Entiat R.	Sp		1	72	28			Hymer et al. 1992b, Chapman et al. 1995
Methow R.	Sp		4	59	38			Hymer et al. 1992b, Chapman et al. 1995
Methow R.	Sp		7	62	32			USFS 1995
Twisp R.	Sp		<1	52	48			Hymer et al. 1992b, Chapman et al. 1995
Chewuch R.	Sp		4	65	34			Hymer et al. 1992b, Chapman et al. 1995
Methow R.	Su		9	27	57	5		Howell et al 1985, Chapman et al. 1994
Okanogan R.	Su		21	44	34	1		Howell et al. 1985, Chapman et al. 1994
Oregon Coast								
Umpqua R.	Sp		5	69	24	2		Nicholas and Hankin 1988
Rogue R.	Sp	8	25	40	23	4	1974-75	Schluchter and Lichatowich 1977

Appendix B (Continued).

Rogue R.	Sp	8	18	65	9			Nicholas and Hankin 1988
Nehalem R.	Su/F	2	12	26	57	4		Nicholas and Hankin 1988
Wilson R.	F	2	9	27	49	16		Nicholas and Hankin 1988
Trask R.	F		7	48	32	14		Nicholas and Hankin 1988
Tillamook R.	F	4	9	45	36	8		Nicholas and Hankin 1988
Nestucca R.	F	4	6	36	38	18		Nicholas and Hankin 1988
Nestucca R.	Early (?)	5	9	38	48			Nicholas and Hankin 1988
Salmon R.	F	18	13	29	72	6		Nicholas and Hankin 1988
Siletz R.	F	1	8	27	48	20		Nicholas and Hankin 1988
Yaquina R.	F	7	21	48	25	1		Nicholas and Hankin 1988
Alsea R.	F	27	10	28	33	4	1977	Nicholas and Hankin 1988
Siuslaw R.	F	13	16	33	36	<1		Nicholas and Hankin 1988
Upper Umpqua R.	F	18	46	37	1			Nicholas and Hankin 1988
Coquille R.	F	18	18	44	24	1	1978-80, 86	Nicholas and Hankin 1988
Sixes R.	F	6	15	47	32	2		Uremovich 1977, Nicholas and Hankin 1988
Elk R.	F	26	17	40	17	2		Burck and Reimers 1978, Nicholas and Hankin 1988
Rogue R.	F	27	27	40	6			Nicholas and Hankin 1988
Pistol R.	F	6	9	67	18			Nicholas and Hankin 1988
Chetco R.	F	22	19	26	33	1	1966, 86	Nicholas and Hankin 1988
California Coast								
Smith R.	Late F	17	30	41	11	1	1980-95	Waldvogel 1995
Eel R.	F	11	40	29	22		1920-92	Grass 1995
Little R.	F	8	53	34	5		1985-95	Mosser 1995
Russian R.	F	5	90	5				Gunter 1995
Klamath River								
Klamath R.	Sp		13	82	5		1992	Tuss et al. 1987, Craig and Fletcher 1994
Trinity R.	Sp	20	35	39	8		1992-93	Moffett and Smith 1950, CDFG 1995

Appendix B (Continued).

S.F. Trinity R.	Sp	22	40	32	6		1992	Dean 1995
Klamath R. (gen)	F	17	40	41	2		1978-92	USFWS 1994
Klamath R.	F		14	70	14	2	1919-20, 1923	Snyder 1931
Klamath R.	F	26	46	29	3		1979-86	Tuss et al. 1987
Salmon R.	F	18	46	34	1	<1	1990-93	USFWS 1995
Scott R.	F	21	39	39	1	<1	1977-95	Leidy and Leidy 1984, Pisano 1995, USFWS 1995
Shasta R.	F	20	39	40	1	<1	1986-94	CDFG 1995
Upper Klamath R.	F	6	17	70	6		1992	Leidy and Leidy 1984, Craig and Fletcher 1994
Trinity R.	F	20	45	33	2		1991-94	Leidy and Leidy 1984, USFWS 1995, Craig 1995
SF Trinity R.	F	46	46	7	<1		1984-86	Sullivan 1989
California Central Valley								
Central Valley	All	1	16	47	33	2	1919, 21	Clark 1929
Sacramento R.	W	1	91	8				Fisher 1994
Sacramento R.	Sp	9	56	31	3	2	1939	Calkins et al. 1940
Sacramento R.	Sp	2	87	11				Fisher 1994
Sacramento R.	F	27	15	59	<1		1939	Calkins et al. 1940
Sacramento R.	F	3	77	20				Fisher 1994
Sacramento R.	F	4	35	50	10	1	1950-59	Reisenbichler 1986
Sacramento R.	F	24	57	19	2		1973-77	Reisenbichler 1986
Sacramento R.	Late F	2	57	41				Fisher 1994
American R.	F	1	93	6				Clark 1929
San Joaquin R. (gen)	F	15	45	35	5		1990-95	Neillands 1995
Toulumne R.	F	30	50	19	1		1990-95	Neillands 1995
Merced R.	F	30	50	19	1		1990-95	Neillands 1995

APPENDIX C:

REPRODUCTIVE TRAITS

Appendix C. Summary of female fecundity data (average female size, average fecundity and egg size, and fecundity and egg size data standardized for female size) for selected stocks of chinook salmon in Asia and North America. Stocks are identified according to run timing (Sp-spring, Su-summer, F-fall, W-winter), life-history type (S-stream, O-ocean), and geographic location (C-coastal, I-inland). For egg weights, (d) indicates weight was estimated from egg diameter, and (w) indicates that weight was directly measured. FL=Fork Length. POH=Post-orbital hyporal length.

River	Run	Stream/ Ocean	Coastal/ Inland	FL (cm)	Fecundity	Fecundity (740 mm POH)	Egg Wt. (g)	Egg Size (740 mm POH)	Sample Year(s)	Reference
Asia										
Kamchatka R.	Su	S	C	90.3	6855		0.160 (d)		1928	Kuznetov 1928
Kamchatka R.	Su	S	C		6623		0.248 (w)			Smirnov 1975
Alaska										
Yukon R.	Su	S	I	94.1	8668	8409				Healey and Heard 1984
Tanana R.	Su	S	C	99.5	10061	8930				Skaugstad and McCraken 1991
Nushagak R.	Su	S	C	98.1	10137	9427				Healey and Heard 1984
Cook Inlet	Su	S	C	94.3	8341	8047				Healey and Heard 1984
Kenai R.	Su	S	C	113.7	12884	8439				Roni 1992
Taku R.	Su	S	C	92.7	5504	5469				Healey and Heard 1984
Nass R.	Su	O/S	C	117.5	6531	6203				Healey and Heard 1984
King Salmon R.	Su	S	C	85.9	5907					Halupka et al. 1993
Skeena R.	Su	O/S	C	117.5	6789	6108				Healey and Heard 1984
British Columbia										
Wannock R.	Su	O/S	C	107.3	9454	7614	0.421 (d)		1991	Roni 1992
Quinsam R.	Su	O	C	108.7	6720	4939				Healey and Heard 1984
Puntledge R.	Su	O	C/I	88.5	4604	5300	0.242 (d)	0.241 (d)		Healey and Heard 1984
Qualicum R.	Su	O	C	93.2	4982	4031	0.376 (d)	0.376 (d)		Healey and Heard 1984, Lister 1990
Robertson Cr.	Su	O	C	89.8	4452	4568				Healey and Heard 1984
Nitinat R.	Su	O	C	94.9	4991	4773				Healey and Heard 1984
Kitsumkalum R.	Su	O	C				0.452 (d)		1991	Roni 1992
Kitmit R.	Su	O	C	99.0			0.376 (d)		1986	Beacham and Murray 1989, Roni 1992

Appendix C (Cont.).

River	Run	Stream/ Ocean	Coastal/ Inland	FL (cm)	Fecundity	Fecundity (740 mm POH)	Egg Wt. (g)	Egg Size (740 mm POH)	Sample Year(s)	Reference
Bella Coola R.	Su	O	C				0.406 (d)		1986	Beacham and Murray 1989
Quesnel R.	Su	O	C	90.8	6653		0.242 (d)		1986	Shepherd et al. 1986, Beacham and Murray 1989
Torpy R.	Su	S	I				0.185 (d)			Shepherd et al. 1986
Slim R.	Su	S	I				0.194 (d)			Shepherd et al. 1986
Sturat R.	Su	S	I				0.202 (d)			Shepherd et al. 1986
Cheakamus R.	Su	S	C			7300	0.253 (d)	0.242 (d)		Lister 1990
Harrison R.	Su	O	C	92.9				0.286 (d)		Lister 1990, Roni 1992
Cowichan R.	Su	O	C					0.362 (d)		Lister 1990
Campbell R.	Su	O	C			4900		0.391 (d)		Lister 1990
Puget Sound										
Elwha R.	F	O	C	89.3	7861		0.362 (d)		1991	Roni 1992
UW- Green R.	F	O	C				0.298 (d)		1992	Gray 1965, Roni 1992
Nooksack R.	Sp	O	C		4818					Fuss and Ashbrook 1995
Samish R.	F	O	C		4618		0.301 (d)		1978-94	Kurras 1996, Fuss and Ashbrook 1995
Skagit R.	Su	O	C		4483		0.361 (w)		1995	Kurras 1996, Fuss and Ashbrook 1995
Skagit R.	Sp	O	C	91.3	4063		0.249 (w)		1994-95	Kurras 1996, Fuss and Ashbrook 1995
Wallace R.	Su	O	C		4772					Fuss and Ashbrook 1995
Stilliguamish R.	F	O	C	88.7						Roni 1992
White River R.	Sp	O	C		3385		0.258 (w)		1991-93	Appleby and Keown 1995
Washington Coast										
Humptulips R.	F	O	C				0.378 (w)			Fuss and Ashbrook 1995
Sol Duc R.	Sp	O	C				0.305 (w)			Allan 1996
Quinault R.	F	O	C							

Appendix C (Cont.).

River	Run	Stream/ Ocean	Coastal/ Inland	FL (cm)	Fecundity	Fecundity (740 mm POH)	Egg Wt. (g)	Egg Size (740 mm POH)	Sample Year(s)	Reference
Columbia River Basin										
Big Cr.	F	O	Lower River	87.6	5504					Olsen et al. 1992
Abernathy R.	F	O	Lower River	85.5	5049	5292	0.275 (d)	0.314 (d)	1970	Fowler 1972
Cowlitz R.	Sp	O	Lower River				0.324 (w)			Hymer et al. 1992a, WDFW 1996
Cowlitz R.	F	O	Lower River	84.4	3898		0.378 (w)		1983-90	Hymer et al. 1992a, WDFW 1996
Kalama R.	Sp	O	Lower River	84.9	4491		0.280 (w)		1980's	Hymer et al. 1992a, Casteneda 1996
Kalama R.	F	O	Lower River	87.1	4731		0.301 (w)			Hymer et al. 1992a, Casteneda 1996
Speelyai R.	Sp	O	Lower River	77.3	4083				1985	Hymer et al. 1992a
Lewis R.	F	O	Lower River	87.6	4429				1982	Hymer et al. 1992a
Carson NFH	Sp	S	Lower River	78.3	4300				1982	Hymer et al. 1992a
Clackamas R.	?	O	Lower River		5000		0.143 (d)		1900	Bowers 1900
Clackamas R.	Sp	O	Lower River		5179		0.170 (d)		1993-95	Olsen et al. 1992, ODFW unpubl.
Willamette R.	Sp	O	Lower River	80.4	4258-4800				1983	Rich 1940a, Mattson 1963, Howell et al. 1985
Bonn. URB	F	O	Lower River	81.0	4502				1977-83	Howell et al. 1985
Deschutes R.	F	O	Lower River	80.0	4439				1977-79	Howell et al. 1985, Olsen et al. 1992
Warm Springs H.	Sp	S	Lower River	71.5	3246		0.183 (w)		1992-95	Lindsay et al. 1989, Watkins[1]
Klickitat R.	Sp	S	Lower River	85.8	4188		0.260 (w)			Hymer et al. 1992a, Roni 1992, Anderson[2]
Yakima R.	Sp	S	I	76.2		8711				Fast et al. 1986, YIN 1996
Yakima/Naches R.	Sp	S	I	79.8	5245				1984	Fast et al. 1986
Upper Yakima R.	Sp	S	I	68.2	3523				1969	Major and Mighell 1969
Leavenworth R.	Sp	S	I	78.4	4400					Hymer et al. 1992, Roni 1992
Rock Island Dam	Su	O	I	83.5	4885	5425			1937	WDF et al. 1938

Appendix C (Cont.).

River	Run	Stream/ Ocean	Coastal/ Inland	FL (cm)	Fecundity	Fecundity (740 mm POH)	Egg Wt. (g)	Egg Size (740 mm POH)	Sample Year(s)	Reference
Wells H.	Su	O	I	90.4	5041		0.284 (w)		1987-82, 94, 95	Hymer et al. 1992b, Moore [3]
Wells H.	Su	O	I			5568				Mathews and Meekin 1971
Methow R.	Sp	S	I	77.1	4958	5893			1993-94	Roni 1992, Chapman et al. 1995
Methow R.	Sp	S	I	83.0	4529				1993	Bartlett and Bugert 1994
Methow R.	Sp	S	I	79.5	4380		0.253 (w)		1992	Bartlett and Bugert 1994
Snake River Basin										
Lyons Ferry H.	F	O	I		3102	4011	0.276 (w)		1995	Mendel et al. 1996
Snake R.	Sp	S	I	77.9	3923				1985-87	Keifer et al. 1992
Tuccannon R.	Sp	S	I	75.9	4007				1986-87	Hymer et al. 1992b, Roni 1992
Imnaha R.	Sp	S	I	86.8	4927				1983-85	Olsen et al. 1992
Grande Ronde R.	Sp	S	I	81.1	4086				1983-89	Olsen et al. 1992
Dworshak NFH	Sp	S	I				0.151 (d)		1988-90	Roseburg 1996
Rapid R.	Sp	S	I	80.4	4535				1982-91	Keifer et al. 1992
Sawtooth R.	Sp	S	I	75.9	5315				1981-91	Keifer et al. 1992
M.F. Salmon R.	Sp	S	I	85.2	5607				1961-69	Keifer et al. 1992
Pahsimeroi R.	Su	S	I		5290				1973-91	Keifer et al. 1992
S.F. Salmon R.	Su	S	I		4100				1980-94	Howell et al. 1985
Oregon Coast										
Alsea R.	F	O	C	96.7	4994	4689	0.391 (d)			Nicholas and Hankin 1988
Chetco R.	F	O	C	92.7	4218	4213	0.391 (d)	0.396 (d)	1972	Nicholas and Hankin 1988
Elk R.	F	O	C	90.2	4920	5168	0.345 (d)			Nicholas and Hankin 1988
Nestucca R.	F	O	C	95.0	5242	5071	0.362 (d)	0.361 (d)		Nicholas and Hankin 1988
Salmon R.	F	O	C	100.2	5390	5016	0.407 (d)	0.359 (d)	1985	Nicholas and Hankin 1988
SixesR.	F	O	C	93.7	5359	5264	0.319 (d)	0.314 (d)	1985	Nicholas and Hankin 1988
Trask R.	F	O	C		5500-6000		0.454 (d)		1991	Kreeger 1995

Appendix C (Cont.).

River	Run	Stream/ Ocean	Coastal/ Inland	FL (cm)	Fecundity	Fecundity (740 mm POH)	Egg Wt. (g)	Egg Size (740 mm POH)	Sample Year(s)	Reference
Trask R.	F	O	C	93.9	5140	5058	0.302 (d)	0.293 (d)	1983	Nicholas and Hankin 1988
Trask R.	Sp	O	C	89.0	5190	5520	0.340 (d)	0.370 (d)	1986	Nicholas and Hankin 1988
Umpqua R.	Sp	O	C	82.1	3826	4994	0.292 (d)	0.351 (d)	1986	Nicholas and Hankin 1988
Rogue R.	Sp	O	C	-	3000-3700		0.231 (d)		1991	Kreeger 1995
Rogue R.	F	O	C	-		4582		0.313 (d)	1986	Nicholas and Hankin 1988
Rogue R.	Sp	O	C	83.9	3890	4443	0.318 (d)	0.406 (d)	1985	Nicholas and Hankin 1988
Klamath and Trinity River Basins										
Fall Cr. H.	F	O	I	73.6	2902		0.228 (d)		-	Leitritz and Lewis 1980
Klamath R.	F	O	C	82.6	3754	4381	0.391 (d)		1919-21	McGregor 1922, Snyder 1931
Trinity R.	F	O	C	77.1	3498	3998			1944-45	Moffett and Smith 1950
Sacramento and San Joaquin River Basins										
Suisun Bay	Mixed	O	I	92.4	7298	7334			1919-21	McGregor 1923b
Tehama	F	O	I	83.1	7279	9287.2			1972-73	Johnson et al. 1973, USFWS 1978
Battle & Mill Ck	Mixed	O	I		5477-6534				1909-38	Needham et al. 1940
Battle Ck	Mixed	O	I		6253				1939	Needham et al. 1940
Baird NFH	Sp	O	I				0.145 (d)		1888	Page 1888
Feather R.	Sp	O	I		5423				1993-94	Broddrick 1995
Coleman NFH	W	O	I	77.3	4495	6270.2	0.161 (d)		1991-92	USFWS 1996a

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[1] J. Watkins, Warm Springs NFH, P.O. Box 790, Warm Springs, OR 97761. Pers. commun., April 1996.

[2] T. Anderson, Hatchery Manager, Washington Department of Fish and Wildlife, Klickitat Hatchery, 301 Fish Hatchery Road, Glenwood, WA 98619-9102. Pers. commun., April 1996.

[3] J. Moore, Hatchery Manager, WDFW, Wells Hatchery, HC 88, Azwell Rt. Box 2A, Pateros, WA 98846. Pers. commun., April 1996.

APPENDIX D:

HATCHERY RELEASES

Appendix D: Hatchery chinook salmon releases, listed by ESU. Duration indicates the time frame of the releases, years indicates the total number of years that fish were actually released within the time frame. The majority of spring-run salmon were released as yearling smolts. Most ocean-type fall- and summer-run chinook salmon were released as subyearlings. Winter-run chinook salmon were primarily released as both yearlings and subyearlings. No releases of eggs or fry (<5g) are included here. Data before 1950 are incomplete (NRC 1995). Releases in bold indicate introductions from outside (o/s) the ESU. Stocks of unknown origin are assumed to be from within (w/i) the ESU. Fish releases derived from adults returning to that river are also assumed to be native regardless of past introductions, unless the river historically never contained a run.

Abbreviations:
COOP - a government agency and private entity cooperative project
H- hatchery
Mix - a mix of two or more stocks from the same area
LCR- lower Columbia R.
MCR - mid-Columbia R.
NFH- National Fish Hatchery
SW- fish released directly into saltwater
X- A cross between two different stocks
/ - A mix of stocks from different areas

				Total Releases		Source Percentage	
Watershed	Duration	Years	Source	(w/i ESU)	(o/s ESU)	In	Out
1) Sacramento R. Winter-Run ESU							
Sacramento R.	1962,64	2	Coleman NFH	107,516			
	1979,83,90	3	Coleman NFH	25,064			
	1966-68	3	Keswick Dam	69,300			
	1990-94	5	Keswick Dam	30,356			
	1992	1	Red Bluff Dam	12,328			
	1991,92	2	Sacramento R.	12,439			
	1993-95	3	Sacramento R.	90,168			
				347,171	0	100	0
			Totals for ESU #1:	347,171	0	100	0
2) Central Valley Spring-Run ESU							
Sacramento R.	1983-93	11	Feather R. H.	3,414,583			
	1943-52	8	Sacramento R.	6,988,658			
				10,403,241	0	100	0
Feather R.	1969-90	21	Feather R. H.	6,532,724			
				6,532,724	0	100	0

Yuba R.	1978-85	4	Feather R. H.	1,237,039			
				1,237,039	0	100	0
Lower Sacramento R.	1974-80	4	Feather R. H.	1,370,475			
				1,370,475	0	100	0
Benicia	1982-92	7	Feather R. H.	14,476,890			
				14,476,890	0	100	0
Vallejo	1983-86	4	Feather R. H.	2,067,786			
				2,067,786	0	100	0
Maritime Academy	1982-85	4	Feather R. H.	169,796			
				169,796	0	100	0
San Francisco Bay	1987	1	Feather R. H.	440,725			
				440,725	0	100	0
Mokelumne R.	1989,90	2	Feather R. H.	2,482,000			
				2,482,000	0	100	0
			Totals for ESU #2:	39,180,676	0	100	0

3) Central Valley Fall-Run ESU

Sacramento R.	1944	1	Balls Ferry	7,662,650			
	1966-73	8	Battle Cr.	55,930,000			
	1968-94	25	Central Valley Mix	77,017,888			
	1950-94	37	Coleman NFH	783,350,901			
	1969-94	26	Feather R. H.	32,814,226			
	1979	1	Mad R. H.		25,175		
	1988-89	2	Merced H.	4,190			
	1972-88	13	mid-Sacramento R.	16,694,596			
	1991	1	Mokelumne R. H.	38,577			
	1976-87	12	Sacramento R.	11,841,587			
	1978	1	Trinity H.		839,400		
	1975-87	13	unknown	132,250,764			
				1,117,605,379	864,575	100	0
Feather R.	1970,78	1	Coleman NFH	990,388			
	1968-94	25	Feather R. H.	56,255,861			
	1969-92	9	Nimbus H.	15,071,785			
	1978	1	Red Bluff/Coleman NFH	78,188			
	1992	1	Samish H.		11,700		
				72,396,222	11,700	>99	<1

Appendix D (Continued).

Yuba R.	1978-87	3	Feather R. H.	82,117			
	1981-89	4	Yuba R.	130,397			
				212,514	0	100	0
American R.	1958-60	3	Coleman NFH	2,998,897			
	1982-89	4	Feather R. H.	362,188			
	1957-94	33	Nimbus H.	220,094,657			
				223,455,742	0	100	0
San Joaquin R.	1974-94	15	Central Valley Mix	8,726,804			
	1954	1	Coleman NFH	2,650			
	1976,94	2	Feather R. H.	99,760			
	1981-94	8	Merced H.	445,993			
	1979-87	8	San Joaquin R.	1,595,476			
	1976	1	unknown	82,442			
				10,953,125	0	100	0
Merced R.	1992	1	Feather R. H.	1,521,560			
	1971-94	16	Merced H.	2,376,880			
	1978-93	6	San Joaquin R.	306,434			
	1971-74	4	Stanislaus R.	690,500			
	1977	1	unknown	100,000			
				4,995,374	0	100	0
Tuolumne R.	1990,94	2	Merced H.	237,106			
	1986-91	4	San Joaquin R.	516,716			
	1990	1	Tuolumne R.	81,285			
				835,107	0	100	0
Stanislaus R.	1982-89	3	Merced H.	280,335			
	1986	1	San Joaquin R.	110,175			
	1988	1	Stanislaus R.	206,370			
				596,880	0	100	0
Mokelumne R.	1977-94	14	Central Valley Mix	6,385,298			
	1954-85	7	Coleman NFH	3,964,013			
	1977-94	16	Feather R. H.	31,363,711			
	1964-94	15	Mokelumne R. H.	3,527,414			
	1976	1	unknown	166,300			
				45,406,736	0	100	0
Suisun Bay	1981-94	13	Central Valley Mix	43,134,918			
	1982-92	3	Coleman NFH	12,371,975			
	1978-94	17	Feather R. H.	34,392,589			
	1984	1	Merced H.	4,950			
	1988	1	mid-Sacramento R.	302,994			
	1992	1	Mokelumne R. H.	65,973			
	1983-85	3	San Joaquin R.	102,212			

Appendix D (Continued).

	1983	1	unknown	50,340			
				90,425,951	0	100	0
San Pablo Bay	1984-94	9	Central Valley Mix	21,608,252			
	1982-93	9	Feather R. H.	46,734,026			
	1985	1	Merced H.	770,679			
	1981	1	Mokelumne R. H.	33,535			
	1980-94	8	Nimbus H.	17,356,190			
	1983,85	2	unknown	100,663			
				86,603,345	0	100	0
3) Central Valley Late Fall-Run ESU							
Sacramento R.	1983-93	7	Battle Cr./Keswick Dam	4,833,032			
	1986-94	7	Coleman NFH	4,483,565			
	1974-94	13	Keswick Dam	10,833,051			
	1975-94	9	Sacramento R.	1,806,690			
	1980-88	8	unknown	7,822,934			
				29,779,272	0	100	0
San Joaquin R.	1993	1	Coleman NFH	59,663			
				59,663	0	100	0
			Totals for ESU #3:	1,683,325,310	876,275	>99	<1
4) Southern Oregon and California Coastal ESU (Fall Run)							
Small Southern Oregon R. Basins	1988-94	7	Elk R. H.		1,414,032		
				0	1,414,032	0	100
Upper Rogue R.	1978	1	Applegate R.	35,552			
	1957-68	5	Butte Falls H.	199,108			
	1975-91	10	Cole Rivers H.	530,274			
	1969-71	3	Lobster Cr.	370,279			
	1992,93	2	Lower Rogue R.	44,476			
	1966	1	unknown	39,994			
				1,219,683	0	100	0
Applegate R.	1982	1	Applegate R.	70,930			
				70,930	0	100	0
Big Butte Cr.	1955-69	10	Butte Falls H.	416,524			
	1966	1	Rock Cr. H.		780		
	1954	1	unknown	27,562			
				444,086	780	100	0

Appendix D (Continued).

Lower Rogue R.	1986,87	2	Cole Rivers H.	311,951			
	1968-90	5	Lobster Cr.	135,324			
	1973	1	unknown	5,100			
				452,375	0	100	0
Libby Pond	1964,65	2	Coquille R.		111,510		
	1966	1	Diamond Lk.	138,656			
	1960	1	tules	24,156			
				162,812	111,510	59	41
Lobster Cr.	1963,65	2	Coquille R.		71,322		
	1967-90	9	Lobster Cr.	497,771			
	1966	1	unknown	41,362			
				539,133	71,322	88	12
Hunter Cr.	1974	1	Chetco R.	7,520			
	1990-94	3	Hunter Cr.	66,288			
				73,808	0	100	0
Pistol R.	1988	1	Chetco R.	14,931			
	1989-94	5	Pistol R.	94,775			
				109,706	0	100	0
Burnt Hill Cr.	1982	1	Applegate R.	59,056			
	1980	1	Lobster Cr.	99,032			
	1973	1	unknown	5,100			
				163,188	0	100	0
Chetco R.	1955	1	Butte Falls H.	4,000			
	1974-93	18	Chetco R.	6,956,460			
	1985-92	4	Coquille R.		137,816		
	1974	1	Elk R. H.		35,460		
	1969-77	6	unknown	1,448,675			
				8,409,135	173,276	98	2
Winchuck R.	1988	1	Chetco R.	10,070			
				10,070	0	100	0
Smith R.	1973-94	14	Smith R.	1,871,032			
	1983	1	unknown	23,294			
				1,894,326	0	100	0
Jolly Giant Cr.	1985	1	Rowdy Cr. H.	1,027			
				1,027	0	100	0
Lower Klamath R.	1981-93	12	Klamath R.	1,077,603			
				1,077,603	0	100	0

Appendix D (Continued).

Prairie Cr.	1986-93	4	Prairie Cr./Lostman Cr.	205,245			
	1965,87	2	unknown	67,187			
				272,432	0	100	0
Redwood Cr.	1984-86	3	Lostman Cr.	44,184			
	1985-94	6	Redwood Cr.	172,493			
	1992	1	Eel R.	69,201			
	1964-68	4	unknown	1,978,059			
				2,263,937	0	100	0
Little R.	1986-92	4	Little R.	191,787			
				191,787	0	100	0
Strawberry Cr.	1993	1	Freshwater Cr.	10,000			
				10,000	0	100	0
Mad R.	1974	1	Freshwater Cr./Mad R. H.	139,887			
	1972-93	17	Mad R. H.	3,569,419			
	1971	1	Minter Cr. H.		648,120		
	1983	1	unknown	51,654			
				3,760,960	648,120	85	15
Freshwater Cr.	1987	1	Cochran Pond	14,189			
	1986-94	7	Freshwater Cr.	59,057			
	1988	1	Mad R. H.	4,088			
	1970-72	3	unknown	584,000			
				661,334	0	100	0
Eel R.	1973-94	12	Eel R.	2,147,443			
	1992-93	2	Freshwater Cr.	75,500			
	1972-77	6	Iron Gate H.		625,853		
	1984-88	4	Redwood Cr.	20,986			
				2,243,929	625,853	78	22
Mattole R.	1985-92	6	Mattole R.	137,714			
				137,714	0	100	0
Tenmile R.	1986-87	2	Tenmile R.	14,000			
				14,000	0	100	0
Russian R.	1956-64	3	Coleman NFH		1,999,400		
	1982-94	6	Feather R. H.		1,154,161		
	1975	1	Iron Gate H.		73,800		
	1983	1	Mad R. H.		9,250		
	1990-94	5	Nimbus H.		648,242		
	1982	1	Ocean King Private	58,500			
	1983	1	Silver King Private	11,500			
	1969,70	2	unknown	879,885			

Appendix D (Continued).

	1982-93	8	Warm Springs H.	635,888			
	1985	1	Warm Springs H./Wisconsin		98,400		
	1982-86	5	Wisconsin		1,173,077		
				1,585,773	5,156,330	24	76
Bodega Bay	1979	1	Feather R. H.		12,040		
				0	12,040	0	100
San Francisco Bay	1984-87	4	American R.		233,810		
	1976-94	17	Feather R. H.		4,389,796		
	1980-89	6	Central Valley Mix		1,696,784		
	1989	1	Merced H.		867,700		
	1983,85	2	unknown	75,340			
				75,340	7,188,090	1	99
Davenport Landing	1980-85	6	unknown	922,491			
				922,491	0	100	0
Monterey Bay	1992	1	Central Coast Salmon	1,628			
	1992	1	Feather R. H.		123,722		
				1,628	123,722	1	99
Moss Landing	1992	1	Central Coast Salmon	429			
	1992	1	Feather R. H.		7,565		
	1992	1	Merced H.		18,536		
	1993	1	Moss Landing COOP	31,975			
				32,404	26,101	55	45
Port San Luis	1987	1	Minnesota		51,082		
	1991	1	Oregon Aqua Foods		65,500		
	1991	1	Samish H.		15,000		
	1991	1	San Louis R.	7,000			
	1991	1	unknown	500			
				7,500	131,582	5	95
Avila Port	1992-93	2	Feather R. H.		103,900		
	1985-86	2	Minnesota		115,991		
				0	219,891	0	100
Pierpont Bay	1992	1	Feather R. H.		4,600		
				0	4,600	0	100
Channel Island	1990	1	unknown	40,000			
				40,000	0	100	0
4) Southern Oregon and Coastal California ESU (Spring Run)							
Applegate R.	1980-90	3	Cole Rivers H.	220,877			

Appendix D (Continued).

				220,877	0	100	0
Big Butte Cr.	1972	1	Butte Falls H.	1,369			
				1,369	0	100	0
Rogue R.	1963-72	6	Butte Falls H.	498,402			
	1974-93	20	Cole Rivers H.	22,213,191			
	1963	1	Roaring R.	9,410			
				22,721,003	0	100	0
Burnt Hill Cr.	1983,89	2	Burnt Hill Cr.	363,396			
	1984-88	5	Pacific Salmon Ranch	1,648,168			
	1980-90	7	Rogue R.	3,819,192			
				5,830,756	0	100	0
Chetco R.	1986	1	Coquille R.		8,568		
				0	8,568	0	100
Eel R.	1979	1	Trinity H.		5,000		
				0	5,000	0	100
Tenmile R.	1979	1	Trinity H.		400,418		
				0	400,418	0	100
Monterey Bay	1985	1	Feather R. H.		50,056		
				0	50,056	0	100
			Totals for ESU #4:	55,623,116	16,371,291	77	23

5) Upper Klamath and Trinity Rivers ESU (Fall Run)

Klamath R.	1992	1	Eel R.		13,824		
	1966-94	27	Klamath R.	197,632,629			
	1985	1	Mad R. H.		6,688		
	1992	1	Mattole R.		6,100		
	1987	1	Redwood Cr.		16,498		
	1976	1	Trinity H.	819,000			
	1985-86	2	unknown	10,297			
				198,461,926	43,110	100	0
Trinity R.	1977-86	3	Klamath R.	258,446			
	1969-94	26	Trinity H.	68,248,736			
				68,507,182	0	100	0
Trinity R.	1964-69	6	Trinity H. (spring/fall mix)	19,074,333			
				19,074,333	0	100	0

5) Upper Klamath and Trinity Rivers ESU (Spring Run)

Appendix D (Continued).

Klamath R.	1968-77	10	Iron Gate H.	202,860			
				202,860	0	100	0
Trinity R.	1969-94	26	Trinity H.	40,905,753			
				40,905,753	0	100	0
			Totals for ESU #5:	286,246,301	43,110	>99	<1
6) Oregon Coast ESU (Fall Run)							
Necanicum R.	1978-91	3	Cedar Cr. H. (Nestucca R.)	208,037			
	1979-89	4	Trask H.	255,952			
	1976	1	unknown	38,880			
				502,869	0	100	0
Nehalem R.	1938-54	12	Bonneville H.		8,732,060		
	1978,79	2	Cedar Cr. H. (Nestucca R.)	171,158			
	1921-25	2	Nehalem R.	668,753			
	1927-81	4	Trask H.	1,251,421			
	1924-76	7	unknown	2,616,379			
				4,707,711	8,732,060	35	65
Miami R.	1937-52	3	Bonneville H.		543,460		
	1981	1	Trask H.	36,530			
				36,530	543,460	6	94
Kilchis R.	1937	1	Bonneville H.		60,000		
	1948,49	2	LCR/Coast Mix		202,209		
	1981-92	4	Trask H.	90,664			
	1950	1	unknown	107,667			
				198,331	262,209	43	57
Wilson R.	1948,49	2	LCR/Coast Mix		129,404		
	1983	1	Trask H.	269,305			
				269,305	129,404	68	32
Trask R.	1929	1	Cedar Cr. H. (Nestucca R.) and Trask H.	19,300			
	1968	1	Hagerman NFH*		47,932		
	1928-58	6	LCR/Coast Mix		3,588,122		
	1907-23	7	Trask H.	11,173,086			
	1961-93	23	Trask H.	7,489,573			
	1950-77	9	unknown	2,338,557			
				21,020,516	3,636,054	85	15
Tillamook R.	1952	1	Bonneville H.		300,504		
	1967,68	2	Hagerman NFH*		532,154		

Appendix D (Continued).

	1969	1	LCR (tules)		8,370		
	1931-49	4	LCR/Coast Mix		1,152,742		
	1918-64	15	Trask H.	7,686,029			
	1988,92	2	Trask H.	300,296			
	1969	1	unknown	419,191			
				8,405,516	1,993,770	81	19
Three R.	1980-92	7	Cedar Cr. H. (Nestucca R.)	447,403			
	1972	1	Coquille R.	58,441			
	1971	1	Hagerman NFH*		55,325		
	1970	1	Irrigon H.		16,008		
	1976,77	2	unknown	110,083			
				615,927	71,333	90	10
Nestucca R.	1955-57	3	Butte Falls H.		85,786		
	1959-93	17	Cedar Cr. H. (Nestucca R.)	1,411,870			
	1974,75	2	Hagerman NFH*		133,571		
	1968	1	Irrigon H.		53,608		
	1948,49,58	3	LCR/Coast Mix		125,838		
	1950,76	2	unknown	124,281			
				1,536,151	398,803	79	21
Salmon R.	1977-93	16	Salmon R.	3,411,870			
				3,411,870	0	100	0
Siletz R.	1934-52	5	Bonneville H.		2,677,398		
	1948	1	LCR/Coast Mix		25,232		
	1950-69	3	unknown	200,506			
				200,506	2,702,630	7	93
Yaquina R.	1978	1	Alsea H.	99,391			
	1934-51	4	Bonneville H.		457,231		
	1975	1	Elk R. H.	13,000			
	1978	1	Lake Washington		157,287		
	1978-84	5	Oregon Aqua Foods/Yaquina R.	1,081,234			
	1982-89	6	Oregon Aqua Foods	3,085,826			
	1976-81	3	Trask H.	300,868			
	1980	1	Trask H./Yaquina R.	151,915			
	1918	1	unknown	177,000			
	1978-80	3	Yaquina R.	116,200			
				5,025,434	614,518	89	11
Five R.	1991	1	Alsea H.	169,100			
	1949	1	Bonneville H.		186,000		
	1948	1	LCR/Coast Mix		155,000		
	1950,51	2	unknown	422,094			
				591,194	341,000	63	37

Appendix D (Continued).

Alsea R.	1902-40	12	Alsea H.	8,230,775			
	1956-93	23	Alsea H.	2,268,725			
	1911	1	Alsea H. /Rock Cr. H.	495,950			
	1932-54	12	Bonneville H.		8,434,032		
	1936,39	2	Bonneville H./Willamette H.		1,946,140		
	1965	1	Carson NFH		209,322		
	1974,75	2	Elk R. H.	141,753			
	1968-74	6	Hagerman NFH*		1,110,202		
	1944	1	Klaskanine H.		756,370		
	1941,48	2	LCR/Coast Mix		2,336,506		
	1965	1	Roaring R.	5,600			
	1981-93	6	Salmon R.	314,253			
	1974-86	4	Trask H.	401,502			
	1918-77	9	unknown	2,541,412			
				14,399,970	14,792,572	49	51
Siuslaw R.	1934-51	4	Bonneville H.		734,016		
	1983	1	Domsea Farms	21,615			
	1952	1	LCR/Coast Mix		75,340		
	1979-82	4	Siuslaw R.	363,587			
	1950	1	unknown	49,105			
				434,307	809,356	35	65
Umpqua R.	1941-51	4	Bonneville H.		578,808		
	1965	1	Butte Falls H.		63,442		
	1959	1	Carson NFH		31,304		
	1976	1	Coquille R.	6,600			
	1967-72	5	Hagerman NFH*		2,418,605		
	1914	1	LCR (OR)/Willamette H.		103,200		
	1957-93	21	Rock Cr. H.	2,166,813			
	1950	1	unknown	49,105			
				2,222,518	3,195,359	41	59
Millicoma R.	1949	1	Bonneville H.		100,016		
	1975	1	Chetco R.		29,546		
	1990	1	Coos R.	47,825			
	1974,75	2	Elk R. H.	616,513			
	1950,73	2	unknown	398,165			
				1,062,503	129,562	89	11
Coos R.	1978-81	3	Alsea H.	159,185			
	1983-88	6	Anadromous Inc.	22,334,350			
	1941-53	5	Bonneville H.		1,688,518		
	1980,81	2	Cedar Cr. H. (Nestucca R.)	24,761			
	1974. 1975	2	Chetco R.		213,625		
	1901-57	40	Coos R.	65,051,593			
	1979-93	14	Coos R.	1,252,432			

Appendix D (Continued).

	1974,75	2	Elk R. H.	851,398			
	1981,82	2	Jordon Pt. (Private)	156,432			
	1952,58	2	LCR (OR)/Oregon Coast Mix		369,266		
	1985,86	2	Oregon Aqua Foods	155,068			
	1952	1	Oxbow H.		625,117		
	1981,85	2	Tioga Cr.	72,765			
	1959,80,81	3	Trask H.	304,545			
	1909-73	5	unknown	6,275,912			
				96,638,441	2,896,526	97	3
Coquille R.	1941-51	3	Bonneville H.		801,760		
	1975	1	Chetco R.		26,326		
	1902-24	10	Coos R.	15,244,822			
	1984-93	7	Coquille R.	603,172			
	1974-1076	3	Elk R. H.	229,228			
	1950,73	2	unknown	340,611			
				16,417,833	828,086	95	5
Elk R.	1990	1	Chetco R.		37,673		
	1974-93	18	Elk R. H.	9,281,569			
	1969-77	8	unknown	2,872,178			
				12,153,747	37,673	100	0
6) Oregon Coast ESU (Spring-Run)							
Nehalem R.	1944,45	2	Klaskanine H.		994,900		
	1923	1	LCR (OR)		969,625		
	1928,32,39	3	LCR (OR)/Oregon Coast		2,388,000		
	1935	1	Marion Forks H.		954,000		
	1942	1	McKenzie R. H.		1,960,000		
	1926	1	Nehalem R.	803,000			
	1940,44	2	Nehalem R./Trask H.	791,000			
	1926-67	6	Trask H.	3,591,400			
	1925-72	3	unknown	2,331,927			
				7,517,327	7,266,525	51	49
Miami R.	1931	1	LCR (OR)/Oregon Coast		15,000		
	1941	1	Trask H.	150,000			
				150,000	15,000	91	9
Kilchis R.	1931	1	LCR (OR)/Oregon Coast		30,000		
	1955-90	5	Trask H.	179,683			
	1974-76	3	unknown	164,837			
				344,520	30,000	92	8
Wilson R.	1988	1	Cedar Cr. H. (Nestucca R.)	20,619			
	1931	1	LCR (OR)/Oregon Coast		150,000		

Appendix D (Continued).

	1937-55	3	Trask H.	669,095			
	1978-93	10	Trask H.	908,547			
	1974,77	2	unknown	186,212			
				1,784,473	150,000	92	8
Trask R.	1928-30	3	Cedar Cr. H. (Nestucca R.) and Trask H.	8,265,248			
	1968	1	Hagerman NFH*		17,918		
	1931-52	7	LCR (OR)/Oregon Coast Mix		5,939,765		
	1913	1	Rogue R./Trask H.		1,747,530		
	1914-67	26	Trask H.	30,375,282			
	1978-93	16	Trask H.	4,215,811			
	1915	1	Trask H./Rock Cr. H.	2,883,428			
	1927	1	Trask H./Wilson R.	2,100,521			
	1950-77	10	unknown	2,824,990			
				50,665,280	7,705,213	87	13
Tillamook R.	1931-49	6	LCR (OR) and Oregon Coast Mix		13,534,607		
	1935	1	Marion Forks H./Trask H.		4,110,730		
	1931-67	21	Trask H.	22,187,802			
	1986-95	5	Trask H.	279,874			
	1969	1	unknown	55,833			
				22,523,509	17,645,337	56	44
Three R.	1972,75	2	Hagerman NFH*		19,084		
	1971	1	Irrigon H.		15,000		
	1971-90	5	Cedar Cr. H. (Nestucca R.)	83,118			
	1977	1	unknown	11,625			
				94,743	34,084	74	26
Nestucca R.	1973-94	17	Cedar Cr. H. (Nestucca R.)	1,200,855			
	1972	1	Deschutes R. (OR)		22,662		
	1972-75	3	Hagerman NFH*		148,404		
	1969-71	3	Irrigon H.		104,101		
	1929-30	2	Nestucca R./Trask H.	2,535,000			
	1926	1	Trask H.	20,000			
	1978-87	5	Trask H.	568,129			
	1976,77	2	unknown	260,190			
				4,584,174	275,167	94	6
Salmon R.	1940	1	Trask H.	50,000			
				50,000	0	100	0
Siletz R.	1932	1	Bonneville H./Trask H.		20,000		
	1935,36	2	McKenzie R. H.		190,500		
	1926	1	Trask H.	80,000			
	1933,74	2	unknown	28,250			

Appendix D (Continued).

				108,250	210,500	34	66
Yaquina R.	1989	1	Anadromous Inc.	1,142,162			
	1935-38	3	McKenzie R. H.		234,500		
	1988	1	OAF/Rogue R.		21,389		
	1983	1	OAF/Yaquina R.	55,176			
	1984-88	8	Oregon Aqua Foods	2,469,650			
	1987-89	3	Rogue R.		7,910,778		
	1975-79	5	Trask H. (Private)	1,111,259			
	1981	1	Yaquina R. (Private)	89,026			
				4,867,273	8,166,667	37	63
Alsea R.	1919-27	6	Alsea H.	9,444,978			
	1928-36	4	LCR (OR)/Oregon Coast		5,118,886		
	1931	1	Marion Forks H.		814,520		
	1935,36	2	McKenzie R. H.		940,000		
	1930	1	Trask H.	497,922			
	1916,74	2	unknown	659,056			
				1,156,978	6,873,406	14	86
Yachats R.	1935	1	McKenzie R. H.		50,000		
				0	50,000	0	100
Siuslaw R.	1935	1	McKenzie R. H.		100,000		
	1974	1	unknown	12,625			
				12,625	100,000	11	89
Umpqua R.	1971	1	Hagerman NFH*		164,000		
	1957-93	26	Rock Cr. H.	6,181,564			
	1976,77	2	unknown	655,879			
				6,837,443	164,000	98	2
Coos R.	1983-89	7	Anadromous Inc.	9,855,503			
	1931-33	3	Coos R.	1,745,572			
	1982,83	2	Jordon Pt. (Private)	13,336			
	1979-82	4	Rogue R.		1,957,959		
	1926-83	4	unknown	772,971			
	1935	1	Willamette H.		1,413,860		
				12,387,382	3,371,819	79	21
Coquille R.	1984-92	7	Coquille R.	140,385			
				140,385	0	100	0
			Totals for ESU #6:	303,075,541	94,172,093	76	24

7) Washington Coast ESU (Fall Run)

Salt Ck.	1975	1	Deschutes R. (WA)		100,800		

Appendix D (Continued).

	1959	1	Elwha R.		42,120		
	1971,73	2	Hood Canal H.		443,890		
	1972	1	Hood Canal H./Elwha R.		234,817		
	1974,75		Hood Canal H./Sol Duc H.		104,830		
	1972	1	Issaquah Cr. H. X White R.		153,016		
				0	1,079,473	0	100
Lyre R.	1959	1	Deschutes R. (WA)		70,425		
	1963	1	Hood Canal H.		112,348		
	1958	1	Green R. H.		101,012		
				0	283,785	0	100
Deep Ck.	1975	1	Deschutes R. (WA)		100,800		
	1975	1	Hood Canal H./Sol Duc H.		25,774		
				0	126,574	0	100
Pysht R.	1959	1	Deschutes R. (WA)		156,432		
	1953-56	4	Elwha R.		126,915		
	1958-65	3	Green R. H.		444,831		
	1963,73	2	Hood Canal H.		408,950		
	1972	1	Hood Canal H./Elwha R.		234,366		
	1974,75	2	Hood Canal H./Sol Duc H.		138,900		
	1972	1	Issaquah Cr. H. X White R.		152,535		
				0	1,662,929	0	100
Clallam R.	1961,75	2	Deschutes R. (WA)		193,185		
	1965,66	2	Green R. H.		504,940		
	1962-73	7	Hood Canal H.		2,096,097		
	1972	1	Hood Canal H./Elwha R.		98,987		
	1964	1	Minter Cr. H.		302,000		
	1974,75	2	Sol Duc H.	226,234			
				226,234	3,195,209	7	93
Hoko R.	1959,75	2	Deschutes R. (WA)		336,400		
	1953,55	2	Elwha R.		84,456		
	1958,60	2	Green R. H.		226,416		
	1984-94	10	Hoko R.	1,805,115			
	1963-73	3	Hood Canal H.		1,850,582		
	1972	1	Hood Canal H./Elwha R.		234,877		
	1974,75	2	Hood Canal H./Sol Duc H.		172,348		
	1972	1	Issaquah Cr. H. X White R.		153,027		
	1983	1	Sooes R.	13,464			
				1,818,579	3,058,106	37	63
Sekiu R.	1975	1	Deschutes R. (WA)		184,800		
	1971,73	2	Hood Canal H.		758,450		
	1971	1	Minter Cr. H.		524,221		

Appendix D (Continued).

				0	1,467,471	0	100
Sail R.	1980	1	Portage Bay		2,000		
				0	2,000	0	100
Waatch R.	1981	1	Sol Duc H.	83,000			
				83,000	0	100	0
Sooes R.	1959	1	Deschutes R. (WA)		71,120		
	1958,60	2	Green R. H.		284,120		
	1971	1	Minter Cr. H.		519,440		
	1982-94	12	Sooes R.	8,822,053			
	1978-79	2	unknown	555,000			
				9,377,053	874,680	91	9
Bogachiel R.	1975	1	Bogachiel R.	20,582			
	1958	1	Green R. H.		95,340		
	1988	1	Sol Duc H.	75,000			
				95,582	95,340	50	50
Sol Duc R.	1959	1	Deschutes R. (WA)		233,400		
	1958	1	Elwha R.		67,520		
	1958,60	2	Green R. H.		459,870		
	1963-73	3	Hood Canal H.		1,898,046		
	1971	1	Issaquah Cr. H.		211,968		
	1972	1	Nemah H./Lake Quinault H.	429,600			
	1973-91	3	Quillayute R.	578,127			
	1974-93	12	Sol Duc H.	4,834,662			
				5,842,389	2,870,804	67	33
Quillayute R.	1988-92	6	Quillayute R.	1,420,877			
	1993	1	Sol Duc H.	174,500			
				1,595,377	0	100	0
Hoh R.	1959	1	Deschutes R. (WA)		144,000		
	1958-60	2	Green R. H.		321,719		
	1976-87	8	Hoh R.	330,975			
	1977-81	3	unknown	143,500			
				474,475	465,719	50	50
Queets R.	1981-82	2	Deschutes R. (WA)		840,528		
	1979	1	Green R. H./Samish H.		222,852		
	1975-93	18	Queets R.	3,150,159			
	1980	1	Queets R./Lake QuinaultH.	357,345			
	1979-80	2	Quillayute R.	221,355			
	1979	1	Lake Quinault H.	28,876			
	1981	1	unknown	137,500			
				3,895,235	1,063,380	79	21

Appendix D (Continued).

Raft R.	1978	1	George Adams H. and Lake Quinault H.		584,853		
	1978	1	Green R. H and Lake Quinault H.		685,291		
	1978	1	Issaquah Cr. H.		610,247		
	1978	1	unknown	713,317			
				713,317	1,880,391	28	72
Quinault R.	1981,82	2	Deschutes R. (WA)		1,240,704		
	1977	1	Deschutes R. (WA)/Nemah H.		199,409		
	1975	1	Green R. H. and Quinault NFH		31,979		
	1970-74	3	Hoh R./Lake Quinault H.	607,352			
	1974	1	Hood Canal H./Quinault NFH		494,700		
	1969-70	3	Issaquah Cr. H.		2,086,603		
	1975-94	15	Lake Quinault H.	12,459,579			
	1972	1	Lake Quinault H./Hoh R.	454,700			
	1974	1	Nemah H.	739,800			
	1976	1	Nemah H./QuinaultNFHR.	258,733			
	1989	1	Queets R.	4,400			
	1968	1	Quilcene NFH		770,626		
	1975,76	2	Quinault NFH./Willapa H.	429,033			
	1982	1	Quinault R./Samish H.		241,447		
	1973-83	9	unknown	7,346,024			
	1974	1	Willapa H.	696,897			
				22,996,518	5,065,468	82	18
Chehalis R.	1991,93	2	Chehalis R.	308,146			
	1964-79	5	Deschutes R. (WA)		1,155,434		
	1957-62	5	Green R. H.		1,578,225		
	1963-74	4	Hood Canal H.		581,630		
	1969,70	2	Nemah H.	647,390			
	1953	1	Spring Cr. NFH		449,203		
	1987,88	2	Wishkah R.	107,739			
	1989-93	5	Wynoochee R.	462,440			
				1,525,715	3,764,492	29	71
Satsop R.	1952	1	Carson NFH		55,724		
	1964-79	11	Deschutes R. (WA)		5,927,465		
	1972,73	2	Deschutes R. (WA)/Nemah H.		363,224		
	1974	1	Elk R. H.		68,689		
	1955-57	4	Green R. H.		2,513,296		
	1985-89	5	Humptulips H.	6,285,099			
	1974-76	3	Nemah H.	472,057			
	1955-93	19	Simpson H.	5,508,944			
	1953	1	Spring Cr. NFH		1,184,176		
	1975	1	Trask H.		18,491		
				12,266,100	10,131,065	55	45

Appendix D (Continued).

Wynoochee R.	1973	1	Deschutes R. (WA)/Nemah H.		8,110		
	1973	1	Simpson H./Hood Canal H.		10,000		
	1974	1	Trask H.		20,000		
	1975	1	unknown	38,215			
	1993		Wynoochee R.	80,000			
				118,215	38,110	76	24
Wishkah R.	1988-92	4	Wishkah R.	285,119			
				285,119	0	100	0
Hoquiam R.	1986	1	Hoquiam R.	1,600			
	1991	1	Humptulips H.	13,000			
				14,600	0	100	0
Humptulips R.	1952	1	Carson NFH		316,706		
	1955-58	3	Green R. H.		1,184,691		
	1977-93	16	Humptulips H.	7,134,418			
	1966-70	3	Satsop Springs H.	172,250			
	1973	1	Simpson H./Hood Canal H.		105,993		
	1953	1	Spring Cr. NFH		299,289		
	1977-81	5	Willapa H.		4,530,360		
				7,306,668	6,437,039	53	47
Johns R.	1952	1	Carson NFH		179,810		
	1970	1	Deschutes R. (WA)		172,800		
	1969	1	Satsop Springs H.	231,000			
	1973	1	Simpson H./Hood Canal H.		720,200		
	1953	1	Spring Cr. NFH		100,170		
				231,000	1,172,980	16	84
North R.	1969-88	7	Nemah H.	2,015,540			
	1953	1	Spring Cr. NFH		96,565		
	1988-93	5	Willapa H.	5,309,000			
				7,324,540	96,565	99	1
Willapa R.	1953-66	14	Ancient Wild Stocks	6,143,013			
	1963-70	7	Deschutes R. (WA)		3,027,371		
	1974	1	Elk R. H.		28,331		
	1954-58	5	Green R. H.		3,721,882		
	1971,72,79		Hood Canal H.		1,391,346		
	1972-88	5	Nemah H.	857,741			
	1973	1	Nemah H./Minter Cr. H.		600,000		
	1953	1	Spring Cr. NFH		1,112,413		
	1974-75	2	Trask H.		48,509		
	1967-74	6	unknown	4,306,161			
	1972-93	22	Willapa H.	51,185,897			
				62,492,812	9,929,852	86	14

Appendix D (Continued).

Palix R.	1955,57	2	Green R. H.		157,160		
	1969-93	7	Nemah H.	1,084,871			
	1973	1	Nemah H./Minter Cr. H.		20,082		
				1,084,871	177,242	86	14
Nemah R.	1972	1	Abernathy NFH		70,173		
	1954	1	Ancient Wild Stocks	5,197			
	1962-67	5	Deschutes R. (WA)		1,342,905		
	1959	1	Elokomin H.		102,276		
	1954-58	5	Green R. H.		2,468,956		
	1958	1	Klickitat H.		75,158		
	1955-93	38	Nemah H.	38,997,916			
	1984-86	3	Nemah H./Willapa H.	4,266,105			
	1953	1	Spring Cr. NFH		145,275		
	1987-93	3	Willapa H.	2,871,200			
				46,140,418	4,204,743	92	8
Naselle R.	1953	1	Ancient Wild Stocks	19,000			
	1970	1	Deschutes R. (WA)		100,000		
	1955-58	4	Green R. H.		545,905		
	1981-93	10	Naselle H.	31,902,250			
	1984-86	3	Naselle H./Willapa H.	8,285,802			
	1959-89	12	Nemah H.	7,413,499			
	1953	1	Spring Cr. NFH		363,419		
	1972,77	2	unknown	416,728			
	1981-93	10	Willapa H.	13,540,734			
				61,578,013	1,009,324	98	2
Bear R.	1988	1	Naselle H.	84,400			
	1972-189	4	Nemah H.	324,411			
				408,811	0	100	0
7) Washington Coast ESU (Spring Run)							
Hoh R.	1960	1	Dungeness H.		100,000		
	1978-85	5	Hoh R.	157,165			
	1978	1	unknown	44,880			
				202,045	100,000	67	33
Sol Duc R.	1974	1	Cowlitz H.		119,605		
	1972,73	2	Cowlitz H. X Rock Cr. H. (OR)		255,085		
	1973-88	9	Dungeness H.		307,435		
	1985	1	Quillayute R.	354,543			
	1976-93	18	Sol Duc H.	7,987,992			
				8,342,535	682,125	92	8
Queets R.	1976	1	Cowlitz H.		72,953		

Appendix D (Continued).

				0	72,953	0	100
Quinault R.	1976,77	2	Cowlitz H.		328,288		
	1977	1	Quillayute R.	170,000			
				170,000	328,288	34	66
Satsop R.	1977	1	Cowlitz H.		2,576		
				0	2,576	0	100
Chehalis R.	1977	1	Skookumchuck R.	1,878			
				1,878	0	100	0
Wynoochee R.	1977	1	Cowlitz H.		59,200		
	1979	1	Sol Duc H.	40,314			
				40,314	59,200	41	59
Willapa R.	1971	1	Cowlitz H.		125,970		
				0	125,970	0	100
Naselle R.	1982	1	Cowlitz H.		270,000		
				0	270,000	0	100
			Totals for ESU #7:	256,651,413	61,793,853	81	19
8) Puget Sound ESU (Fall Run)							
San Juan SW	1984-92	4	Glenwood Springs COOP	857,350			
	1980-92	3	Samish H.	452,207			
	1990,91	2	Skagit H.	17,138			
	1983	1	unknown	15,000			
				1,341,695	0	100	0
San Juan Islands	1987-91	4	Glenwood Springs COOP	1,357,800			
	1981-93	4	Samish H.	261,190			
	1991,92	2	Skagit H.	11,700			
	1987-91	3	Skykomish H.	56,080			
				1,686,770	0	100	0
Lummi Sea Pond	1976-89	7	Green R. H.	3,696,783			
	1986,91	2	Lummi Bay Sea Ponds	154,000			
	1992,93	2	Nooksack H.	1,881,729			
	1991	1	Nooksack H./Samish H.	350,000			
	1979-90	10	Samish H.	11,551,579			
				17,634,091	0	100	0
Nooksack R.	1984	1	Deschutes R. (WA)	26,603			
	1988,89	2	Glenwood Springs COOP	730,456			

Appendix D (Continued).

	1956-89	18	Green R. H.	33,650,357			
	1977-79	3	Hood Canal H.	1,778,623			
	1979	1	Issaquah Cr. H.	399,000			
	1968	1	Minter Cr. H.	451,156			
	1955-93	38	Nooksack H.	48,817,932			
	1986,91	2	Nooksack H./Samish H.	2,970,171			
	1955-93	24	Samish H.	97,363,151			
	1976-85	3	Skagit H.	952,976			
	1984	1	Skookum Cr. H.	1,390,000			
	1967,74	2	Skykomish H.	962,181			
	1953	1	Spring Cr. NFH		977,297		
	1967	1	Toutle H.		334,930		
	1951-79	4	unknown	699,905			
	1985-93	8	Whatcom Cr.	1,266,518			
				191,459,029	1,312,227	99	1
Whatcom Cr.	1985-93	8	Whatcom Cr.	1,266,518			
				1,266,518	0	100	0
Samish R.	1987	1	Glenwood Springs COOP	49,680			
	1966-81	8	Green R. H.	6,607,175			
	1973-77	4	Green R. H./Skagit H.	2,744,647			
	1974	1	Humptulips H./Willapa H.	508,421			
	1963	1	Klickitat H.		886		
	1973	2	Issaquah Cr. H.	3,132,914			
	1970,74	2	Minter Cr. H.	3,045,999			
	1973,74	2	Minter Cr. H./Skagit H.	961,195			
	1953-93	41	Samish H.	140,016,207			
	1975,76	2	Skagit H.	2,011,464			
	1967	1	Skykomish H.	1,768,824			
	1953,60	2	Spring Cr. NFH		225,345		
	1960	1	unknown	14,506			
				160,861,032	226,231	100	0
Skagit R.	1983	1	Deschutes R. (WA)	71,600			
	1988	2	Glenwood Springs COOP	792,500			
	1955-90	18	Green R. H.	20,281,936			
	1972,73	2	Green R. H./Skagit H.	6,407,418			
	1963	1	Issaquah Cr. H.	1,469,018			
	1970	1	Minter Cr. H.	1,984,159			
	1973	1	Minter Cr. H./Skagit H.	3,401,731			
	1953-90	16	Samish H.	22,402,823			
	1957-93	28	Skagit H.	25,775,809			
	1981,82	2	Skykomish H.	1,662,213			
	1953	1	Spring Cr. NFH		209,736		
				84,249,207	209,736	100	0
North Puget Sound	1984	1	Deschutes R. (WA)	10,000			

Appendix D (Continued).

SW Releases	1989,90	2	Green R. H.	128,200			
	1984-93	4	Samish H.	771,646			
	1985-91	3	Skagit H.	197,750			
				1,107,596	0	100	0
Whidbey Island	1975	1	Deschutes R. (WA)	275,000			
	1964-71	4	Green R. H.	1,629,384			
	1962-70	5	Issaquah Cr. H.	2,600,010			
	1962,64	2	Samish H.	1,530,772			
				6,035,166	0	100	0
Whidbey Island SW	1984	1	Deschutes R. (WA)	26,000			
	1988	1	Glenwood Springs COOP	15,000			
	1989-93	4	Samish H.	142,950			
	1985-91	5	Skagit H.	156,337			
	1974,77	2	unknown	65,746			
				406,033	0	100	0
Stillaguamish R.	1957-74	11	Green R. H.	11,305,757			
	1974	1	Hood Canal H.	1,793,131			
	1963,66	2	Issaquah Cr. H.	1,230,133			
	1970	1	Minter Cr. H.	590,400			
	1989-93	5	NF Stillaguamish R.	459,647			
	1958	1	Samish H.	363,542			
	1973	1	Skykomish H.	290,000			
	1981-88	6	Stillaguamish R.	578,074			
				16,610,684	0	100	0
Tulalip Cr.	1983	1	Deschutes R. (WA)	1,059,000			
	1976-93	8	Green R. H.	6,608,432			
	1975	1	Green R. H./Skagit H.	415,397			
	1979,80	2	Green R. H./Skykomish H.	1,468,292			
	1988	1	Green R. H./Tulalip H.	1,425,000			
	1983	1	Hood Canal H.	441,000			
	1976	1	Issaquah Cr. H.	998,000			
	1992	1	Samish H.	1,188,000			
	1986	1	Samish H./Tulalip H.	1,500,000			
	1974-85	5	Skagit H.	2,935,410			
	1977-89	7	Skykomish H.	4,986,792			
	1987	1	Snohomish R.	1,057,660			
	1974,78	2	unknown	575,800			
				24,658,783	0	100	0
Mission Cr.	1979-80	2	Green R. H.	725,811			
	1979-81	3	Green R. H./Skykomish H.	1,469,711			
	1979,81	2	Skykomish H.	763,903			
				2,959,425	0	100	0

Appendix D (Continued).

Skykomish R.	1975-86	4	Deschutes R. (WA)	1,841,582			
	1955-88	12	Green R. H.	9,318,391			
	1975	1	Green R. H./Skagit H.	453,690			
	1959-77	3	Issaquah Cr. H.	3,896,856			
	1953	1	Lower Kalama H.		654,464		
	1957	1	Puyallup H.	895,007			
	1964,77	2	Samish H.	1,751,994			
	1954-93	37	Skykomish H.	51,373,126			
	1976	1	Skykomish H./Cowlitz H.		34,861		
	1973-80	5	Snohomish R.	2,194,208			
	1948-51	4	unknown	981,399			
				72,706,253	689,325	99	1
Snoqualimie R.	1963-74	3	Green R. H.	1,267,977			
	1960	1	Issaquah Cr. H.	702,400			
	1966,73	2	Skykomish H.	738,454			
	1977	1	unknown	20,216			
				2,729,047	0	100	0
Snohomish R.	1960-65	3	Green R. H.	693,119			
	1960	1	Issaquah Cr. H.	567,676			
	1966	1	Skykomish H.	167,086			
	1990-93		Samish H.	26,100			
	1989	1	Skagit H.	3,500			
				1,457,481	0	100	0
Lake Washington	1953-93	16	Green R. H.	15,535,797			
	1979	1	Green R. H. X Issaquah Cr. H.	2,712,063			
	1972,73	2	Green R. H. X White R.	352,809			
	1953-93	39	Issaquah Cr. H.	95,465,568			
	1972,73	2	Issaquah Cr. H. X White R.	852,333			
	1988	1	Lake Samamish	2,996,000			
	1972-76	3	Lake Washington/ B.C.		837,330		
	1953	1	Lower Kalama H.		1,109,682		
	1965-93	23	Portage Bay	4,150,670			
	1955	1	Puyallup H.	768,734			
	1958	1	Samish H.	1,372,583			
	1972-79	4	unknown	726,202			
				124,932,759	1,947,012	98	2
Duwamish R.	1975	1	Capilano H. (BC)		148,272		
	1977,82	2	Deschutes R. (WA)	2,181,726			
	1991,93	2	Green R. (native)	5,728,805			
	1953-93	41	Green R. H.	185,825,121			
	1972,73	2	Green R. H. X White R.	832,352			
	1972,73	2	Green R. H./Hoh R.		279,851		
	1975	1	Green R. H./Skagit H.	49,361			

Appendix D (Continued).

	1985	1	Grovers Cr. H.	789,600			
	1983	1	Hood Canal H.	29,550			
	1959	1	Issaquah Cr. H.	95,500			
	1972,73	2	Issaquah Cr. H. / B.C.		494,013		
	1972	1	Minter Cr. H.	77,055			
	1973	1	Puyallup H. X White R.	208,400			
	1990	1	S. Puget Sound	3,770,574			
	1981,82	2	Skagit H.	44,129			
	1981-84	4	Skykomish H.	2,860,559			
	1985	1	Sooes R.		859,600		
	1973,74	2	unknown	348,000			
				202,840,732	1,781,736	99	1
Duwamish R. SW	1979	1	Cowlitz H.		7,824		
	1984	1	Deschutes R. (WA)	43,679			
	1976	1	Deschutes R. (WA) X B.C.		22,283		
	1988,89	2	Glenwood Springs COOP	73,099			
	1969-91	6	Green R. H.	163,167			
	1981	1	Issaquah Cr. H.	14,787			
	1974,75	2	Minter Cr. H.	24,576			
	1956-93	5	Samish H.	199,305			
	1981-91	6	Skagit H.	279,913			
	1980-83	3	Skykomish H.	79,210			
	1977-79	3	unknown	86,080			
				963,816	30,107	97	3
Seahurst Park	1977-79	3	unknown	13,799			
				13,799	0	100	0
Des Moines Cr.	1990,91	2	Deschutes R. (WA)	34,900			
	1993	1	Samish H.	40,000			
				74,900	0	100	0
East Puget Sound SW	1990	1	Green R. H.	400			
SW Releases	1974	1	unknown	8,000			
				8,400	0	100	0
Puyallup R. SW	1988-90	3	Deschutes R. (WA)	66,120			
	1976	1	Deschutes R. (WA) X B.C.		5,585		
	1989	1	Glenwood Springs COOP	24,200			
	1974,76	2	Minter Cr. H.	20,283			
	1987	1	Samish H.	10,700			
	1990	1	Skagit H.	29,500			
	1974	1	unknown	16,469			
				167,272	5,585	97	3
Puyallup R.	1976-90	5	Deschutes R. (WA)	4,351,976			

Appendix D (Continued).

	1953-90	17	Green R. H.	11,649,460			
	1975	1	Green R. H./Skagit H.	48,500			
	1974	1	Hood Canal H.	1,458,660			
	1973	1	Humptulips R.	69,190			
	1960,72	2	Issaquah Cr. H.	1,676,163			
	1978	1	Minter Cr. H.	611,200			
	1953-93	41	Puyallup H.	64,999,696			
	1979	1	Puyallup H./Green R. H.	1,195,746			
	1979	1	Skagit H./Skykomish H.	1,265,621			
	1967	1	Skykomish H.	150,995			
				87,477,207	0	100	0
Chambers Cr.	1988-93	4	Chambers Cr.	1,916,580			
	1976-993	8	Deschutes R. (WA)	1,692,431			
	1975	1	Deschutes R. (WA) X B.C.		45,000		
	1983-91	11	Garrison Springs H.	6,613,859			
	1959-88	7	Green R. H.	1,010,527			
	1981	1	Green R. H./Issaquah Cr. H.	173,223			
	1960-81	3	Issaquah Cr. H.	695,117			
	1973-79	3	Minter Cr. H.	534,302			
	1976-81	3	Portage Bay	249,639			
	1980-93	3	Puyallup H.	819,320			
	1980	1	Puyallup H./Deschutes R. (WA)	349,342			
	1982	1	S. Puget Sound	866,378			
	1961,83	2	Samish H.	847,200			
	1990,91		Skagit H.	62,800			
				15,830,718	45,000	>99	<1
Nisqually R.	1986	1	Coulter Cr. H.	1,000,000			
	1962,76-92	12	Deschutes R. (WA)	14,395,312			
	1992	1	Deschutes R. (WA) and McAllister Cr. H.	1,339,800			
	1985,88	2	Garrison Springs H.	808,200			
	1956-88	16	Green R. H.	16,117,962			
	1984,85	2	Grovers Cr. H.	484,400			
	1983,92	1	Hood Canal H.	2,239,040			
	1973	1	Hood Canal H. X White R.	30,000			
	1960,71	2	Issaquah Cr. H.	700,230			
	1985-91	7	McAllister Cr. H.	7,833,400			
	1971,73	2	Minter Cr. H.	1,688,760			
	1985-93	4	Nisqually R.	5,538,696			
	1984-93	4	Nisqually R./Green R. H.	3,369,347			
	1957-81	5	Puyallup H.	985,482			
	1980	1	Puyallup H./Green R. H.	893,000			
	1984	1	Samish H.	3,238,100			
	1982	1	Skykomish H.	1,747,309			
	1994	1	unknown	770,000			
				63,179,038	0	100	0

Appendix D (Continued).

Deschutes R.	1982-92	5	Coulter Cr. H.	1,335,656			
	1956-93	31	Deschutes R. (WA)	110,062,126			
	1976	1	Deschutes R. (WA) and Hood Canal H.	460,157			
	1979	1	Deschutes R. (WA) and Minter Cr. H.	599,866			
	1968-81	3	George Adams H.	2,550,360			
	1953-91	19	Green R. H.	26,278,938			
	1984-90	4	Grovers Cr. H.	2,953,500			
	1965-84	11	Hood Canal H.	13,206,917			
	1974	1	Hood Canal H. X White R.	17,917			
	1980	1	Hood Canal H./Green R. H.	1,009,931			
	1967-81	6	Issaquah Cr. H.	3,520,277			
	1986-91	3	McAllister Cr. H.	3,414,450			
	1968-92	6	Minter Cr. H.	3,827,326			
	1981,84	2	Puyallup H.	767,652			
	1972-88	6	S. Puget Sound/Hood Canal H.	12,260,519			
	1981,84	2	Samish H.	3,495,771			
	1982,86,90	3	Skagit H.	313,343			
	1980-83	4	Skykomish H.	2,860,779			
	1953	1	Spring Cr. NFH		110,400		
	1972-80	4	unknown	29,937,966			
				218,873,451	110,400	100	0
South Puget Sound SW Releases	1960-87	12	Deschutes R. (WA)	3,392,734			
	1958,82	1	Green R. H.	365,485			
	1965,80	2	Hood Canal H.	511,700			
	1959	1	Issaquah Cr. H.	251,600			
	1971,92	2	Minter Cr. H.	1,003,180			
	1982	1	Puyallup H.	282,577			
	1984	1	S. Puget Sound	5,050			
	1958,80	2	Samish H.	511,020			
				6,323,346	0	100	0
South Puget Sound	1987	1	Coulter Cr. H.	18,930			
	1986-93	8	Deschutes R. (WA)	5,410,874			
	1985-87	2	Garrison Springs H.	176,800			
	1975-91	5	Green R. H.	669,603			
	1985	1	Grovers Cr. H.	143,300			
	1972-76	3	Hood Canal H.	416,388			
	1974-93	4	Minter Cr. H.	242,093			
	1977-82	4	Portage Bay	546,712			
	1980,82	2	Puyallup H.	381,299			
	1983-92	3	Samish H.	196,000			
	1991	1	Skagit H.	19,000			
	1974,75	2	unknown	62,605			
				8,283,604	0	100	0

Appendix D (Continued).

Coulter Cr.	1981-92	10	Coulter Cr. H.	8,595,982			
	1962-91	3	Deschutes R. (WA)	1,063,007			
	1981	1	Deschutes R. (WA) and Minter Cr. H.	173,337			
	1980-89	4	Green R. H.	1,859,518			
	1985	1	Grovers Cr. H.	373,500			
	1983	1	Hood Canal H.	685,343			
	1959	1	Issaquah Cr. H.	253,640			
	1993	1	Minter Cr. H.	1,082,500			
	1983	1	Minter Cr. H. and Deschutes R. (WA)	280,552			
	1957	1	Quilcene NFH	2,805			
	1981,82	2	S. Puget Sound	1,836,054			
	1958	1	Samish H.	188,020			
				16,394,258	0	100	0
Minter Cr.	1984,88	2	Coulter Cr. H.	397,600			
	1959-93	7	Deschutes R. (WA)	3,060,375			
	1975	1	Deschutes R. (WA) X B.C.		140,256		
	1979	1	Deschutes R. (WA) and Minter Cr. H.	1,265,982			
	1955-89	13	Green R. H.	10,829,986			
	1981	1	Green R. H./Minter Cr. H.	182,908			
	1983-90	6	Grovers Cr. H.	4,977,500			
	1965-71	4	Hood Canal H.	1,008,202			
	1959,74	2	Issaquah Cr. H.	1,354,321			
	1974,75	2	Issaquah Cr. H. X B.C.		103,402		
	1953-92	38	Minter Cr. H.	45,810,377			
	1976	1	Portage Bay	364,160			
	1974-76	3	Rivers Inlet (BC)	43,052			
	1980,82	2	S. Puget Sound	2,811,521			
	1958	1	Samish H.	118,106			
	1971	1	unknown	29,025			
				72,253,115	243,658	100	0
Hupp Springs	1981,84	2	Deschutes R. (WA)	143,728			
	1984,85	2	Grovers Cr. H.	224,500			
	1982-88	4	Minter Cr. H.	568,864			
				937,092	0	100	0
West Puget Sound	1986	1	Chambers Cr.	970,000			
	1961-90	5	Deschutes R. (WA)	2,448,904			
	1959-91	16	Green R. H.	8,615,741			
	1972	1	Green R. H. X White R.	121,672			
	1983-94	12	Grovers Cr. H. H	15,869,199			
	1965,79	2	Hood Canal H.	506,003			
	1963,71	2	Issaquah Cr.	349,190			
	1966	1	Issaquah Cr. H.	1,362,126			

Appendix D (Continued).

	1969-93	8	Minter Cr. H./White R.	8,816,635			
				39,059,470	0	100	0
West Puget Sound	1976	1	Deschutes R. (WA) X B.C.		5,632		
SW Releases	1965	1	Green R. H.	52,500			
	1972,73	2	Green R. H. X White R.	67,098			
	1970	1	Hood Canal H.	4,148			
	1963-75	3	Minter Cr. H.	664,294			
	1972	1	Skykomish H.	595,668			
	1973-78	4	unknown	46,776			
				1,430,484	5,632	100	0
East Hood Canal	1960	1	Deschutes R. (WA)	249,600			
	1975	1	unknown	15,000			
				264,600	0	100	0
Big Beef Cr.	1982-93	6	Big Beef Cr.	293,834			
	1983,84	2	Deschutes R. (WA)	227,337			
	1993	1	George Adams H.	49,387			
	1981	1	Hood Canal H.	1,224			
	1990	1	Portage Bay	30,000			
	1972	1	unknown	400			
				602,182	0	100	0
Dewatto R.	1960	1	Deschutes R. (WA)	409,100			
	1971	1	George Adams H.	150,200			
	1958,62	2	Green R. H.	1,326,428			
	1964,83	2	Hood Canal H.	531,806			
	1959	1	Issaquah Cr. H.	251,322			
	1958	1	Samish H.	170,280			
				2,839,136	0	100	0
Tahuya R.	1971,81	2	George Adams H.	239,100			
	1958-62	3	Green R. H.	640,334			
	1983	1	Hood Canal H.	102,148			
	1959	1	Issaquah Cr. H.	250,680			
				1,232,262	0	100	0
Union R.	1992	1	Deschutes R. (WA)	9,550			
	1971	1	George Adams H.	310,788			
	1990	1	Hood Canal H.	15,000			
				335,338	0	100	0
Skokomish R.	1986	1	Big Beef Cr.	84,000			
	1959-93	13	Deschutes R. (WA)	20,131,521			
	1985,92	2	Enetai Cr. H.	345,279			
	1960-93	22	George Adams H.	31,990,130			
	1954-81	1	Green R. H.	2,758,822			

Appendix D (Continued).

	1962-93	21	Hood Canal H.	32,426,037			
	1975-93	5	Hood Canal H. and Deschutes R. (WA)	4,683,549			
	1975,88-93	5	Hood Canal Mixed	13,143,630			
	1959,81	2	Issaquah Cr. H.	1,091,355			
	1984-87	3	McKernan H.	484,669			
	1980,81	2	S. Puget Sound	3,486,761			
	1982,86	2	S. Puget Sound/Hood Canal H.	5,327,387			
	1958	1	Samish H.	373,560			
				116,326,700	0	100	0
Finch Cr.	1976-92	3	Deschutes R. (WA)	123,690			
	1976	1	Deschutes R./George Adams H.	143,400			
	1953	1	Dungeness H.	148,946			
	1974	1	George Adams H.	29,841			
	1954-65	7	Green R. H.	4,945,959			
	1959-93	35	Hood Canal H.	59,320,883			
	1971,72	2	Hood Canal H. X Cowlitz H.	113,349			
	1973,74	2	Hood Canal H. X White R.	146,575			
	1975	1	Trask H.		8,991		
	1971	1	unknown	20,054			
				64,992,697	8,991	100	0
Sund Cr.	1992	1	Deschutes R. (WA)	156,477			
	1992	1	Hood Canal H.	44,623			
				201,100	0	100	0
Hamma Hamma R.	1984,85	2	Deschutes R. (WA)	360,200			
	1987-92	5	George Adams H.	1,139,100			
	1981	1	Green R. H. and Issaquah Cr. H.	503,846			
	1971-89	7	Hood Canal H.	1,742,065			
				3,745,211	0	100	0
Duckabush R.	1959-85	4	Deschutes R. (WA)	912,250			
	1987-92	6	George Adams H.	1,037,300			
	1958	1	Green R. H.	166,800			
	1971-89	7	Hood Canal H.	2,058,271			
				4,174,621	0	100	0
Dosewallips R.	1959-85	4	Deschutes R. (WA)	961,720			
	1990-92	3	George Adams H.	499,100			
	1958,72	2	Green R. H.	782,300			
	1963-89	7	Hood Canal H.	2,230,447			
	1987	1	Nooksack H.	54,629			
				4,528,196	0	100	0
Walcott Slough	1978	1	Quilcene NFH	648,858			
	1977,78	2	Issaquah Cr. H.	3,360,606			

Appendix D (Continued).

	1960,61	2	unknown	923,354			
				4,932,818	0	100	0
Quilcene R.	1975	1	Hood Canal H.	998,380			
	1975,76	2	Issaquah Cr. H.	1,139,624			
	1965-79	12	Quilcene NFH	15,673,927			
	1979	1	Skykomish H.	557,710			
	1962-64,86	4	unknown	6,432,131			
				24,801,772	0	100	0
Hood Canal SW	1992	1	Deschutes R. (WA)	29,140			
	1993	1	George Adams H.	217,600			
	1991	1	Hood Canal H.	211,020			
				457,760	0	100	0
Snow, Salmon and Tarboo Creeks	1993,93	2	George Adams H.	185,000			
	1958,65	1	Green R. H.	95,700			
	1965,70	2	Hood Canal H.	61,375			
	1971	1	Minter Cr. H.	311,823			
				653,898	0	100	0
Dungeness R.	1959	1	Deschutes R. (WA)	298,235			
	1953-62	6	Elwha R.	303,600			
	1958-67	5	Green R. H.	2,413,099			
	1963-74	5	Hood Canal H.	1,688,427			
	1968	1	Issaquah Cr. H.	416,892			
	1971	1	Minter Cr. H.	629,694			
				5,749,947	0	100	0
Morse Cr.	1989	1	Elwha R.	198,100			
	1972	1	unknown	27,500			
				225,600	0	100	0
Elwha R.	1955	1	Dungeness H.	115,680			
	1953-94	34	Elwha R.	41,706,945			
	1960-67	4	Green R. H.	2,061,771			
	1964-70	3	Hood Canal H.	1,879,897			
	1968	1	Issaquah Cr. H.	366,109			
	1989-90	3	Lower Elwha R.	1,044,550			
	1953	1	Spring Cr. NFH		194,976		
				47,174,952	194,976	100	0
8) Puget Sound ESU (Spring-Run)							
San Juan SW	1993	1	Nooksack H.	170,900			
				170,900	0	100	0
Nooksack R.	1981-93	13	Nooksack H.	5,125,660			

Appendix D (Continued).

	1986-92	4	Skookum Cr. H.	161,837			
	1977-80	3	Sol Duc H.		288,180		
				5,287,497	288,180	95	5
Samish R.	1954-60	3	Skagit H.	29,238			
	1982	1	Sol Duc H.		80,010		
				29,238	80,010	27	73
Skagit R.	1978-81	4	Buck Cr. (Skagit R.)	157,914			
	1953-93	24	Skagit H.	3,618,218			
	1989-90	2	Suiattle R. (Skagit R.)	105,867			
	1962	1	unknown	27,192			
				3,909,191	0	100	0
North Puget Sound	1963	1	Dungeness H.	278,280			
SW Releases	1955	1	Skagit H.	218			
				278,498	0	100	0
Whidbey Island SW	1973	1	Cowlitz H. X White R.		19,303		
				0	19,303	0	100
Stillaguamish R.	1953,54	2	Skagit H.	250,810			
				250,810	0	100	0
Skykomish R.	1972	1	Cowlitz H. X White R.		209,205		
	1973	1	Skykomish H.	43,200			
	1976,77	2	Snohomish R.	428,921			
				472,121	209,205	69	31
Lake Washington	1986	1	Issaquah Cr. H.	8,000			
	1977	1	unknown	3,000			
Duwamish R.	1977	1	Cowlitz H. X Rock Cr. H.		24,000		
	1973	1	Cowlitz H. X White R.		195,600		
	1977	1	Green R. H.	51,800			
	1977-82	3	Hood Canal H.	164,376			
	1979	1	Skykomish H.	22,500			
	1976	1	Skykomish H. X Cowlitz H.		98,714		
	1976,78	2	Sol Duc H.		1,266,790		
				238,676	1,585,104	13	87
Duwamish R. SW	1977	1	Sol Duc H.		13,855		
				0	13,855	0	100
White R.	1974-94	10	White R.	2,480,424			
				2,480,424	0	100	0
Chambers Cr.	1972	1	Skykomish H.	19,125			

Appendix D (Continued).

				19,125	0	100	0
Deschutes R.	1976	1	Cowlitz H. X Dungeness H.		19,600		
	1977	1	Hood Canal H.	134,354			
				134,354	19,600	87	13
Hupp Springs	1974-94	17	White R.	2,013,488			
				2,013,488	0	100	0
South Puget Sound SW	1977	1	Hood Canal H.	50,541			
				50,541	0	100	0
West Puget Sound SW	1977	1	unknown	9,270			
				9,270	0	100	0
Skokomish R.	1974,75	2	Cowlitz H.		247,251		
	1976	1	Cowlitz H. X Dungeness H.		90,900		
	1977	1	Hood Canal H.	108,097			
				108,097	338,151	24	76
Finch Cr.	1973,74	2	Cowlitz H.		54,027		
	1973	1	Cowlitz H. X Dungeness H.		25,435		
	1974	1	Cowlitz H. X White R.		19,612		
	1973-93	4	Dungeness H.	88,299			
	1976-79	4	Hood Canal H.	414,110			
	1990-93	4	Quilcene NFH	198,468			
	1990-93	4	Sol Duc H.		376,290		
				700,877	475,364	60	40
Dosewallips R.	1974,75	2	Cowlitz H.		299,798		
	1960-72	5	Dungeness H.	587,782			
	1979,82	2	Hood Canal H.	109,085			
	1977	1	Sol Duc H.		208,835		
				696,867	508,633	58	42
Quilcene R.	1982-85	4	Cowlitz H. X Nooksack H.		1,345,792		
	1960	1	Dungeness H.	165,000			
	1980	1	Hood Canal H.	119,287			
	1986-91	7	Quilcene NFH	707,881			
	1990-94	5	Sol Duc H.		593,611		
				992,168	1,939,403	34	66
Snow Cr.	1975	1	Cowlitz H.		30,000		
				0	30,000	0	100
Dungeness R.	1950-82	29	Dungeness H.	11,480,061			
	1977,78	2	Sol Duc H.		186,760		
				11,480,061	186,760	98	2

Appendix D (Continued).

Morse Cr.	1975	1	Cowlitz H.		10,000		
				0	10,000	0	100
Elwha R.	1954-73	4	Dungeness H.	865,747			
	1977	1	Sol Duc H.		532,647		
				865,747	532,647	62	38
			Totals for ESU #8:	1,757,915,434	13,046,831	99	1

9) Lower Columbia R. ESU (Fall Run)

Chinook R.	1964,71	2	Big Cr. H.	1,150,865			
	1981-93	12	Chinook H.	8,403,778			
	1989	1	Elokomin H.	124,700			
	1970	1	Issaquah Cr. H.		97,511		
	1982	1	LCR (WA)	830,589			
	1953,88,89	3	Lower Kalama H. and Kalama Falls H.	1,105,550			
	1965-83	4	Spring Cr. NFH	3,146,137			
	1970-80	3	Toutle H.	1,177,853			
	1972-79	4	unknown	2,473,102			
	1987,90	2	Washougal H.	1,584,500			
				19,997,074	97,511	>99	<1
Deep R.	1980,93	2	Cowlitz H./Kalama R.	960,456			
				960,456	0	100	0
Grays R.	1968-83	9	Abernathy NFH	8,795,726			
	1977,84	2	Big Cr. H.	1,406,632			
	1981-84	3	Bonneville H.	4,970,683			
	1980,86	2	Cowlitz H.	4,018,755			
	1967-89	5	Elokomin H.	3,434,258			
	1966-93	26	Grays R. H.	22,542,491			
	1986	1	Grays R. H./Elokomin H.	102,000			
	1981,93	2	Kalama R./Grays R. H.	190,073			
	1981	1	Klickitat H.	225,134			
	1981,82	2	LCR (WA)	5,768,516			
	1957,66	2	Lewis R. H.	1,400,329			
	1953,54	2	Lower Kalama H.	399,997			
	1968-93	8	Lower Kalama H.	9,578,125			
	1987	1	Skamokawa Cr.	107,000			
	1953-92	15	Spring Cr. NFH	17,437,295			
	1980	1	Toutle H.	1,951,871			
	1984-87	4	Washougal H.	1,572,395			
				83,901,280	0	100	0

Appendix D (Continued).

Skamokawa Cr.	1958	1	Klickitat H.	237,380			
				237,380	0	100	0
Elokomin R.	1966-78	3	Abernathy NFH	709,546			
	1981	1	Basin Stocks	2,928,957			
	1964	1	Big Cr. H.	2,049,806			
	1980	1	Cowlitz H.	2,310,420			
	1974	1	Elk R. H.		30,070		
	1956-93	26	Elokomin H.	78,855,922			
	1986	1	Elokomin H./Kalama R.	1,194,177			
	1980	1	Elokomin H./Toutle H.	2,411,131			
	1956	1	Green R. H.	67,484			
	1975-93	5	Kalama Falls H.	5,392,994			
	1958,82	2	Klickitat H.	1,759,005			
	1982	1	LCR (WA)	1,300,072			
	1956-66	3	Lewis R. H.	3,007,696			
	1953-54	2	Lower Kalama H.	400,080			
	1971	1	Nemah H.	132,750			
	1987	1	Skamokawa Cr.	511,300			
	1953-67	12	Spring Cr. NFH	14,699,029			
	1975,80	2	Toutle H.	2,337,931			
	1974	1	Trask H.		38,974		
	1955	1	unknown	3,758			
	1988	1	Washougal H.	418,000			
				120,490,058	69,044	>99	<1
Abernathy Cr.	1974-94	21	Abernathy NFH	29,120,068			
	1977	1	Spring Cr. NFH	5,090			
	1960-77	18	unknown	15,273,548			
				44,398,706	0	100	0
Columbia R. -RM 29	1971,77,79	2	Abernathy NFH	3,481,359			
	1979	1	Carson NFH	966,240			
	1979	1	Cascade H.	25,617			
	1980	1	Cowlitz H.	7,565,885			
	1957,58	2	Klickitat H.	731,595			
	1980	1	LCR (WA)	50,414			
	1968	1	Lower Kalama H.	77,693			
	1971	1	Priest Rapids H.		1,804,000		
	1957-69	4	Spring Cr. NFH	5,183,331			
	1969	1	Toutle H.	500,396			
	1990,91	2	Tule Stocks	1,000			
	1960-85	10	unknown	471,660,276			
	1971	1	Wells H.		1,784,000		
	1979	1	Willard NFH	148,575			
				490,392,381	3,588,000	99	1

Appendix D (Continued).

Cowlitz R.	1981	1	Big Cr. H. (OR)	807,000			
	1981	1	Bonneville H.	4,217,937			
	1961-93	27	Cowlitz H.	152,192,405			
	1953-81	3	Lower Kalama H.	2,830,087			
	1953,55	2	Spring Cr. NFH	586,673			
	1968,79	2	Toutle H.	1,008,357			
	1978,90	2	Washougal H.	2,606,330			
	1952	1	Carson NFH	24,506			
				164,273,295	0	100	0
Toutle R.	1967	1	Big Cr. H. (OR)	463,459			
	1952	1	Carson NFH	1,164,070			
	1991,93	2	Cowlitz H.	641,382			
	1989	1	Elokomin H.	868,700			
	1988	1	Grays R. H.	3,937,000			
	1966-75	4	Green R. H.	8,024,234			
	1957	1	Lewis R. H.	348,799			
	1953-93	5	Lower Kalama H. and Kalama Falls H.	6,880,135			
	1953-60,93	8	Spring Cr. NFH	9,400,907			
	1953-93	28	Toutle H.	55,647,988			
	1964,65	2	unknown	6,479,628			
	1987,93	2	Washougal H.	987,600			
	1960	1	Willard NFH	795,932			
				95,639,834		92	8
Kalama R.	1978	1	Big Cr. H. (OR)	88,568			
	1977,82	2	Bonneville H.	734,074			
	1958-93	31	Kalama Falls H.	169,592,860			
	1956	1	Lewis R. H.	661,447			
	1952-84	28	Lower Kalama H.	51,969,100			
	1976-81	3	Priest Rapids H.		280,209		
	1972	1	Ringold H.		190,316		
	1978-84	6	Snake R.		2,194,002		
	1959,60	2	Spring Cr. NFH	5,168,368			
	1978,79	2	Toutle H.	4,286,684			
	1980	1	Tucannon R.	183,034	183,034		
				232,684,135	2,847,561	99	1
Lewis R.	1979	1	Grays R. H.	23,567			
	1952-93	30	Lewis R. H.	15,283,070			
	1954	1	Lower Kalama H.	41,128			
	1954,74	2	Lower Kalama H. and Kalama Falls H.	274,978			
	1961-79	3	Speelyai H.	1,315,749			
	1959-81	3	Spring Cr. NFH	3,121,717			
	1948-51	4	unknown	510,252			
	1984,85	2	Upriver Brights		1,187,029		
	1980	1	Washougal H.	28,267			

Appendix D (Continued).

				20,598,728	1,187,029	95	5
Salmon Cr.	1969	1	Lower Kalama H..	3,000			
	1969	1	Toutle H.	3,000			
				6,000	0	100	0
Washougal R.	1967,86	2	Abernathy NFH	2,239,237			
	1971	1	Big Cr. H. (OR)	856,650			
	1977-83	3	Bonneville H.	4,437,019			
	1980,86	2	Cowlitz H.	7,489,190			
	1986	1	Elokomin H.	75,600			
	1985	1	Grays R. H.	79,750			
	1966-85	7	Kalama Falls H.	8,996,220			
	1981	1	LCR (OR/WA)	5,509,822			
	1955-66	4	Lewis R. H.	2,449,402			
	1953	1	Lower Kalama H.	175,000			
	1989	1	Priest Rapids H.		1,216,800		
	1958-65	8	Spring Cr. NFH	21,186,454			
	1992	1	Spring Cr. NFH/Toutle H.	5,522,700			
	1969-80	5	Toutle H.	7,451,494			
	1979	1	Toutle H./Washougal H.	5,342,147			
	1964,67	2	unknown	4,776,903			
	1959-93	24	Washougal H.	83,605,011			
				160,192,599	1,216,800	99	1
Columbia R. – RM 141	1992,93	2	Bonneville H.	857,601			
	1978-88	9	LCR (WA)	653,305			
	1992	1	Little White Salmon NFH	1,628,987			
	1977	1	Priest Rapids H.		241,000		
	1977	1	Snake R. (WA)		3,326		
	1955-79	4	unknown	1,510,096			
	1982	1	Washougal H.	49,034			
				4,699,023	244,326	95	5
Hamilton Cr.	1977	1	Spring Cr. NFH	50,160			
				50,160	0	100	0
North Bonneville Dam	1984	1	Abernathy NFH	12,087			
(bypass system tests)	1987-90	4	Bonneville H.	7,915,781			
	1980,81	1	Snake R (ID)		119,247		
	1973	1	Snake R. (WA)		45,812		
				7,927,868	165,059	98	2
Wind R.	1952-68	11	unknown	54,803,553			
	1976	1	Carson NFH	668,692			
				55,472,245	0	100	0
Spring Cr. NFH	1979-84	5	Abernathy NFH	29,113,699			

Appendix D (Continued).

	1985-91	7	Bonneville H.	44,276,578			
	1991	1	Clackamas R. (early)	3,292,304			
	1987,88	2	LCR (WA)	10,771,008			
	1987	1	Little White Salmon NFH	973,610			
	1987	1	Priest Rapids H.		1,100,000		
				88,427,199	1,100,000	99	1
	1973-94	18	Spring Cr. NFH	228,514,095			
	1988	1	Tule Stock	1,084,816			
	1988	1	unknown	217,350			
				229,816,261	0	100	0
Little White Salmon R.	1985	1	Bonneville H.	203,996			
	1994	1	Carson NFH	1,797,922			
	1976-85	9	Little White Salmon NFH	86,649,137			
	1978,94	2	Spring Cr. NFH	5,937,253			
	1983	1	Tule Stock	8,430,082			
	1951-79	16	unknown	152,096,514			
	1983-93	11	Upriver Brights		20,708,020		
				255,114,904	20,708,020	92	8
Columbia R. -RM 164	1994	1	Carson NFH	325			
	1981	1	Little White Salmon NFH	37,400			
	1979	1	unknown	265,472			
				303,197	0	100	0
Big White Salmon R.	1976-84	4	Abernathy NFH	8,231,545			
	1979	1	LCR (WA)	101,896			
	1981	1	Little White Salmon NFH	1,084,839			
	1954,79	2	Spring Cr. NFH	3,082,047			
	1950-79	18	unknown	74,351,025			
	1979	1	Willard NFH	98,597			
				86,949,949	0	100	0
Klickitat R.	1986	1	Big Cr. H. (OR)	3,843,600			
	1978-92	3	Bonneville H.	7,746,095			
	1979	1	Cascade H.	3,230,872			
	1971-76	6	Cowlitz H.	5,335,817			
	1972,84	2	Kalama R.	1,625,300			
	1954-92	27	Klickitat H.	29,977,441			
	1979	1	Klickitat H./Cascade H.	3,595,413			
	1952,86	2	Little White Salmon NFH	718,027			
	1975,76	2	Lower Kalama H.	677,137			
	1991,92	2	Lyons Ferry H.		3,472,700		
	1964	1	Minter Cr. H.		5,687,976		
	1987-93	7	Priest Rapids H.		23,987,100		
	1952-83	25	Spring Cr. NFH	39,585,532			
	1966-75	4	Toutle H.	2,568,845			

Appendix D (Continued).

	1951,68	2	unknown	3,171,742			
	1978	1	Washougal H.	819,219			
	1977-91	5	Wells Dam (includes Summer Run)		2,069,109		
				102,895,040	35,216,885	75	25
Skipanon R.	1987	1	Klaskanine H.	15,500			
				15,500	0	100	0
Lewis and Clark R.	1951,52	2	LCR (OR)	146,230			
	1950	1	unknown	61,600			
				207,830	0	100	0
Youngs R.	1988,91	2	Big Cr. H.	621,005			
	1986	1	Bonneville H.	26,397			
	1989-92	3	Cole Rivers H.		475,352		
	1961,89	2	Klaskanine H.	122,625			
				770,027	475,352	62	38
Klaskanine R.	1979	1	Abernathy NFH	56,260			
	1950-89	10	Big Cr. H.	33,173,221			
	1931	1	Big White Salmon R.	737,702			
	1929 1936	2	Bonneville H.	5,955,830			
	1978-86	9	Bonneville H.	32,704,826			
	1975	1	Chetco R.		41,079		
	1983-88	6	Cole Rivers H.		572,601		
	1925-78	13	Klaskanine H.	16,042,881			
	1927,28	2	Klaskanine H./USBF	2,145,108			
	1960,62	1	Klaskanine H./Willard NFH	1,993,540			
	1932-66	8	LCR (OR)	11,302,002			
	1933,42	2	LCR (OR)/Willamette H.		7,371,078		
	1931-39	4	LCR (WA)/Willamette H.		9,209,991		
	1946,58	2	Oxbow H.	860,537			
	1959	1	Spring Cr. NFH	965,428			
	1975	1	Trask H.		39,369		
	1923-77	5	unknown	13,334,263			
				119,271,598	17,234,118	87	13
Big Cr.	1944-93	31	Big Cr. H.	123,924,819			
	1946,48	2	Big Cr. H./Bonneville H.	1,573,622			
	1959,60	2	Big Cr. H./Willard NFH	3,171,214			
	1943	1	Bonneville H.	338,500			
	1981-87	3	Bonneville H.	14,313,343			
	1984-94	11	Cole Rivers H.		3,519,553		
	1941	1	McKenzie R. H.		1,290,875		
	1950,68-76	9	unknown	54,142,951			
	1942	1	Willamette H.		568,500		
				197,464,449	5,378,928	97	3

Appendix D (Continued).

Gnat Cr.	1952	1	Big Cr. H.	29,520			
	1954-57	4	Bonneville H.	150,769			
	1957,58	2	Trask H.		52,220		
				180,289	52,220	78	22
Clatskanie R.	1951-53	3	Big Cr. H.	208,200			
				208,200	0	100	0
Mid-Columbia R. OR	1979-84	5	Abernathy NFH	965,896			
	1964,87	2	Big Cr. H.	1,949,466			
	1978-83	4	Bonneville H.	5,806,919			
	1939,54	2	Bonneville H./Oxbow H.	2,714,025			
	1965	1	Carson NFH	411,965			
	1978,81	2	Cascade H.	5,625,444			
	1978	1	Deschutes R (OR)	73,092			
	1910	1	LCR (OR)	15,170,324			
	1981	1	Little White Salmon NFH	25,933			
	1940,41,63	3	Oxbow H.	5,246,079			
	1977-80	3	Spring Cr. NFH	3,359,797			
	1966	1	Tules Stock	377,520			
	1940,69,70		unknown	1,119,151			
	1987-91	5	Upriver Brights		1,804,107		
	1966	1	Willamette H.		11,025		
				42,845,611	1,815,132	96	4
Scappoose Cr.	1952,53	2	Big Cr. H.	69,450			
				69,450	0	100	0
Clackamas R.	1952-54	3	Bonneville H.	2,160,060			
	1981	1	Bonneville H.	4,080			
	1965	1	LCR (OR)	921,545			
	1955,65	2	Oxbow H.	1,214,851			
	1960	1	Spring Cr. NFH	1,012,607			
	1960-72	7	unknown	16,585,148			
				21,898,291	0	100	0
Eagle Cr.	1938,53	2	Bonneville H.	630,000			
	1961,67	2	Cascade H.	10,923,441			
	1949,60-65	4	LCR (OR)	20,420,776			
	1962	1	LCR (OR)/Mt Shasta H.		4,853,922		
	1929	1	LCR (OR)/Willamette H.		347,000		
	1934-65	7	unknown	978,056			
				32,952,273	5,200,922	86	14
Sandy R.	1938-54	3	Bonneville H.	4,057,279			

Appendix D (Continued).

	1966	1	Cascade H.	174,648			
	1945-65	8	LCR (OR)	18,696,769			
	1960	1	LCR (OR/WA)	2,919,481			
	1955-64	5	Sandy H.	2,207,995			
	1934-77	12	unknown	4,758,926			
				32,815,098	0	100	0
Multnoma Cr.	1951	1	LCR (OR)	50,400			
	1953	1	Oxbow H.	152,064			
				65,832,660	0	100	0
Tanner Cr.	1990-92	3	Big Cr. H.	14,585,543			
	1928-66	14	Bonneville H.	106,965,953			
	1977-93	17	Bonneville H.	130,296,696			
	1912-61	14	Bonneville H. Mix	80,763,654			
	1945	1	Bonneville H. and Rock Cr. H.		4,601,000		
	1958	1	Bonneville H./Trask H.		4,225,234		
	1965	1	Bonneville H./unknown	9,601,000			
	1940-67	6	LCR (OR)	34,203,415			
	1955-62	3	LCR (OR/WA)	27,961,223			
	1979-81	3	Snake R. (OR)		512,440		
	1957	1	Trask H.		3,756,712		
	1986-91	3	Tule Stock	2,894,909			
	1918-77	21	unknown	206,351,204			
	1978-93	16	Upriver Brights		46,736,964		
				613,623,597	59,832,350	91	9
Herman Cr.	1918	1	Bonneville H.	3,937,598			
	1928-54	4	LCR (OR)	4,402,471			
	1958	1	LCR (OR/WA)	2,348,962			
	1951-67	12	Oxbow H.	39,619,232			
	1925-68	3	unknown	8,998,412			
				59,306,675	0	100	0
Hood R.	1938-54	7	Bonneville H.	1,473,180			
	1951	1	LCR (OR)	503,200			
	1934-37	4	unknown	680,000			
				2,656,380	0	100	0
Fifteenmile Cr.	1949	1	LCR (OR)	80,500			
				80,500	0	100	0
9) Lower Columbia R. ESU (Spring Run)							
Grays R.	1977	1	Kalama Falls H.	116,800			
				116,800	0	100	0

Appendix D (Continued).

Abernathy Cr.	1975	1	Abernathy NFH	91,744			
	1969,75		unknown	90,050			
				181,794	0	100	0
Cowlitz R.	1968-93	26	Cowlitz H.	68,063,606			
	1979	1	Little White Salmon NFH	224,590			
	1948-70	4	unknown	1,716,588			
	1968,69	2	Willamette H.		999,295		
				70,004,784	999,295	99	1
Toutle R.	1974-84	7	Cowlitz H.	2,661,471			
	1953	1	unknown	11,184			
				2,672,655	0	100	0
Kalama R.	1964	1	Ancient Wild Stocks	46,657			
	1964,66	2	Bitter Cr.	147,074			
	1967,81	2	Cowlitz H.	525,909			
	1969-93	25	Kalama Falls H.	9,084,007			
	1965	1	Klaskanine H.	195,800			
	1972,73	2	LCR mix	99,175			
	1978	1	Little White Salmon NFH	136,989			
	1964	1	Sherwood Cr.	132,054			
				10,367,665	0	100	0
Lewis R.	1973-81	4	Carson NFH		702,708		
	1972-87	9	Cowlitz H.	2,476,235			
	1981-93	5	Kalama Falls H.	2,415,550			
	1975,76	2	Klickitat H.		203,660		
	1977-93	11	Lewis R. H.	6,999,862			
	1980	1	Lewis R. H./Kalama R.	807,408			
	1977-82	4	Speelyai H.	2,011,325			
	1948-51	4	unknown	192,943			
				14,903,323	906,368	94	6
Columbia R. (Beacon Rock)	1978-88	8	LCR (WA)	959,953			
	1973-90	14	Snake R. (WA)		1,412,152		
				959,953	1,412,152	40	60
North Bonneville Dam (bypass system tests)	1978	1	Carson NFH		76,060		
	1980	1	Kooskia H.		62,300		
	1978,80	2	Rapid R. H.		35,000		
	1973-77	4	Snake R. (WA)		425,801		
				0	599,161	0	100
Columbia R.-RM 164	1974,94	2	Carson NFH		5,350		

Appendix D (Continued).

				0	5,350	0	100
Wind R.	1976	1	Abernathy NFH	82,697			
	1979	1	LCR (WA)	45,014			
	1956-75	19	unknown	27,098,613			
				27,226,324	0	100	0
Spring Cr. NFH	1993	1	Kalama Falls H./Ringold H. and Carson NFH		669,400		
				0	669,400	0	100
Little White Salmon R.	1985	1	Abernathy NFH	946,959			
	1986-94	7	Carson NFH		9,819,820		
	1976-89	13	Little White Salmon NFH	13,759,232			
	1966-75	8	unknown	4,807,330			
				19,513,521	9,819,820	67	33
Big White Salmon	1986-94	8	Carson NFH		4,880,790		
	1982	1	Cowlitz H.	149,071			
	1991	1	Little White Salmon NFH	942,804			
				1,091,875	4,880,790	18	82
Youngs R.	1991,92	2	Clackamas R. early	242,534			
	1994	1	Marion Forks H.		301,361		
	1989-92	4	Willamette H.		1,048,266		
				242,534	1,349,627	15	85
Klaskanine R.	1931	1	Big White Salmon R. and McKenzie R. H.		158,643		
	1991	1	Clackamas R. (early)	119,627			
	1994	1	Marion Forks H.		109,974		
	1928-34	3	McKenzie R. H.		4,404,514		
	1994	1	Santiam R.		100,000		
	1930	1	Trask H.		953,400		
	1920-24	3	unknown	14,548,862			
	1989-92	3	Willamette H.		577,944		
	1927	1	Willamette H. mix		2,101,000		
				14,668,489	8,405,475	64	36
Big Cr.	1985	1	Clackamas R. (early)	20,449			
				20,449	0	100	0
Mid-Columbia R. OR	1980	1	Carson NFH		44,344		
	1979,90	2	Clackamas R. (early)	17,909			
	1991	1	Lookingglass H.		8,398		
	1946	1	unknown	605,750			
				623,659	52,742	92	8

Appendix D (Continued).

Scappoose Cr.	1930		Marion Forks H./Trask H.		60,000		
				0	60,000	0	100
Clackamas R.	1975	1	Carson NFH		289,710		
	1977,78	2	Cascade H.	195,203			
	1985,92	2	Clackamas R.	232,947			
	1978-94	14	Clackamas R. (early)	11,595,754			
	1979	1	Clackamas R. (late)	98,461			
	1975-87	5	Eagle Cr. NFH	1,294,822			
	1978	1	Marion Forks H.		188,261		
	1979-88	4	Santiam R.		1,653,231		
	1939-89	30	unknown	25,649,266			
	1982-89	6	Willamette H.		4,319,098		
				39,066,453	6,450,300	86	14
Sandy R.	1990	1	Bonneville H.	258,629			
	1978	1	Carson NFH		57,861		
	1979-93	11	Clackamas R. (early)	3,067,038			
	1948,49	2	LCR (OR)	441,169			
	1942,59	2	McKenzie R. H.		1,066,949		
	1952-60	7	Sandy H.	2,192,294			
	1939-47	4	Sandy H./McKenzie R. H.		3,903,646		
	1957	1	Sandy H./Willamette H.		40,475		
	1979,81,86	3	Santiam R.		305,729		
	1920-84	8	unknown	2,007,960			
	1973,74	2	USFWS-unspecified	37,483			
	1982-88	4	Willamette H.		1,153,877		
				8,004,573	6,528,537	55	45
Tanner Cr.	1925-45	8	Bonneville H./Willamette H.		27,815,501		
	1930	1	Marion Forks H./Trask H.		1,710,240		
	1920-22	3	unknown	15,861,909			
				15,861,909	29,525,741	35	65
Herman Cr.	1920-35	3	Bonneville H.	7,119,680			
	1924	1	Oxbow H.	3,963,540			
	1921-72	19	unknown	50,327,069			
				61,410,289	0	100	0
			Totals for ESU #9:	3,364,477,082	233,492,623	94	6

ESU 10) Upper Willamette R. Spring ESU

Molalla R.	1991	1	Clackamas R. (early)		469,890		
	1964	1	McKenzie R. H.	72,975			
	1981-92	3	Santiam R.	2,032,335			
	1964-65	2	unknown	375,209			
	1982-92	10	Willamette H.	7,520,897			

Appendix D (Continued).

Pudding R.	1964	1	McKenzie R. H.	62,550			
	1983-85	3	Willamette H.	453,479			
				516,029	0	100	0
Luckiamute R.	1968	1	unknown	88,128			
				88,128	0	100	0
Santiam R.	1965-82	7	Carson NFH		1,416,271		
	1980,81	2	Clackamas R. (early)		752,939		
	1967-75	4	Hagerman NFH*	645,175	645,175		
	1923-94	53	Marion Forks H.	87,932,370			
	1936,37	2	Marion Forks H./McKenzie R. H.	8,441,800			
	1961-78	7	McKenzie R. H.	1,009,442			
	1941,48	2	McKenzie R. H./Santiam R.	1,663,717			
	1932-94	46	Santiam R.	61,605,990			
	1963,64	2	Santiam R./Willamette H.	1,989,604			
	1962	1	Spring Cr. NFH		191,298		
	1918-81	26	unknown	16,976,462			
	1981-86	6	Willamette H.	10,566,693			
				190,831,253	3,005,683	98	2
Willamette R.	1952,62-67	4	Marion Forks H.	343,676			
	1949,78	2	McKenzie R. H.	50,003			
	1955	1	McKenzie R. H./Willamette H.	1,173,991			
	1953,87	2	Santiam R.	420,240			
	1916-77	14	unknown	12,567,419			
	1955-67	7	Willamette H.	9,457,376			
	1979-92	11	Willamette H.	10,089,414			
				34,102,119	0	100	0
Calapooya R.	1981,85	2	Santiam R.	46,188			
	1982-85	4	Willamette H.	500,522			
				546,710	0	100	0
McKenzie R.	1969-75	7	Hagerman NFH*		1,424,563		
	1966	1	Marion Forks H.	47,418			
	1952	1	Marion Forks H. and McKenzie R. H.	1,125,897			
	1966	1	Marion Forks H./Willamette H.	3,030			
	1902-69	62	McKenzie R. H.	192,671,426			
	1978-94	17	McKenzie R. H.	15,997,516			
	1951-65	4	McKenzie R. H./Willamette H.	1,309,620			
	1972-91	4	Santiam R.	288,820			
	1918-77	17	unknown	4,144,703			
	1966-84	4	Willamette H.	1,318,574			

Appendix D (Continued).

				216,907,004	1,424,563	99	1
M. Fork Willamette R.	1974	1	Hagerman NFH*		41,379		
	1920-76	4	LCR (OR)/Willamette H.		1,885,217		
	1983,90	1	Marion Forks H.	290,174			
	1979-90	4	McKenzie R. H.	1,038,153			
	1928,52	2	McKenzie R. H. and Willamette H.	8,310,778			
	1958	1	Nehalem R./Willamette H.		19,962		
	1978-91	7	Santiam R.	3,439,419			
	1952-66	6	Santiam R./Willamette H.	6,984,701			
	1950-77	9	unknown	17,681,493			
	1958	1	Wenatchee R./Willamette H.		67,827		
	1921-94	59	Willamette H.	17,934,084			
				55,678,802	2,014,385	97	3

10) Willamette R. Spring ESU (Fall Run)

Molalla R.	1965,67	2	Big Cr. H.		1,397,158		
	1958	1	Bonneville H./Trask H.		100,000		
	1978	1	Cascade H.		2,111,600		
	1959,60	2	LCR (OR)/Willamette H.		401,858		
	1967	1	Oxbow H.		500,132		
	1957	1	Trask R. (Bonneville H.)		75,000		
	1964-76	11	unknown		9,310,823		
				0	13,896,571	0	100
Luckiamute R.	1974,76	2	unknown		1,945,098		
				0	1,945,098	0	100
Mary's R.	1970	1	Hagerman NFH*		176,400		
				0	176,400	0	100
Santiam R.	1966	1	Big Cr. H.		1,000,848		
	1921,51	2	Bonneville H./Oxbow H.		1,669,444		
	1966	1	Cascade H.		350,000		
	1956,57	2	Klickitat H.		175,974		
	1958,66	2	Oxbow H.		599,911		
	1964-76	11	unknown		54,236,434		
				0	58,032,611	0	100
Willamette R.	1953-56	4	Bonneville H.		2,922,337		
	1977-93	16	Bonneville H.		88,960,581		
	1949	1	Bonneville H./Trask H.		8,776		
	1970	1	Hagerman NFH*		14,560		
	1965-85	13	Willamette H.		34,294,598		
				0	126,200,852	0	100

Appendix D (Continued).

McKenzie R.	1966	1	Bonneville H.		510,150		
	1966	1	Cascade H.		650,454		
	1964-68	3	unknown		3,399,591		
				0	4,560,195	0	100
			Totals for ESU #10:	498,670,045	204,811,727	71	29
ESU 11) Mid-Columbia R. Spring-Run ESU							
Klickitat R.	1964,65	2	Bitter Cr.		1,119,891		
	1961-87	7	Carson NFH		1,465,349		
	1976-84	4	Cowlitz H.		2,731,131		
	1953-93	39	Klickitat H.	25,854,158			
	1966,67	2	unknown	499,910			
				26,354,068	5,316,371	83	17
Mid-Columbia R.	1978-88	6	MCR Mixed (WA)	317,051			
(McNary Dam)				317,051	0	100	0
Yakima R.	1964	1	Bitter Cr.		85,280		
	1979-85	4	Carson NFH		393,088		
	1960	1	Dungeness H.		154,000		
	1959	1	Klickitat H.	20,000			
	1979	1	Little White Salmon NFH		150,000		
	1997-91	7	Leavenworth NFH		2,362,187		
	1977	1	unknown	13,300			
	1994	1	Wenatchee R.		17,913		
	1988	1	Yakima R.	13,255			
				46,555	3,162,468	1	99
Marion Drain	1976	1	Klickitat H.	20,613			
				20,613	0	100	0
Mid-Columbia R.	1973-92	9	Carson NFH		5,715,196		
(Hanford Reach)	1977-82	5	Cowlitz H.		3,244,442		
	1972-90	4	Klickitat H.	2,379,150			
	1978. 1983	2	Leavenworth NFH		234,560		
	1980	1	MCR Mixed (WA)	102,367			
	1985-87	3	Methow R.		108,644		
	1990	1	Priest Rapids H.	13,000			
	1977	1	Wells H.		97,854		
				2,494,517	9,400,696	21	79
Mid-Columbia R.	1977,79	2	Carson NFH		246,774		
(Priest Rapids Dam)	1976-82	4	Leavenworth NFH		803,721		
	1984-86	3	MCR (WA)	176,378			
				176,378	1,050,495	14	86

Appendix D (Continued).

Eagle Cr.	1920-77	7	unknown	1,755,347			
				1,755,347	0	100	0
Hood R.	1985-92	6	Carson NFH		880,036		
	1979-90	4	Clackamas R. (early)		111,303		
	1993	1	Deschutes R. (OR)		69,127		
	1987-90	4	Lookingglass H.		710,028		
	1919,49	2	unknown	341,860			
				341,860	1,770,494	16	84
Deschutes R.	1949-94	34	Deschutes R. (OR)	12,510,365			
	1953,55	2	Deschutes R. (OR) and Wenatchee R.		162,318		
	1966	1	Marion Forks H.		11,266		
	1918-88	25	unknown	13,670,162			
	1960-67	6	Willamette H.		751,123		
	1948-58	3	Willamette H./Deschutes R.		413,307		
				26,180,527	1,338,014	95	5
John Day R.	1978-82	5	John Day R.	89,094			
	1952	1	Sandy H.		19,957		
				89,094	19,957	82	18
Umatilla R.	1986-93	7	Carson NFH		4,180,707		
	1988-92	5	Lookingglass H.		1,356,998		
	1990	1	Umatilla R.		29,522		
				178,188	5,567,227	3	97

11) Mid-Columbia R. Spring-Run ESU-(Fall Run)

Umatilla R.	1990	1	Bonneville H.		143,728		
	1982	1	Bonneville H.		2,828,835		
	1979	1	Chetco R.		46,320		
	1982	1	Spring Cr. NFH		978,336		
	1992	1	Umatilla R.		504,369		
	1983-93	11	Upriver Brights		30,619,004		
				0	35,120,592	0	100
			Totals for ESU #11:	57,954,198	62,746,314	48	52

12) Upper Columbia R. Summer and Fall-Run ESU (Fall and Late-Fall Run)

San Poil R.	1975	1	Chehalis R.		94,391		
	1977	1	Spring Cr. NFH		74,889		
				0	169,280	0	100
Turtle Rock	1975	1	Chehalis R.		41,639		
	1981	1	Elokomin H.		296,127		

Appendix D (Continued).

	1987-93	5	Priest Rapids H.	1,069,467			
	1993	1	Priest Rapids H./Wells H.	1,522,000			
	1984-86	3	Snake R. (WA) and Priest Rapids H.		1,135,368		
	1984	1	Upriver Brights	226,276			
	1987-91	4	Wells H.	1,377,502			
				4,195,245	1,473,134	74	26
Entiat R.	1975	1	Chehalis R.		673,250		
				0	673,250	0	100
Lake Chelan	1978	1	Bonneville H.		48,000		
	1975	1	Deschutes R. (WA)		50,188		
	1975	1	Green R. H./Skagit H.		21,000		
	1976	1	Issaquah Cr. H.		54,665		
	1976	1	Skykomish H.		17,820		
	1974,77	2	Spring Cr. NFH		140,312		
	1990	1	Washougal H.		123,023		
	1991-93	3	Wells H.	401,208			
				401,208	455,008	47	53
Priest Rapids Dam	1992,93	2	Little White Salmon NFH		2,620,000		
	1975-93	19	Priest Rapids H.	74,663,183			
	1960,62	2	unknown	4,275			
	1972-84	9	Upriver Brights	29,651,319			
	1991,92	2	Wells H.	249,200			
				104,567,977	2,620,000	98	2
Hanford Reach	1989-93	5	Hanford Reach	1,087,096			
	1962-66	3	Klickitat H.		397,911		
	1982-88	6	MCR Mixed (WA)	6,432,150			
	1964	1	Minter Cr. H.		132,804		
	1976-86	4	Priest Rapids H.	3,601,626			
	1962-74	3	Spring Cr. NFH		2,202,130		
	1968,72	2	unknown	3,031,529			
				14,152,401	2,732,845	84	16
Banks Lake	1975	1	Deschutes R. (WA)		35,510		
	1976	1	Skykomish H.		26,400		
	1974	1	Spring Cr. NFH		37,715		
				0	99,625	0	100
Yakima R./Hanford Reach/ Battell NW	1992	1	Little White Salmon NFH		124,546		
				0	124,546	0	100
Yakima R.	1994	1	Carson NFH		1,703,892		
	1992,93	2	Little White Salmon NFH		850,966		

Appendix D (Continued).

	1988	1	Lyons Ferry H.		9,825		
	1987	1	Priest Rapids H.	1,000,059			
	1980-91	9	Upriver Brights	12,051,380			
				13,051,439	2,564,683	84	16
Marion Drain	1976	1	Kalama Falls H.		138,360		
				0	138,360	0	100

12) Upper Columbia R. Summer- and Fall-Run ESU (Summer Run)

Similkameen R.	1991-93	3	Wells H.	1,568,290			
				1,568,290	0	100	0
Methow R.	1947	1	Entiat NFH	112,100			
	1943,44	2	Leavenworth NFH	77,200			
	1977-93	7	Wells H.	2,573,577			
				2,762,877	0	100	0
Columbia R.	1976,86	2	Wells H.	3,100,650			
				3,100,650	0	100	0
Wells Dam	1974	1	LCR (WA)		2,447,800		
	1974-93	19	Wells H.	30,314,948			
				30,314,948	2,447,800	93	7
Turtle Rock	1981-83	3	Wells H.	306,965			
				306,965	0	100	0
Entiat R.	1945	1	Carson NFH		8,200		
	1946-64	19	Entiat NFH	6,396,100			
	1941,45	2	GCFMP	175,700			
	1945	1	Methow R.	27,000			
	1964	1	Spring Cr. NFH		990,800		
				27,000	999,000	3	97
Wenatchee R.	1944	1	GCFMP	59,000			
	1947-62	13	Leavenworth NFH	602,800			
	1991-93	3	Wenatchee R.	1,035,619			
				1,697,419	0	100	0
Hanford Reach	1979	1	Wells H.	88,284			
				88,284	0	100	0
Yakima R.	1961	1	Leavenworth NFH	18,500			
				18,500	0	100	0

12) Upper Columbia R. Summer- and Fall-Run ESU (Mixed Spring and Summer Runs)

Entiat R.	1941,42	2	GCFMP	776,700			

Appendix D (Continued).

				776,700	0	100	0
Methow R.	1941	1	GCFMP	182,000			
				182,000	0	100	0
Wenatchee R.	1941,42	2	GCFMP	336,300			
				336,300	0	100	0
			Totals for ESU #12:	177,548,203	14,497,531	92	8
13) Upper Columbia R. Spring-Run ESU							
Methow R.	1979-94	5	Carson NFH		3,525,748		
	1994	1	Chinook H.		2,587		
	1976	1	Cowlitz H.		271,139		
	1950	1	Entiat NFH	143,000			
	1941,43	2	GCFMP	379,842			
	1990	1	Klickitat H.		203,472		
	1977,80	2	Little White Salmon NFH		1,619,000		
	1944,82-93	5	Leavenworth NFH	1,951,361			
	1944-94	30	Methow R.	11,755,470			
	1977-84	3	unknown	2,758,289			
	1977,78	2	Wells H.	1,127,307			
				18,115,269	5,621,946	76	24
Entiat R.	1976-92	7	Carson NFH		3,173,969		
	1976	1	Cowlitz H.		436,634		
	1977-94	14	Entiat NFH	9,020,433			
	1942,44	2	GCFMP	1,034,800			
	1973,75	2	Klickitat H.		189,200		
	1980,83	2	Little White Salmon NFH		1,279,942		
	1977-82	3	Leavenworth NFH	701,672			
	1990	1	MCR Mixed (WA)	53,306			
	1989,90	2	Methow R.	386,176			
				11,196,387	5,079,745	69	31
Chelan R.	1972,73	2	LCR (WA)		4,468,730		
				0	4,468,730	0	100
Wenatchee R.	1971-93	15	Carson NFH		16,686,457		
	1991-93		Chiwawa R.	158,307			
	1976,78	2	Cowlitz H.		1,935,263		
	1967,68	2	Eagle Cr. NFH		336,606		
	1943,44	2	GCFMP	1,171,195			
	1979,80	2	Little White Salmon NFH		1,126,918		
	1944,76-94	17	Leavenworth NFH	32,921,882			
	1942	1	McKenzie R. H.		239,400		

	1980	1	MCR Mixed (WA)	199,882			
	1971	1	unknown	64,350			
				34,515,616	3,638,187	90	10
			Totals for ESU #13:	63,827,272	18,808,608	77	23

14) Snake R. Fall-Run ESU

Clearwater R.	1948-54,74	7	unknown	279,462			
				279,462	0	100	0
Deschutes R.	1945-54	5	Bonneville H.		1,253,706		
	1980	1	Cascade H.		119,040		
	1969-80	8	Deschutes R. (OR)	908,415			
	1918-76	6	unknown	2,139,341			
				3,047,756	1,372,746	69	31
Salmon R.	1949-51	3	unknown	55,760			
				55,760	0	100	0
Snake R. Reservoirs	1982	1	Snake R.	70,272			
	1963-92	13	unknown	1,751,757			
	1985	1	Snake R.	124,119			
	1955-70	9	unknown	3,453,526			
				5,399,674	0	100	0
Snake R. (WA)	1982	1	Klickitat H.		221,759		
	1985-93	5	Lyons Ferry H.	17,123,090			
	1979-84	6	Snake R.	1,339,452			
				18,462,542	221,759	99	1
			Totals for ESU #14:	27,245,194	1,594,505	94	6

15) Snake R. Spring- and Summer-Run ESU-(Spring Run)

Clearwater R.							
	1968-82	10	Carson NFH		5,226,748		
	1990	1	Clearwater R.	307,103			
	1985-94	9	Dworshak NFH.	13,752,425			
	1981-94	10	Kooskia H.	7,807,437			
	1977-86	5	Leavenworth NFH		2,019,822		
	1982-84	3	Little White Salmon NFH		1,012,173		
	1993-94	2	Powell H.	398,611			
	1976-94	17	Rapid R. H.	9,848,204			
	1990-93	3	Red R. H.	650,759			
	1976	1	Santiam R. R		1,043,200		
	1986-87	2	Sawtooth H.	211,879			
	1963	1	Sweetwater H.	125,000			

Appendix D (Continued).

	1968-93	24	Unknown	16,193,772			
				49,295,190	9,301,943	84	16
Lower Salmon R.							
	1968-90	5	Rapid R. H.	556,370			
	1949-51	3	McCall H.	55,760			
				612,130	0	100	0
Rapid R.							
	1969-80,90	12	Rapid R. H.	25,311,919			
				25,311,919	0	100	0
Salmon R. (unspecified)							
	1968-1978	8	Unknown	3,542,213			
				3,542,213	0	100	0
East Fork Salmon R.		(spring)					
	1986-94		Sawtooth H.	1,683,344			
	1977	1	unknown	100,170			
				1,783,514	0	100	0
Main Salmon R. (below Stanley)							
	1985-86	2	Hayden Cr..	259,717			
	1970-1987	8	Pahsimeroi H.	1,929,472			
	1971-94	22	Rapid R. H.	54,484,159			
	1989-91	4	Sawtooth H.	1,998,947			
	1966-81	11	unknown	7,013,172			
				65,685,467	0	100	0
Main Salmon R. (above Stanley)							
	1983-85	3	McCall H.	841,705			
	1974-77,84	6	Rapid R. H.	3,152,428			
	1982-94	12	Sawtooth H.	11,253,193			
	1989	1	unknown	174,434			
				15,421,760	0	100	0
Grande Ronde R.	1914	1	Bonneville H.		1,000		
	1982-87	6	Carson NFH		6,880,696		
	1982	1	Fall Cr. Res.		460,744		
	1983-91	6	Lookingglass H.	2,096,340			
	1980-94	9	Rapid R. H.	5,865,714			
	1972	1	unknown	17,339			
				7,979,393	7,342,440	52	48
Imnaha R.	1984-94	11	Imnaha R.	4,215,385			
				4,215,385	0	100	0

Appendix D (Continued).

Tucannon R.							
	1964	1	Bitter Cr. H.		10,500		
	1962	1	Klickitat H.		15,957		
	1987-1993	7	Lyons Ferry H.	780,186			
	1988-94	6	Tucannon H.	698,283			
				1,478,469	26,457	98	2
Lower Snake R.							
	1963-81	5	Carson NFH		127,619		
	1979	1	Columbia R. Mixed		41,260		
	1963-64	2	Klickitat H.		20,640		
	1978	1	Kooskia H.	439,201			
	1974,81	2	Leavenworth NFH		274,586		
	1973-89	9	unknown	582,750			
				1,021,951	464,105	69	31
Snake R.							
	1971-94	13	Rapid R.	5,711,134			
	1961-63, 87	4	Unknown	759,489			
				6,470,623	0	100	0

15) Snake R. Spring- and Summer-run ESU-(Summer Run)

South Fork Salmon R.							
	1976-93	18	MCall H.	12,200,695			
	1976	1	unknown (Eagle Cr. H.)	11,520			
				12,212,215	0	100	0
Main Salmon R. (below Stanley)							
	1972-94	18	Pahsimeroi H.	5,984,084			
				5,984,084	0	100	0
			Totals for ESU #15:	201,014,313	17,134,945	92	7

*Hagerman NFH. - Oregon Department of Game hatchery release records contain a stock code that identifies the Hagerman NFH as the source (according to the Oregon Department of Fish and Wildlife stock list). We have found no other supporting documentation for these transfers and conclude that it is unlikely that the fish originated from Hagerman NFH (Idaho). Oregon Department of Fish and Wildlife is currently trying to clarify the origin of these fish.

Appendix D (Continued).

APPENDIX E:

ABUNDANCE DATA

Appendix E: Summary of chinook salmon abundance data considered, by ESU and River/Stock.

ESU					**Status summaries**[3]							**Recent abundance**		**Trends**		
River Basin	**Sub-basin**	Run[1]	**Production**[2]	A	**B**	**C**	**D**	**E**	**P?**[4]	**Data Years**	**Data type**[5]	**5-Year Geometric mean**[6]	**Long-term**[7]	**Short-term**[8]	**Data References**
1-Sacramento River Winter Run															
¤* Sacramento R		Wi	Natural	E						1967-96	DC	628	-18.1	-8.1	BE and LGL 1995, PSMFC 1997a,b
San Joaquin R	Calaveras R	Wi		X					P						
2-Central Valley Spring-Run															
¤* Sacramento R		Sp	Natural	B					P	1967-96	DC	435	-9.9	-35.3	BE and LGL 1995, PSMFC 1997a,b
	American R	Sp/Su		X											
¤*	Feather R	Sp	Mixed						P	1954-96	TE	4,260	3.3	9.1	BE and LGL 1995, PFMC 1997
	Yuba R	Sp		B					P						
¤*	Butte Cr	Sp	Natural						P	1955-96	TE	1,188	-3.2	40.6	BE and LGL 1995, PSMFC 1997a,b, CDFG 1997c
	Big Chico Cr	Sp							P						
¤*	Deer Cr	Sp	Natural						P	1949-97	TE	564	-4.5	+17.1 (1987-97)	BE and LGL 1995, PSMFC 1997a,b, CDFG 1997c
¤*	Mill Cr	Sp	Natural						P	1947-96	TE	252	-5.2	-0.6	BE and LGL 1995, PSMFC 1997a,b
	Antelope Cr	Sp							P						
	McCloud R	Sp/Su		X											
	Pit R	Sp/Su		X											
San Joaquin R (& tribs)		Sp/Su		X											
3-Central Valley Fall-Run															
Sacramento R		Early Fa							P						
		Fa	Mixed							1967-96	DC	78,996	0.5	0.5	BE and LGL 1995, PSMFC 1997a
¤*			Natural							1952-96	TE	43,454	-3.7	-9.1	BE and LGL 1995, PSMFC 1997a,b

Appendix E (Cont.).

¤*			Late Fa	Mixed		P	1967-94	DC	7,199	-5.4	-11.8	BE and LGL 1995, PFMC 1997, PSMFC 1997a
		American R	Fa	Natural		P	1944-94	TE	20,638	0.8	1.7	BE and LGL 1995, PSMFC 1997b
¤*							1970-96	TE	28,818	-1.7	16.8	PFMC 1997
		Feather R	Fa	Natural		P	1953-94	TE	39,873	0.9	-4.2	BE and LGL 1995, PSMFC 1997b
¤*							1970-96	TE	38,141	-1.0	0.5	PFMC 1997
¤*		Yuba R	Fa	Natural		P	1953-96	TE	10,515	1.2	3.8	BE and LGL 1995, PFMC 1997, PSMFC 1997b
		Deer Cr	Fa	Natural			1951-94	TE	105	-5.3		BE and LGL 1995, PSMFC 1997a,b
		Mill Cr	Fa	Natural			1947-94	TE	1,333	-3.2		BE and LGL 1995, PSMFC 1997a,b
		Battle Cr	Fa	Mixed			1946-96	TE	36,256	2.1	8.6	BE and LGL 1995, PSMFC 1997a,b
*				Natural			1952-96	TE	15,238	1.6	6.1	PSMFC 1997a,b
		Clear Cr	Fa	Natural			1953-96	TE	2,524	1.6	13.0	PSMFC 1997a,b
		Cottonwood Cr	Fa	Natural			1953-92	TE	774	-0.5		BE and LGL 1995, PSMFC 1997a,b
	San Joaquin R		Fa	Natural	C		1947-94	TE	2,796	-2.8	-16.1	BE and LGL 1995, PSMFC 1997b
							1970-96	TE	4,502	-3.6	-6.3	PFMC 1997
¤*		Mokelumne R	Fa	Natural		P	1945-96	TE	1,582	-0.5	27.8	BE and LGL 1995, EBMUD 1997, PSMFC 1997b
¤		Cosumnes R	Fa	Natural	C	P	1941-94	TE	245	-6.4		BE and LGL 1995, PSMFC 1997b
¤*		Stanislaus R	Fa	Natural		P	1947-96	TE	378	-5.6	-30.2	BE and LGL 1995, CDFG 1997d, 1997f, PSMFC 1997b
¤*		Tuolumne R	Fa	Natural		P	1940-96	TE	595	-5.4	-15.3	BE and LGL 1995, CDFG 1997d, 1997f, PSMFC 1997b
¤*		Merced R	Fa	Mixed		P	1954-96	TE	2,043	6.2	22.1	BE and LGL 1995, CDFG 1997d, 1997f, PSMFC 1997b

Appendix E (Cont.).

4-Southern Oregon and California Coastal

	Euchre Creek	Upper	Fa	Natural	A	D		P	1986-96	PI		0.3	-2.8	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤	Rogue R		Sp	Natural				P	1968-92	AC	30,426			Nicholas and Hankin 1988, ODFW 1993
*									1942-96	DC	7,365	-1.9	-12.7	BE and LGL 1995, PFMC 1997, PSMFC 1997b
¤			Fa	Natural					1977-96	AC/CS	95,379	-1.1	-18.9	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
*									1942-96	DC	9,546	5.4	5.2	BE and LGL 1995, PSMFC 1997b
		Lower	Fa		A	D		P						
		Middle	Fa			H	H-II							
		Upper	Sp			H								
			Fa			H	H-II							
		Illinois R	Fa			D		P						
		Applegate R	Fa			H	H-II							
	Hunter Creek		Fa		A	D		P						
		Upper	Fa	Natural					1986-96	PI		36.3	36.3	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤*	Pistol R	Deep Cr	Fa	Natural	B	D		P	1960-96	AC/PI	163	3.6	20.1	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
¤*	Chetco R	Big Emily Cr	Fa	Natural		S-2		P	1971-96	AC/PI	5,811	-4.2	8.3	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b

Appendix E (Cont.).

¤*	Winchuck R	Bear Cr	Fa	Natural	B		D	P	1964-96	AC/PI	592	-2.3	12.0	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
	Smith R		Sp		A	A								
			Fa		B			P						
		South Fork	Sp					P	1991-97	SC		30.7	+30.7 (1987-97)	USFS 1997a
		Middle Fork	Sp					P	1991-97	SC		-4.4	-4.4 (1987-97)	USFS 1997a
		North Fork	Sp					P	1992-96	SC		26.2		USFS 1997a
*		Mill Cr	Fa	Mixed					1980-96	SC		-1.1	1.9	BE and LGL 1995, PSMFC 1997b, Waldvogel 1997
	Klamath R	Lower tributaries	Fa		B	B		P						
*		Blue Cr	Fa						1988-96	SN		14.9	14.9	YTFP 1997b
	Redwood Cr		Fa		B	C		P						
		Little R	Fa			C		P						
	Mad R		Fa		B	C		P						
*		North Fork	Fa	Mixed					1985-93	SC		-29.0		BE and LGL 1995, PSMFC 1997b
*		Canon Cr	Fa	Natural					1964-97	PI		-4.9	+0.1 (1987-97)	PFMC 1997
	Humboldt Bay	Tributaries	Fa		A	A		P						
¤*	Eel R		Fa			C		P	1951-97	DC	16	3.6	-29.7 (1987-97)	PSMFC 1997b, SEC 1997
		Lower	Fa		B									
*		Sprowl Cr	Fa	Natural					1967-97	PI		-4.7	-12.4 (1987-97)	PFMC 1997
¤*		Tomki Cr	Fa	Natural					1964-97	TE	25	-15.6	-37.5 (1987-97)	BE and LGL 1995, PFMC 1997, PSMFC 1997b
¤*		South Fork	Fa	Natural					1938-75	WC	4,022	-0.2		BE and LGL 1995
	Bear R		Fa			C		P						
	Mattole R		Fa		A	A		P						
	Russian R		Fa		A			P						

Appendix E (Cont.).

5-Upper Klamath and Trinity Rivers

	Klamath R		Sp		A	A							
¤*			Fa	Natural	X(OR)			1978-96	TE	2,028	-3.0	14.8	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
		Lower (middle tribs)	Fa				P						
		Clear Cr	Sp				P						
¤*			Fa	Natural				1957-93	TE	1,211	0.2		BE and LGL 1995, PSMFC 1997b
		Elk Cr	Sp				P						
		Indian Cr	Sp				P						
		Upper (mid main\tribs)	Fa				P						
		Wooley Cr	Sp				P						
¤*		Salmon R	Sp	Natural		(A)	P	1980-97	SN	1,317	9.7	+17.9 (1987-97)	BE and LGL 1995, USFS 1997b
¤*			Fa	Natural			P	1978-96	TE	3,421	6.5	2.7	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
		Salmon R, S Fk	Sp				P						
		Salmon R, E Fk of S F	Sp				P						
		Salmon R, N Fk	Sp				P						
¤*		Scott R	Fa	Natural	C	C	P	1978-96	TE	5,955	0.8	7.6	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
¤*		Shasta R	Fa	Natural	A	A	P	1930-96	WC	2,433	-2.4	5.6	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
		Upper (main & Bogus Cr)	Fa				P						
¤*		Bogus Cr	Fa	Natural				1978-96	TE	7,083	1.5	11.1	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
		Williamson R	Sp/Su		X								
			Fa		X								
		Sprague R	Sp/Su		X								
			Fa		X								
		Wood R	Sp/Su		X								

Appendix E (Cont.).

			Fa		X									
¤*	Trinity R	Mainstem	Sp	Natural		C		P	1978-96	TE	3,163	-0.8	-18.1	BE and LGL 1995, CDFG 1996, 1997g, PSMFC 1997b
¤*			Fa	Natural					1978-96	TE	21,552	-0.1	-2.7	BE and LGL 1995, CDFG 1997a, PSMFC 1997b
		Lower Mainstem & Tribs	Fa					P						
		South Fork	Sp			A		P	1991-97	SN		54.5	+54.5 (1987-97)	CDFG 1997e, YTFP 1997a
			Fa			C		P						
		Hayfork Cr	Sp					P						
		New R	Sp	Natural				P	1989-96	SN		16.4	16.4	USFWS 1997b
		North Fork	Sp					P						
		Canyon Cr	Sp					P						
		Middle Mainstem & Tribs	Fa					P						
		Upper Mainstem	Fa					P						

6-Oregon Coast

	Nehamlem Bay	Nehalem R	Sp				H							
			Sp/Su					P						
			Su		C									
¤*			Fa	Natural			H		1950-96	AC/PI	11,521	1.7	-9.9	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
		Cook Cr	Fa	Natural					1986-96	PI		-9.5	-10.4	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
*		Salmonberry R	Fa	Natural			U		1986-96	PI		-14.4	-17.7	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
		Cronin Cr	Fa	Natural					1950-96	PI		0.1	1.8	BE and LGL 1995, ODFW 1997e, PSMFC 1997b

Appendix E (Cont.).

	E Humbug Cr	Fa	Natural				1950-96	PI		1.1	-0.6	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
	Nehalem R, N Fork	Fa		H								
	Soapstone Cr	Fa	Natural				1950-96	PI		3.3	-2.7	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤* Tillamook Bay	Miami R	Fa	Natural	H	H-II		1976-84	AC/PI	612	7.8		Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PSMFC 1997b
	Kilchis R	Sp		S-2		P						
¤*		Fa	Natural	H	H-I		1952-96	AC/PI	1,500	-3.0	-2.0	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤*	Wilson R	Sp	Natural	S-2		P	1965-97	AC/RH	472	1.6	+8.6 (1987-97)	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997c, PSMFC 1997b
¤*	Wilson R, N Fk	Fa	Natural	H	H-I		1950-96	AC/PI	8,834	3.3	-6.0	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤*	Trask R	Sp	Natural	S-2		P	1965-97	AC/RH	3,039	2.8	-14.5 (1987-97)	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997c, PSMFC 1997b
¤*		Fa	Natural	H	H-I		1978-95	AC/PI	16,177	2.5	-7.5	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b

Appendix E (Cont.).

¤*		Tillamook R	Fa	Natural		H	H-I		1952-96	AC/PI	3,296	1.5	-16.3	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
¤*	Nestucca Bay	Nestucca R	Sp	Natural		S-2		P	1965-97	AC/RH	3,809	2.8	-13.0 (1987-97)	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997c, PSMFC 1997b
¤*			Fa	Natural		H	H-I		1950-96	AC/PI	8,584	2.4	-6.4	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
		Little Nestucca R	Fa			H	H-I							
	Neskowin Cr		Fa			U-1								
¤	Salmon R		Fa	Natural		S-2			1968-92	AC	5,129			Nicholas and Hankin 1988, ODFW 1993
¤	Siletz Bay	Siletz R	Sp	Natural		H-3		P	1968-92	AC	660			Nicholas and Hankin 1988, ODFW 1993
			Sp/Su		C									
¤*			Fa	Natural		H	H-II		1952-96	AC/PI	4,283	2.3	8.3	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
		Schooner Cr	Fa			U								
		Drift Cr	Fa			U	H-II							
		Euchre Cr	Fa	Natural					1952-96	PI		3.8	0.3	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤*	Yaquina Bay	Yaquina R	Fa	Natural	C	H	H-II		1952-96	AC/PI	6,409	1.7	27.9	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b

Appendix E (Cont.).

		Grant Cr	Fa	Natural					1950-93	PI		3.3	-12.0	BE and LGL 1995, ODFW 1997e, PFMC 1997b, PSMFC 1997b
	Beaver Cr		Fa			U-1								
¤	Alsea Bay	Alsea R	Sp	Natural	C	H-3		P	1968-92	AC	628			Nicholas and Hankin 1988, ODFW 1993
¤*			Fa	Natural		H	H-II		1952-96	AC/PI	12,208	4.4	-8.2	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
		North Fork	Fa	Natural					1952-96	PI		6.9	2.4	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
		Drift Cr	Fa	Natural		H	H-II		1952-96	PI		0.8	-10.4	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
	Yachats R		Fa		B	U								
	Big Cr		Fa			U-1								
	Siuslaw Bay	Siuslaw R	Sp			U-1		P						
¤*			Fa	Natural		H	H-II		1952-96	AC/PC	11,541	6.3	-2.2	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, PFMC 1997, PSMFC 1997b
		North Fork	Fa	Natural		H	H-II		1952-96	PI		5.9	-6.2	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
	Umpqua Bay	Smith R	Fa			H	H-II							
¤		Umpqua R	Sp	Natural					1968-92	AC	3,330			Nicholas and Hankin 1988, ODFW 1993
¤			Fa	Natural					1968-92	AC	8,188			Nicholas and Hankin 1988, ODFW 1993
*		N Umpqua R	Sp	Natural		H		P	1946-96	DC	3,722	-0.2	-8.0	BE and LGL 1995, PFMC 1997b, PSMFC 1997b
*			Fa	Natural		H			1949-96	DC	145	2.7	-7.9	BE and LGL 1995, ODFW 1997e, PSMFC 1997b

Appendix E (Cont.).

		S Umpqua R	Sp	Natural	A	D		P	1961-96	SN		-0.2	2.3	BE and LGL 1995, ODFW 1997d, PSMFC 1997b
			Fa			H								
¤*	Coos Bay	Coos R	Fa	Natural	C	H			1961-96	AC/PI	10,319	13.1	7.4	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b
		Williams Cr	Fa	Natural					1961-96	PI		10.4	14.8	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
*		Millicoma R, W Fk	Fa	Natural		H	H-II		1961-96	PI		6.4	19.1	BE and LGL 1995, PFMC 1997b, PSMFC 1997b
	Coquille R		Sp		A	D		P						
¤*			Fa	Natural		H	H-II		1952-96	AC/PC	9,760	3.0	0.8	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b
		South Fork	Fa	Natural		H	H-II		1959-96	PI		9.3	0.8	BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤*	Floras Cr		Fa	Natural		U			1959-96	AC/PI	591	-0.8	-0.6	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW1997e, PSMFC 1997b
¤*	Sixes R		Fa	Natural		S-2			1967-96	AC/PC	1,676	-1.5	2.8	Nicholas and Hankin 1988, ODFW 1993, BE and LGL 1995, ODFW 1997e, PSMFC 1997b
¤	Elk R		Fa	Natural		S-2		P	1962-92	AC	3,198			Nicholas and Hankin 1988, ODFW 1993
7-Washington Coast														
	Pysht R		Fa		X			(P)						

Appendix E (Cont.).

¤*	Hoko R		Fa	Natural		NCD		P	1986-96	TE	799	2.3	3.8	BE and LGL 1995, WDFW 1997b, 1997d
	Sooes R		Fa			NCU		P						
	Ozette R		Fa		A+									
	Quillayute R	Basinwide	Sp/Su	Natural					1976-96	TE	1,152	-1.8	0.8	PFMC 1997
			Fa	Natural					1976-96	TE	5,702	3.3	-10.9	PFMC 1997
¤*		Quillayute/ Bogachiel R	Su	Natural		NWU		P	1980-96	TE	114	-0.9	-10.6	BE and LGL 1995, WDFW 1997d
¤*			Fa	Natural		NWH	H-I		1982-96	TE	1,034	2.0	-13.9	BE and LGL 1995, WDFW 1997d
¤*		Dickey R	Fa	Natural		NWH	H-II		1983-96	TE	216	-13.2	-21.7	BE and LGL 1995, WDFW 1997d
?		Sol Duc R	Sp	Mixed		XCH			1977-96	HE	337	-1.7	-16.8	BE and LGL 1995, WDFW 1997d
¤*			Su	Mixed		NCH	H-II	P	1980-96	TE	686	3.1	1.1	BE and LGL 1995, WDFW 1997d
¤*			Fa	Mixed		NCH			1982-96	TE	3,947	0.7	-9.3	BE and LGL 1995, WDFW 1997d
¤*		Calawah R	Su	Natural		NWU		P	1980-96	TE	167	3.5	-8.6	BE and LGL 1995, WDFW 1997d
¤*			Fa	Natural		NWH	H-II		1982-96	TE	1,653	3.0	-8.3	BE and LGL 1995, WDFW 1997d
¤*	Hoh R		Sp/Su	Natural		NWH	H-II	P	1968-96	TE	1,297	1.4	-9.3	BE and LGL 1995, WDFW 1997d
¤*			Fa	Natural		NWH	H-II		1973-96	TE	3,000	2.2	-5.3	BE and LGL 1995, WDFW 1997d
¤*	Queets/ Clearwater R		Sp	Natural					1969-96	TE	602	-0.5	-9.3	BE and LGL 1995, WDFW 1997d
¤*			Fa	Natural					1967-96	TE	3,535	2.8	-11.9	BE and LGL 1995, WDFW 1997d
		Queets R	Sp/Su			NWD		P						
			Fa			NWH	H-II							
		Clearwater R	Sp/Su			NWD		P						
			Fa			NWH	H-II							
?	Raft R		Fa			NWU								
¤*	Quinault R		Sp/Su	Natural		NWD		P	1987-93	TE	650	-2.8	-2.8	BE and LGL 1995
¤*			Fa	Natural		NWH			1977-94	TE	3,231	7.8	0.3	BE and LGL 1995
		Cook Cr	Fa	Mixed		MCH			1977-91	TE	3,550	10.7	26.5	BE and LGL 1995
¤*	Grays Harbor	Humptulips R	Fa	Natural		MWH			1985-96	TE	3,706	-0.1	-6.3	BE and LGL 1995, WDFW 1997d

Appendix E (Cont.).

¤*		Hoquiam R	Fa	Natural		NWH	H-II		1985-96	TE	593	-2.5	-6.1	BE and LGL 1995, WDFW 1997d
¤*		Chehalis R	Sp	Natural		NWH	H-II	P	1985-96	TE	1,979	4.7	5.7	BE and LGL 1995, WDFW 1997d
¤*			Fa	Natural		MWH			1985-96	TE	4,190	0.2	-4.6	BE and LGL 1995, WDFW 1997d
¤*		Wishkah R	Fa	Mixed		NCH	H-II		1985-96	TE	669	-8.1	-9.1	BE and LGL 1995, WDFW 1997d
		Wynoochee R	Sp		A									
¤*			Fa	Natural		NWH	H-II		1985-96	TE	1,884	-4.6	-10.3	BE and LGL 1995, WDFW 1997d
¤*		Satsop R	Su	Natural		MWD		P	1985-96	TE	70	-11.2	-7.2	BE and LGL 1995, WDFW 1997d
¤*			Fa	Mixed		MCH			1986-96	TE	3,939	5.0	2.7	BE and LGL 1995, WDFW 1997d
¤*		Skookumchuck R	Sp	Natural					1970-81	TE	532	7.9		BE and LGL 1995
¤*			Fa	Natural					1969-81	TE	7,247	-0.5		BE and LGL 1995
¤*		Newaukum R	Su/Fa	Natural					1987-93	TE	616	-29.7		BE and LGL 1995
		John/Elk & S Bay Tribs	Fa			MWU								
¤*	Willapa Bay		Fa	Mixed		MCH			1985-96	TE	2,404	-7.0	-13.4	BE and LGL 1995, WDFW 1997d
¤*		Fall R Early (North R)	Fa	Natural		NWD			1985-96	TE	120	-11.0	-13.3	BE and LGL 1995, WDFW 1997d
¤*		Clearwater Cr (Smith Cr)	Fa	Natural					1981-91	TE	2,103	8.3	-3.9	BE and LGL 1995

8-Puget Sound

	Misc 7A Streams		Su/Fa	Natural					1968-96	TE	88	-3.2	-3.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
?	Nooksack/ Samish		Fa			XCU								
¤*		Nooksack R	Su/Fa	Natural					1968-96	TE	134	-10.0	-32.6	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
		Nooksack R, N.F.	Sp/Su	Mixed	A	NCC			1984-96	CS		1.5	-0.9	BE and LGL 1995, WDFW 1997b
		Nooksack R, S.F.	Sp/Su	Natural	A	NWC			1984-96	TE	183	-6.1	-5.7	BE and LGL 1995, WDFW 1997b
?		Samish R	Su/Fa	Natural					1968-96	TE	562	-0.5	-9.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b

Appendix E (Cont.).

¤*	Skagit R		Sp	Natural				1968-96	TE	1,198	-0.6	-3.8	BE and LGL 1995, WDFW 1997b
¤*			Su/Fa	Natural				1968-96	TE	7,537	-2.6	-3.0	BE and LGL 1995, WDFW 1997b
		Lower Skagit R	Fa	Natural		NWD	P	1974-96	TE	1,023	-5.9	-11.7	BE and LGL 1995, WDFW 1997d
		Upper Skagit R	Su	Natural		NWH	P	1974-96	TE	5,619	-1.4	-1.3	BE and LGL 1995, WDFW 1997d
		Lower Sauk R	Su	Natural		NWD	P	1974-96	TE	309	-6.9	-11.5	BE and LGL 1995, WDFW 1997d
		Upper Sauk R	Sp	Natural		NWH	P	1967-96	TE	458	1.8	-7.4	BE and LGL 1995, WDFW 1997d
		Suiattle R	Sp	Natural		NWD	P	1967-96	TE	247	-3.6	-12.7	BE and LGL 1995, WDFW 1997d
		Upper Cascade R	Sp	Natural		NWU	P	1984-96	PR		13.0	17.0	BE and LGL 1995, WDFW 1997d
	Stillaguamish R		Sp		A+		P						
			Su	Mixed		NCD	P	1985-96	TE	648	-2.8	0.4	BE and LGL 1995, WDFW 1997d
¤*			Su/Fa	Natural				1968-96	TE	953	1.1	1.1	BE and LGL 1995, NWIFC 1997b, WDFW 1997b,d
			Fa	Natural		UWD	P	1985-96	TE	155	4.1	3.9	BE and LGL 1995, WDFW 1997d
	Snohomish R		Sp		X		P						
			Su	Natural		NWD	P	1979-96	TE	664	-3.2	-2.4	BE and LGL 1995, WDFW 1997d
¤*			Su/Fa	Natural				1968-96	TE	3,576	-1.6	-1.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b,d
			Fa	Natural		NWD	P	1979-96	TE	1,474	-0.7	-1.7	BE and LGL 1995, WDFW 1997d
		Wallace R	Su/Fa	Mixed		MCH	P	1979-96	TE	290	-11.3	-5.8	BE and LGL 1995, WDFW 1997d
		Bridal Veil Cr	Fa			NWU	P	1992-96	TE	634	19.3		WDFW 1997d
¤*	Misc 10 - Seattle		Su/Fa	Natural				1968-91	TE	39	1.5		BE and LGL 1995, NWIFC 1997b, WDFW 1997b
¤*	Lk Washington		Su/Fa	Natural				1983-96	TE	557	-8.4	-10.9	BE and LGL 1995, NWIFC 1997b, WDFW 1997b,d
		Cedar R	Su/Fa	Natural		NWU	P	1964-96	TE	377	-2.2	-10.1	BE and LGL 1995, WDFW 1997d
?		Issaquah Cr	Su/Fa	Mixed		XCH		1986-96	CS		-9.8	-8.0	BE and LGL 1995, WDFW 1997d
		N Lk Washington Tribs	Su/Fa	Natural		NWU	P	1983-96	TE	145	-11.1	-16.6	BE and LGL 1995, WDFW 1997d

Appendix E (Cont.).

	Duwamish/ Green R		Sp		X		P						
¤*			Su/Fa	Natural		MCH	P	1968-96	TE	4,889	1.4	-7.8	BE and LGL 1995, WDFW 1997d
		Duwamish R	Unk	Natural				1965-88	PI	5,216	-1.4		BE and LGL 1995
		Newaukum Cr	Su/Fa			MWH	P						
	Puyallup R		Sp		X								
¤*			Su/Fa	Natural			P	1968-96	TE	2,518	2.5	8.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
			Fa	Mixed	C	UCU		1953-92	IT		0.2		BE and LGL 1995, WDFW 1997d
		White R	Sp	Natural	B	NCC		1967-96	TC	473	0.2	23.9	WDFW 1997b,d
			Su/Fa			UWU	P						
	Nisqually R		Sp/Su		X								
¤*			Su/Fa	Natural		MCH	P	1968-96	TE	699	1.2	7.9	BE and LGL 1995, WDFW 1997b,d
?	Deschutes R		Su/Fa	Natural			(P)	1972-96	TE	1,479	20.6	24.6	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
	South Sound Tribs.		Su/Fa	Mixed		MCH	P	1972-96	TE	5,449	15.3	8.3	BE and LGL 1995, WDFW 1997d
¤*	Misc 13 - S Pug Sound		Su/Fa	Natural			(P)	1984-96	TE	452	-1.9	-10.0	BE and LGL 1995, NWIFC 1997b
¤*	Misc 13A - Carr Inlet		Su/Fa	Natural			(P)	1968-96	TE	563	8.9	8.6	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
¤*	Misc 13B Streams		Su/Fa	Natural				1968-96	TE	721	8.5	-8.3	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
¤*	Misc 10E - Port Orchard		Su/Fa	Natural				1968-96	TE	519	4.5	7.3	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
	Hood Canal		Su/Fa	Mixed		MCH	P	1968-96	TE	1,194	-2.6	-6.0	BE and LGL 1995, WDFW 1997d
¤*		SE Hood Canal	Su/Fa	Natural				1968-96	TE	26	-10.7	-14.9	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
	Skokomish R		Sp		A+		P						
¤*			Su/Fa	Natural			(P)	1968-96	TE	937	-1.0	-8.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b

Appendix E (Cont.).

¤*	Hamma Hamma R		Su/Fa	Natural			(P)	1987-96	TE	32	-4.3	-4.3	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
¤*	Duckabush R		Su/Fa	Natural			(P)	1987-96	TE	7	-16.7	-16.7	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
			Fa		A								
	Dosewallips R		Sp		A+								
¤*			Su/Fa	Natural			(P)	1987-96	TE	82	18.0	18.0	BE and LGL 1995, NWIFC 1997b, WDFW 1997b
			Fa		A								
	Dungeness R		Sp		A								
¤*			Sp/Su	Natural		NWC		1986-96	TE	105	-5.7	-4.2	BE and LGL 1995, WDFW 1997b,d
			Fa		A								
	Elwha R		Sp		A+		P						
¤*			Su/Fa	Natural		NCH	P	1976-96	TE	1,768	5.4	-14.5	BE and LGL 1995, NWIFC 1997b, WDFW 1997b

9-Lower Columbia River

	Lower Columbia Small Tribs.		Fa		A+								
*	Youngs Bay	Lewis and Clark R	Fa	Natural			P	1948-96	PI		9.6		BE and LGL 1995, PSMFC 1997b
¤				Natural				1978-86	TE	277	63.9		BE and LGL 1995, PSMFC 1997b
*		Youngs R	Fa	Natural			P	1948-96	PI		-1.5		BE and LGL 1995, PSMFC 1997b
				Natural				1980-86	TE	10	-15.2		BE and LGL 1995, PSMFC 1997b
	Klaskanine R		Fa				P						
		South Fork	Fa	Natural				1968-96	PI		-2.1		BE and LGL 1995, PSMFC 1997b
		North Fork	Fa	Natural				1948-96	PI		-4.2		BE and LGL 1995, PSMFC 1997b
¤*	Grays R		Fa	Natural		MCH	P	1964-96	TE	39	-3.0	-29.9	BE and LGL 1995, WDFW 1997f
	Bear Cr		Fa	Natural			P	1983-96	PI		-29.3	-29.0	BE and LGL 1995, PSMFC 1997b
*	Big Cr		Fa	Natural			P	1970-96	PI		-1.1	-4.0	BE and LGL 1995, PSMFC 1997b

Appendix E (Cont.).

¤				Natural				1977-86	TE	2,663	19.6		BE and LGL 1995, PSMFC 1997b
*	Gnat Cr		Fa	Natural			P	1970-96	PI		-4.6	-23.3	BE and LGL 1995, PSMFC 1997b
¤				Natural				1977-86	TE	53	-3.7		BE and LGL 1995
¤*	Skamokawa Cr		Fa	Natural		MCH	P	1964-96	TE	148	-9.5	-22.0	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
	Hunt Cr		Fa				P						
¤*	Elochoman R		Fa	Natural		MCH	P	1964-96	TE	317	0.7	-10.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
*	Plympton Cr		Fa	Natural			P	1968-96	PI		4.8	-0.7	BE and LGL 1995, PSMFC 1997b
¤				Natural				1977-86	TE	1,161	3.4		BE and LGL 1995, PSMFC 1997b
¤*	Clatskanie R		Fa	Natural			P	1948-96	TE	6	1.2	-13.0	BE and LGL 1995, PSMFC 1997b
¤*	Mill Cr		Fa	Natural		MCH	P	1984-96	TE	117	24.1	-24.3	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*	Abernathy Cr		Fa	Natural		MCH	P	1981-96	TE	418	-10.0	-14.1	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*	Germany Cr		Fa	Natural		MCH	P	1981-96	TE	183	-0.6	-12.4	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*	Cowlitz R		Sp	Natural		MCH	P	1980-96	TE	169	-4.3	-7.6	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*			Fa	Natural	A	MCH	P	1964-96	TE	2,349	-3.2	-14.6	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*		Coweeman R	Fa	Natural		MCH	P	1964-96	TE	679	5.5	17.5	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
		Toutle R	Sp				P						
			Fa	Natural				1964-81	PI		-8.3		BE and LGL 1995, PSMFC 1997b
		Toutle R, N Fork	Fa	Natural				1964-81	TE	478	-10.8		BE and LGL 1995, PSMFC 1997b
¤		Green R	Fa	Mixed		UCD	P	1964-96	TE	358	-7.7	35.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤		Toutle R, S Fork	Fa	Natural		UCD	P	1964-96	TE	38	-6.3		BE and LGL 1995, PSMFC 1997b, WDFW 1997f

Appendix E (Cont.).

¤*	Kalama R		Sp	Natural		MCH		P	1980-96	TE	236	-9.6	-2.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*			Fa	Natural		MCH		P	1964-96	TE	3,496	0.3	-14.3	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*	Lewis R		Sp	Natural	X	MCH		P	1980-96	TE	662	-1.9	-28.1	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤*			Fa	Natural		NWH	H-I	P	1964-96	TE	9,995	0.1	-6.3	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
		East Fork	Fa	Natural		NWH		P	1964-96	TE	235	-3.8	-4.6	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
	Milton Cr		Fa					P						
	Scappoose Cr		Fa					P						
?	Clackamas R		Sp	Mixed				P	1950-95	DC	2,823	5.8	-3.9	BE and LGL 1995, Nicholas 1995, PSMFC 1997b
?				Natural					1946-94	TE	7,367	2.9	3.1	BE and LGL 1995, PSMFC 1997b
*			Fa	Natural				P	1967-94	RC		-2.0	4.8	BE and LGL 1995, PSMFC 1997b
?	Sandy R		Sp	Natural	A+			P	1977-96	DC	2,750	11.8	5.9	BE and LGL 1995, Nicholas 1995, PSMFC 1997b
¤			Fa	Natural	A				1975-87	TE	1,027	1.0		BE and LGL 1995, PSMFC 1997b
*			Fa (bright)	Natural				P	1988-96	PI		-24.1		BE and LGL 1995, PSMFC 1997b
			Fa (tule)	Natural				P	1951-94	PI		8.3	1.5	BE and LGL 1995, PSMFC 1997b
		Trout Cr	Fa	Natural					1956-96	PI		-4.1		BE and LGL 1995, PSMFC 1997b
¤*	Washougal R		Fa	Natural	A+	MCH		P	1964-96	TE	3,184	10.6	-1.2	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
	Wind R		Fa	Natural	X				1960-84	PI		-0.5		BE and LGL 1995, PSMFC 1997b
¤*			Fa(tule)	Natural		MCD		P	1967-96	TE	30	-7.2	-31.3	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
	White Salmon R		Fa	Natural	A+				1965-84	PI		-4.1		BE and LGL 1995, PSMFC 1997b

Appendix E (Cont.).

¤*			Fa(tule)	Natural		MCD	P	1965-96	TE	127	-9.2	-9.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
?	Hood R		Sp	Natural	A		P	1963-94	DC	10	7.7		BE and LGL 1995, PSMFC 1997b
?			Fa	Natural	A		P	1963-94	DC	10	1.2		BE and LGL 1995, PSMFC 1997b
		Herman Cr	Fa				P						
?	Klickitat R		Fa(tule)	Mixed		MCH	P	1964-96	TE	1,148	-6.3	0.4	BE and LGL 1995, PSMFC 1997b, WDFW 1997f

10-Upper Willamette River

	Willamette R		Sp	Natural	C			1946-96	DC	25,979	0.2	-14.0	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
?			Fa	Mixed				1954-94	DC	5,823	17.6	-7.0	BE and LGL 1995, PSMFC 1997b
¤*		Molalla R	Sp	Natural			P	1961-93	TE	341	-0.8	-14.1	BE and LGL 1995, PSMFC 1997b
								1961-96	FM		-1.1	-15.1	BE and LGL 1995, PSMFC 1997b
?			Fa	Natural				1976-88	TE	937	-13.0		BE and LGL 1995, PSMFC 1997b
		Abiqua Cr	Sp				P						
		Mill Cr	Sp				P						
?			Fa	Natural				1970-88	TE	1,131	-9.3		BE and LGL 1995, PSMFC 1997b
?		Santiam R	Fa	Natural				1969-87	TE	7,014	2.7		BE and LGL 1995, PSMFC 1997b
¤*		N Santiam R	Sp	Natural			P	1960-88	DC	1,136	-3.7		BE and LGL 1995, PSMFC 1997b
		Marion Fks Hatchery	Sp				P						
		S Santiam R	Sp				P						
		S Santiam Hatchery	Sp				P						
¤*		McKenzie R	Sp	Natural			P	1970-95	DC	2,720	1.0	-12.9	BE and LGL 1995, Nicholas 1995, PSMFC 1997b
		McKenzie Hatchery	Sp				P						
¤*		Fall Cr	Sp	Natural				1966-87	DC	241	-1.0		BE and LGL 1995, PSMFC 1997b

11-Middle Columbia River Spring-Run

	Small Tribs. (Bonneville to Priest Rapids)		Sp		X								
?	Wind R		Sp	Natural		XCD	P	1970-96	TE	162	-2.9	0.1	BE and LGL 1995, PSMFC 1997b
	White Salmon R		Sp		X		P						
¤*	Klickitat R		Sp	Natural	A+	MCD	P	1970-96	TE	214	3.5	-12.4	BE and LGL 1995, PSMFC 1997b
¤*	Deschutes R		Sp	Natural			P	1977-96	TC	42	-3.9	-7.2	ODFW 1997b
¤*		Warm Springs R	Sp	Natural				1977-96	WC	546	-6.4	-15.5	ODFW 1997b
				Natural				1969-96	RC		-1.5	-12.2	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
		Metolius R	Sp		X								
¤	John Day R		Sp	Natural	C		P	1970-94	TE	2,352	-3.8	-3.8	BE and LGL 1995, PSMFC 1997b
								1964-96	RM		4.7	-4.1	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
		North Fork	Sp	Natural			P	1964-96	RM		-0.2	-8.9	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
		Granite Cr	Sp	Natural				1959-96	RM		-2.4	-4.3	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
		Middle Fork	Sp	Natural			P	1960-96	RM		4.1	-13.3	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
		Clear Cr	Sp	Natural				1959-96	RM		-3.8	-7.4	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
*		Combined John Day R	Sp	Natural				1959-96	RMC		-2.5	-7.9	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
	Umatilla R		Sp	Natural	X		P	1988-94	DC	835	60.7	60.7	BE and LGL 1995, PSMFC 1997b
	Walla Walla R		Sp		X								
¤	Yakima R		Sp	Natural				1970-96	DC	1,094	1.7	-19.3	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
*		Upper	Sp	Natural		NWD	P	1960-96	RC		7.3	3.5	BE and LGL 1995, PSMFC 1997b, WDFW 1997b

Appendix E (Cont.).

*		Naches R	Sp	Natural		NWD		P	1958-96	RC		7.3	-9.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997b
*		American R	Sp	Natural		NWD		P	1956-96	RC		5.6	-11.1	BE and LGL 1995, PSMFC 1997b, WDFW 1997b

12-Upper Columbia River Summer- and Fall-Run

?	Wind R		Fa (bright)	Natural		UCH		P	1988-96	TE	241	-12.6	-12.6	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
?	White Salmon R		Fa (bright)	Mixed		MCH		P	1988-96	TE	1,225	-5.2	-5.2	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
?	Klickitat R		Fa (bright)			XCH		P						
	Yakima R		Su		X									
			Fa (bright)			UCH								
¤*			Fa	Mixed					1983-94	TE	2,950	6.5	23.0	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
?		Marion Drain	Fa	Natural		NWH			1983-96	RC		-9.4	-5.7	BE and LGL 1995, PSMFC 1997b, WDFW 1997b
¤*	Hanford Reach		Fa	Natural		NWH	H-I		1964-96	TE	47,010	3.5	-9.9	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤	Wenatchee R		Su	Natural		MWH			1975-95	TE	7,012	-0.1	-8.9	BE and LGL 1995, PSMFC 1997b, WDFW 1997c
*									1956-95	RC		1.5	-5.4	Chapman et al. 1994, BE and LGL 1995, Peven and Mosey 1996
	Entiat R		Su		X									
?	Lake Chelan		Fa			XWH								
¤	Methow R		Su	Natural	B	MWD			1963-96	TE	666	-5.4	0.6	BE and LGL 1995, PSMFC 1997b, WDFW 1997c, 1997f
*				Natural					1956-96	RC		-2.5	3.0	Chapman et al. 1994, BE and LGL 1995, WDFW 1997f

Appendix E (Cont.).

¤	Okanogan R		Su	Natural	C	NWD		1977-96	TE	491	-5.2	-8.8	BE and LGL 1995, WDFW 1997c,f
*				Natural				1956-96	RC		1.5	3.5	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤	Similkameen R		Su	Natural				1977-96	TE	995	5.3	8.1	BE and LGL 1995, WDFW 1997c,f
*				Natural				1957-96	RC		4.6	8.0	Chapman et al. 1994, BE and LGL 1995, PSMFC 1997b, WDFW 1997f
	Sanpoil R		Fa		X								
	Spokane R		Fa		X								
	Pend Oreille R		Fa		X								
	Kootenay R		Fa		X								

13-Upper Columbia River Spring-Run

¤	Wenatchee R		Sp	Natural		NWD	P	1977-95	TE	27	-11.5	-37.4	BE and LGL 1995, WDFW 1997c
*				Natural				1959-96	RC		-2.1	-36.6	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
		Icicle Cr	Sp	Natural				1954-90	PI		0.2		BE and LGL 1995, PSMFC 1997b
				Natural				1958-96	RC		0.5	-16.1	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
¤		Chiwawa R	Sp	Natural		NWD	P	1977-95	TE	134	-8.1	-29.3	BE and LGL 1995, WDFW 1997c
*				Natural				1958-96	RC		-3.1	-35.1	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
¤		Nason Creek	Sp	Natural		NWD	P	1977-95	TE	85	-9.0	-26.0	BE and LGL 1995, WDFW 1997c
*				Natural				1958-96	RC		-4.1	-20.9	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
¤		Little Wenatchee	Sp	Natural		NWD	P	1978-95	TE	57	-5.5	-25.8	BE and LGL 1995, WDFW 1997c

Appendix E (Cont.).

*				Natural				1958-96	RC		-0.7	-26.5	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
¤		White R	Sp	Natural		NWD	P	1977-95	TE	25	-10.6	-35.9	BE and LGL 1995, WDFW 1997c
*				Natural				1958-96	RC		0.9	-25.0	BE and LGL 1995, Peven and Mosey 1996, PSMFC 1997b
¤	Entiat R		Sp	Natural		NWD	P	1977-95	TE	89	-18.8	-19.4	BE and LGL 1995, WDFW 1997c
*				Natural				1959-96	RC		-5.4	-25.9	BE and LGL 1995, Carie 1996, PSMFC 1997b
¤	Methow R		Sp	Mixed		NCD	P	1977-95	TE	144	1.1	-15.3	BE and LGL 1995, WDFW 1997c
*				Natural				1959-96	RC		-1.3	-8.4	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤		Twisp	Sp	Natural		NWD	P	1977-95	TE	87	-5.8	-27.4	BE and LGL 1995, WDFW 1997c
*				Natural				1959-96	RC		-4.1	-21.0	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
¤		Chewuch R (Chewack)	Sp	Natural		NWD	P	1977-95	TE	62	-5.1	-28.1	BE and LGL 1995, WDFW 1997c
*				Natural				1960-96	RC		-2.1	-22.5	BE and LGL 1995, PSMFC 1997b, WDFW 1997f
		Early Winters Cr	Sp	Natural				1959-96	RC		0.6		BE and LGL 1995, WDFW 1997c, 1997f
¤		Lost R	Sp	Natural		NWD	P	1972-95	TE	62	-0.1	-23.2	BE and LGL 1995, WDFW 1997c
*				Natural				1959-96	RC		-2.2	-16.1	BE and LGL 1995, WDFW 1997c, 1997f
	Okanogan R		Sp		X								
	Sanpoil R		Sp/Su		X								
	Spokane R		Sp/Su		X								
	Colville R		Sp/Su		X								
	Kettle R		Sp/Su		X								
	Pend Oreille R		Sp/Su		X								

Appendix E (Cont.).

14-Snake River Fall-Run

¤*	Deschutes R		Su	Unresolved				1957-90	TC	57	-1.6		BE and LGL 1995, PSMFC 1997b
¤*			Fa	Natural			P	1977-96	TE	6,078	3.0	10.3	BE and LGL 1995, ODFW 1997c, PSMFC 1997b
	John Day R		Fa				P						
	Umatilla R		Fa	Natural	X		P	1983-94	DC	402	60.4	34.5	BE and LGL 1995, PSMFC 1997b
	Walla Walla R		Fa		X								
¤*	Snake R		Fa	Natural	A	NWD		1975-96	TE	514	-2.4	10.8	BE and LGL 1995, WDFW 1997f
				Mixed				1975-96	DC	1,020	2.7	6.8	BE and LGL 1995, PSMFC 1997b, DARTAP 1997
		Snake R above Hells Canyon Dam	Fa		X								

15-Snake River Spring- and Summer-Run

¤	Tucannon R		Sp	Natural	A	NWD		1986-91	TL	190	-11.0		BE and LGL 1995, PSMFC 1997b
*				Natural				1957-91	RC		-1.3		BE and LGL 1995, PSMFC 1997b
¤	Asotin Cr		Sp	Natural	A	NWC	P	1986-91	TL	2	10.3		BE and LGL 1995, PSMFC 1997b
	Grande Ronde R		Sp	Natural	B			1964-90	TL	675	-7.6		BE and LGL 1995, PSMFC 1997b
¤				Natural				1986-93	TE	37	-8.5		BE and LGL 1995, PSMFC 1997b
0				Natural				1964-93	RC		-5.5	-7.6	BE and LGL 1995, PSMFC 1997b
*		Wenaha R	Sp	Natural				1957-95	RC		-8.2	-23.6	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
*		Wallowa R	Sp	Natural				1957-95	RC		-8.0		BE and LGL 1995, ODFW 1997b, PSMFC 1997b
¤		Minam R	Sp	Natural				1986-93	TE	69	-9.1	-14.5	BE and LGL 1995, PSMFC 1997b
*				Natural				1957-95	RC		-5.9	-29.8	BE and LGL 1995, ODFW 1997b, PSMFC 1997b

Appendix E (Cont.).

*		Lostine R	Sp	Natural		1964-95	RC		-6.5	-21.2	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
¤		Catherine Cr	Sp	Natural		1986-93	TE	45	-22.5		BE and LGL 1995, PSMFC 1997b
*				Natural		1957-95	RC		-1.8	-26.7	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
*	Salmon R		Sp	Natural	A	1957-96	RC		-8.6	-27.3	PSMFC 1997b
*			Su	Natural	A	1957-96	RC		-8.1	-27.7	PSMFC 1997b
*		South Fork	Su	Natural		1957-96	RC		-4.8	-13.6	PSMFC 1997b
*		Middle Fork	Sp/Su	Unresolved		1957-93	RC		-7.2	-7.1	BE and LGL 1995
*		Big Cr	Sp	Natural		1957-96	RC		-7.2	-34.2	PSMFC 1997b
*			Su	Natural		1957-93	RC		-11.2	-27.9	PSMFC 1997b
*		Valley Cr	Sp	Natural		1957-96	RC		-12.1	-25.9	PSMFC 1997b
*			Su	Natural		1957-96	RC		-8.4	-29.3	PSMFC 1997b
*		Lemhi R	Sp	Natural		1957-96	RC		-10.6	-27.4	PSMFC 1997b
*		East Fork	Sp	Natural		1957-96	RC		-10.9		PSMFC 1997b
*			Su	Natural		1957-96	RC		-8.7	-32.9	PSMFC 1997b
		Upper	Sp	Natural		1957-88	RC		-8.1		BE and LGL 1995
¤	Imnaha R		Sp/Su	Mixed	B	1984-90	TE	216	-24.1		BE and LGL 1995
*				Unresolved		1957-96	RC		-4.6	-10.8	BE and LGL 1995, ODFW 1997b, PSMFC 1997b
*		Big Sheep Cr	Sp	Natural		1957-96	RC		-11.4		BE and LGL 1995, ODFW 1997b, PSMFC 1997b
*		Lick Cr	Sp	Natural		1964-95	RC		-12.0		BE and LGL 1995, ODFW 1997b, PSMFC 1997b
	Powder R		Sp		X						
	Weiser R		Sp		X						
	Payette R		Sp/Su		X						
	Malheur R		Sp/Su		X						
	Boise R		Sp/Su		X						
	Owyhee R		Sp/Su		X						
	Bruneau R		Sp/Su		X						
?	Clearwater R		Sp	Natural	X	1973-83	TL	1,170	-6.1		BE and LGL 1995

?			Natural			1950-72	DC	2,006	28.4		BE and LGL 1995
?		Su		X							
?		Fa	Natural	X		1952-72	DC	41	27.6		BE and LGL 1995
?			Natural			1988-94	RC		21.6	21.6	BE and LGL 1995
?	Lower	Sp			P						
?	Dworshak Hatchery	Sp			P						
?	South Fork	Sp			P						
?	Kooksia Hatchery	Sp			P						
?	Lochsa R	Sp	Mixed		P	1967-91	RC		-0.4	-23.8	BE and LGL 1995
	Lohsa R, Crooked Fork	Sp	Natural			1969-96	RC		-5.8	-19.4	BE and LGL 1995, PSMFC 1997b
?	Selway R	Sp	Natural		P	1969-96	RC		-8.9	-12.3	PSMFC 1997b

NOTES

? Not an ESA issue (chinook salmon were not historically present in the watershed or current stocks are not representative of historical stocks).
¤ Denotes recent abundance mapped in Figures 28 - 45.
* Denotes long-term trend mapped in Figures 28 – 45. (Only data with an adequate time series were mapped.)

[1] Run timing designations: Fa -- fall; Sp -- spring; Su -- summer; Wi -- winter (as reported by data reference).

[2] Production: (as reported by data reference).

[3] Status summaries from the following sources:
A--Nehlsen et al. (1991):
E, endangered (US); X, extinct; A+, possibly extinct; A, high extinction risk; B, moderate extinction risk; C, special concern.
B--Higgins et al. (1992):
A, high risk of extinction; B, moderate risk of extinction; C, stock of concern.
C--Nickelson et al. (1992):
H, healthy; D, depressed; S, special concern; U, unknown.
1, May not be a viable population; 2, Hatchery strays; 3, Small, variable run.
D--WDF et al. (1993): Three characters represent stock origin, production type, and status, in that order.
Origin: N, native; M, mixed; X, non-native; U, unknown; -, unresolved by state and tribes.
Production: W, wild; C, composite; A, cultured; U, unknown; -, unresolved.
Status: H, healthy; D, depressed; C, critical; U, unknown.

E--Huntington et al. (1996):

H-I, healthy Level I (abundance at least two-thirds as great as would be found in the absense of human impacts).

H-II, healthy Level II (abundance between one-third and two thirds as great as expected without human impacts).

[4] Petition status [P?]: Indicates (by 'P') stocks included in the ONRC and Nawa petition dated 31 January 1995. Parentheses indicate stock is included as part of a larger unit in the petition.

[5] Data Type Codes: AC, angler catch expanded (1988-92); CS, carcass; DC, dam count; FM, fish per mile; HE, total estimated hatchery escapement; IT, index total; PC, peak or index live fish, surveys combined; PI, peak or index live fish; PR, peak redd count; RC, redd count; RH, resting hole counts; RM, redds per mile; RMC, redds per mile (surveys combined); SC, spawner counts; SN, snorkle counts; TC, trap count; TE, total estimated escapement (includes hatchery escapement only for mixed production type); TL, total live fish count; WC, wier count.

[6] Most recent 5 years of data used to calculate spawning escapement geometric mean. (Expanded angler catch = 1988-92).

[7] Trend (Long-term): Calculated for all data collected after 1950.

[8] Short-term Trend: Calculated for most recent 7-10 years during the period 1987-96, except as noted.

APPENDIX F:

THE RISK MATRIX METHOD

Appendix F: The Risk Matrix Method

To tie the various risk considerations into an overall assessment of extinction risk for each ESU, the Biological Review Team (BRT) members scored risks in a number of categories using a matrix form (Table F-1). For scoring and reaching an overall conclusion regarding extinction risk for an ESU, the following method was used. 1) After reviewing previous documents and hearing presentations and discussions during the meeting, each BRT member filled in as much of the matrix as possible, scoring the various factors according to the relative degree of risk based on available information. 2) Scores from individual members were tallied on a single sheet, and summarized. 3) The BRT reached an overall conclusion regarding the degree of extinction risk facing each ESU after steps 1 and 2 were completed for all ESUs.

Following is a list of factors considered, along with sub-categories and important questions for each. This is not a complete list, but covers the considerations that have been important in past status reviews. Specific considerations within each of these areas are discussed more fully in the main report.

Abundance

Questions regarding abundance can be put into three sub-categories:

Small population risks **—**Is the overall ESU (or discrete populations within the ESU) at such low abundance that small-population risks (random genetic effects, Allee effects, random demographic or environmental effects) are likely to be significant?

Distribution **—**Do present populations adequately represent historical patterns of geographic distribution and ecological/genetic/life-history diversity? Does fragmentation of previously connected populations pose a risk? Is the ESU at risk in a significant portion of its range?

Habitat capacity **—**Is abundance limited by current habitat capacity? If so, is current habitat capacity adequate to ensure continued population viability? (Here, only habitat capacity is considered. Habitat quality as it affects trends or productivity is considered in the next section.)

Trends, Productivity, and Variability

Again, considerations may be divided into three sub-categories:

Population trends —Is the overall ESU (or populations within it) declining in abundance at a rate that risks extinction in the near future? Is variation in population abundance, in combination with average abundance and trends, sufficiently high to cause risk of extinction?

Productivity —Has population productivity declined or is it declining toward the point where populations may not be sustainable? Is there evidence that natural populations are/can be self-sustaining without the infusion of hatchery-reared fish?

Limiting factors —Are there factors (such as poor freshwater or ocean habitat quality, harvest or other human-induced mortality, interactions with other species) that currently limit productivity to the point where populations may not be sustainable? Are such factors expected to continue into the future? Are there natural or anthropogenic factors that have increased variability in reproduction or survival for populations beyond the historic range of environmental variability? Are there factors that have increased the vulnerability of populations to natural levels of environmental variability?

Genetic integrity

Genetic integrity can be affected through either random effects (included under "Small population risks" above) or directional effects. The major sources of directional effects of concern here are introduced genotypes, interactions with local or non-native hatchery fish, or artificial selection (e.g., through selective harvest or habitat modification). These directional effects pose two major types of risk for natural populations:

Loss of fitness —Has interbreeding or artificial selection reduced fitness of natural populations to the point that this is a significant extinction risk factor?

Loss of diversity —Has there been a substantial loss of diversity within or between populations?

For both types of risk, it may also be important to ask the following question: Even if such interactions are not occurring at present, have past events substantially affected fitness and/or diversity of natural populations within the ESU to the extent that long-term population sustainability is compromised?

Other risks

Are there other factors that indicate risks to the sustainability of the ESU or component populations? Such factors may include disease prevalence, predation, and changes in life-history characteristics such as spawning age or size.

Recent events

This category was included to recognize events (natural or human-induced) that have predictable effects on risk for the ESU, but which have occurred too recently to be reflected in abundance, trend, genetic, or other data considered by the BRT. Examples might include recent changes in management (such as harvest rates or hatchery practices), human-induced changes in the environment (habitat degradation or enhancement), or natural events (such as floods or volcanic eruptions). Recent changes in management were considered only where they were already fully or partially implemented and had reasonably predictable consequences.

SCORING CATEGORIES

Levels of Risk—Individual Factors

Risk from individual factors were ranked on a scale of 1 (very low risk) to 5 (high risk):

1) Very Low Risk —Unlikely that this factor contributes significantly to risk of extinction, either by itself or in combination with other factors.

2) Low Risk —Unlikely that this factor contributes significantly to risk of extinction by itself, but some concern that it may in combination with other factors.

3) Moderate Risk —This factor contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

4) Increasing Risk —Present risk is Low or Moderate, but is likely to increase to high risk in the foreseeable future if present conditions continue.

5) High Risk —This factor by itself indicates danger of extinction in the near future.

Levels of Risk—Recent Events

The "Recent Events" category does not represent specific risk factors, but rather factors that may alter the overall risk score for an ESU from the conclusion based on data available to date. This category was scored as follows: "++" Expect a strong improvement in status of the ESU; "+" Expect some improvement in status; "0" Neutral effect on status; '-' Expect some decline in status; "--" Expect strong decline in status.

Levels of Risk—Overall Summary

The summary score of overall risk uses categories that correspond to definitions in the ESA: in danger of extinction, likely to become endangered in the foreseeable future, or neither. (Note, however, that these scores do not correspond to recommendations for a particular listing action because they are based only on past and present biological condition of the populations and do not contain a complete evaluation of conservation measures as required under the ESA.)

This summary score is not a simple average of the risk factors for individual categories, but rather a judgment of overall risk based on likely interactions among factors. A single factor with a "High Risk" score may be sufficient to result in an overall score of "in danger of extinction," but such an overall score could also result from a combination of several factors with low or moderate risk scores.

LEVELS OF CONFIDENCE

While the table has no specific box for scoring level of confidence in risk scores, this can be an important consideration in reaching listing decisions. Concerns about confidence were noted in the "Comments" section.

RESULTS FOR THE CHINOOK SALMON REVIEW

BRT scores for the three major categories of risk for each chinook salmon ESU are summarized in Table F-2. We do not summarize the “Other Risks” and “Recent Events” categories here, because factors included in these categories varied among ESUs; these factors are discussed in the main report. ESUs for which reviews had previously been completed were not scored.

Table F-1. Example of a blank risk matrix for a single ESU. Each Biological Review Team member filled out scores on one form for each ESU.

Risk Factor	Comments	Risk
Abundance Small Population Risks Distribution Habitat Capacity		
Trends/Productivity/Variability Population Trends Productivity Risk Agents		
Genetic Integrity Loss of Fitness Loss of Diversity		
Other Risks		
Recent Events		
Summary: Overall Risk level		
Concerns:		

Table F-2. Summary of main risk categories for the chinook salmon ESUs. Numbers in each cell are the mean score, with range of scores in parentheses. "NS" means "not scored" and applies to ESUs that had been previously evaluated and had no boundary changes.

ESU	Abundance	Trends/ Productivity/Variability	Genetic Integrity
1) Sacramento Winter Run	NS	NS	NS
2) Central Valley Spring Run	4.6 (4-5)	4.2 (4-5)	3.6 (2-5)
3) Central Valley Fall Run	3.3 (2-5)	3.3 (2-5)	3.3 (2-5)
4) Southern Oregon and California Coasts	3.7 (2-5)	3.7 (2-5)	2.0 (1-3)
5) Upper Klamath and Trinity Rivers	3.1 (2-5)	2.4 (1-5)	2.6 (2-4)
6) Oregon Coast	1.6 (1-2)	2.2 (1-4)	3.5 (2-5)
7) Washington Coast	2.2 (1-4)	2.6 (2-4)	2.6 (1-4)
8) Puget Sound	3.5 (2-5)	3.9 (3-5)	3.6 (2-5)
9) Lower Columbia River	3.1 (1-4)	3.3 (2-4)	3.5 (2-5)
10) Upper Willamette River	3.6 (2-5)	3.3 (1-5)	3.1 (2-5)
11) Middle Columbia River Spring Run	2.8 (2-5)	3.1 (2-4)	2.4 (1-4)
12) Upper Columbia River Summer and Fall Run	NS	NS	NS
13) Upper Columbia River Spring Run	4.5 (4-5)	4.7 (3-5)	3.3 (2-5)
14) Snake River Fall Run	3.8 (3-5)	3.3 (2-5)	2.9 (2-4)
15) Snake River Spring and Summer Run	NS	NS	NS

GLOSSARY

alevin

Life-history stage of a salmonid immediately after hatching and before the yolk-sac is absorbed. Alevins usually remain buried in the gravel in or near the egg nest (**redd**) until their yolk sac is absorbed when they **swim up** and enter the water column.

allele

An **allele** is an alternate form of a **gene** (the basic unit of heredity passed from parent to offspring). By convention, the "**100 allele**" is the most common allele in a population and is the reference for the electrophoretic mobility of other alleles of the same gene. Other genetic terms used in this document include **allozymes** (alternate forms of an enzyme produced by different alleles and often detected by protein electrophoresis); **dendrogram** (a branching diagram, sometimes resembling a tree, that provides one way of visualizing similarities between different groups or samples); **gene locus** (pl. **loci**; the site on a chromosome where a gene is found); **genetic distance** (**D**) (a quantitative measure of genetic differences between a pair of samples); and **introgression** (introduction of genes from one population or species into another). *See also* **DNA** and **electrophoresis**.

allozymes

The alternative forms of an enzyme produced by different alleles and often detected by protein electrophoresis.

anadromy

The life-history pattern that features egg incubation and early juvenile development in freshwater, migration to seawater for adult development, and a return to freshwater for spawning.

Obligatory anadromy: type of anadromy where migration to seawater is required for survival.

artificial propagation

Artificial propagation of salmon refers to the practice of manually spawning adult fish and rearing the progeny in hatcheries, **egg boxes**, **remote site incubators**, or other facilities before release into the natural environment. See also **hatchery**.

Biological Review Team (BRT)

The team of scientists from National Marine Fisheries Service formed to conduct the status review.

Cape Blanco

A geographic feature on the Oregon coast at lat. 43°50’N.

Cape Mendocino

A geographic feature on the California coast at lat. 40°25’N.

Ceratomyxa shasta

A freshwater myxosporean parasite of salmonids that causes high mortalities in susceptible strains of fish. Other common diseases of Pacific salmon include **vibriosus**, **cold water disease**, **bacterial kidney disease**, and **furunculosis**.

coded-wire tag (CWT)

A small piece of wire, marked with a binary code, that is normally inserted into the nasal cartilage of juvenile fish. Because the tag is not externally visible, the adipose fin of coded wire-tagged fish is removed to indicate the presence of the tag. Groups of thousands to hundreds of thousands of fish are marked with the same code number to indicate stock, place of origin, or other distinguishing traits for production releases and experimental groups.

co-managers

Federal, state, county, local, and tribal agencies that cooperatively manage salmonids in the Pacific Northwest.

dendrogram

A branching diagram, sometimes resembling a tree, that provides one way of viewing genetic data to suggest similarities and differences between groups or samples. See **multidimensional scaling**.

DNA (deoxyribonucleic acid)

DNA is 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**.

electrophoresis

Electrophoresis refers to the movement of charged particles in an electric field. It has proven to be a very useful analytical tool for biochemical characters because molecules can be separated on the basis of differences in size or net charge. **Protein electrophoresis**, which measures differences in the amino acid composition of proteins from different individuals, has been used for over two decades to study natural populations, including all species of anadromous Pacific salmonids. Because the amino acid sequence of proteins is coded for by DNA, data provided by protein electrophoresis provide insight into levels of genetic variability within populations and the extent of genetic differentiation between them. Genetic techniques that focus directly on variation in DNA also routinely use electrophoresis to separate fragments formed by cutting DNA with special enzymes (**restriction endonucleases**). *See also* **allele** and **DNA**.

ESA

The U.S. Endangered Species Act.

escapement

The number of fish that survive to reach the spawning grounds or hatcheries. The escapement plus the number of fish removed by harvest form the **total run-size**.

evolutionarily significant unit (ESU)

A "distinct" population of Pacific salmon, and hence a species, under the Endangered Species Act.

fry

Stage in the salmonid life history when the juvenile has absorbed its yolk sac and leaves the gravel of the redd to swim up into the water column. The fry stage follows the **alevin** stage and in most salmonid species is followed by the parr, fingerling, and **smolt** stages. Hatcheries historically released chinook salmon after one or two months of feeding as **fed fry**, although **unfed fry** (defined as all fish released at less than 0.4 g) were also released. The survival of these fry releases was generally negligible.

genetic distance

A quantitative measure of genetic difference between a pair of samples.

hatchery stock (see stock)

A term that refers to a population of fish associated with a hatchery. A hatchery stock is spawned and reared in a hatchery before release. Historically, hatchery stocks were often transferred among hatcheries, but this practice is now less common.

introgression

Introduction by interbreeding or hybridization of genes from one population or species into another.

locus (pl. loci)

The site on a chromosome where a gene is found. The term locus is often used more or less synonymously with gene. See polymorphic loci.

hatchery

Salmon hatcheries typically spawn adults in captivity and raise the resulting progeny in fresh water for release into the natural environment. In some cases, fertilized eggs are outplanted (usually in "hatch-boxes"), but it is more common to release **fry** (young juveniles) or **smolts** (juveniles that are physiologically prepared to undergo the migration into salt water). The fish are released either at the hatchery (**on-station release**) or away from the hatchery (**off-station release**). Releases may also be classified as **within basin** (occurring within the river basin in which the hatchery is located or the stock originated from) or **out-of-basin** (occurring in a river basin other than that in which the hatchery is located or the stock originated from).

The broodstock of some hatcheries is based on adults that return to the hatchery each year; others rely on fish or eggs from other hatcheries, or capture adults in the wild each year.

IHN

Infectious Hematopoietic Necrosis; a viral disease endemic to salmonid fishes of the Pacific Coast of North America that can cause high mortality in 3-week to 6-month-old fish.

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jacks

Male salmon that return from the ocean to spawn one or more years before full-sized adults return. For chinook salmon in Washington, Oregon, California, and Idaho, jacks are 1, 2, or 3 years old, having spent only 6-18 months in the ocean. In contrast to adults, which are 3, 4, and 5 years old after spending 1+ years in the ocean.

jills

Female salmon that return from the ocean to spawn one or more years before full-sized adults return. For chinook salmon in Washington, Oregon, California, and Idaho, jills are 2 or 3 years old, having spent only one or two winters in the ocean, in contrast to more typical chinook salmon that are age 3, 4, and 5 on return.

natural fish

A fish that is produced by parents spawning in a stream or lake bed, as opposed to a controlled environment such as a hatchery.

Ocean type

One of two races of chinook salmon (see Healey 1991). **Ocean-type** chinook salmon populations primarily emigrate to the ocean as subyearlings, although yearling emigrants do occur in some populations. Once in the ocean, **ocean-type** chinook salmon tend to migrate along the coastlines rather than move directly offshore. Morphologically, **ocean-type** chinook salmon have fewer vertebrae (70>) than **stream-type** chinook salmon (>70). Genetic differences between **ocean**- and **stream-type** populations are similar to those observed between coastal and inland steelhead and odd- and even-year pink salmon. **Ocean-type** populations are most commonly found along the coast below 55°N longitude, including all populations south of the mouth of the Columbia River, and in mainstem areas east of the Cascade Range.

polymorphic

Having more than one form (e.g., polymorphic gene loci have more than one allele).

polymorphic locus

If different alleles can be detected at a **gene locus**, the locus is considered to be polymorphic. If all alleles are of the same type, the locus is considered to be monomorphic. Many population genetic analyses are based on the frequency of different alleles at polymorphic loci.

principal component analysis (**PCA**)

A statistical technique that attempts to explain variation among several (*n*) variables in terms of a smaller number of composite independent factors called **principal components**. These principal components are represented by **eigenvectors**, or the perpendicular axes of central trend that pass through the clouds of points represented in *n*-dimensional space. The matrix of eigenvectors and the **matrix of correlations** of independent variables are used with linear algebra to calculate the equations describing the principal components that account for the greatest amount of the variation expressed in the original variables. Principal component one (**PC1**) is defined as a linear combination of the *n* variables that accounts for more of the variance in the data than any other linear combination of variables. Second (**PC2**) and subsequent components are defined as linear combinations that account for residual variance after the effect of the first (and subsequent) component(s) is removed from the data. PC values or "scores" are calculated for each individual and subjected to statistical analysis.

Punta Gorda

A geographic feature of the California coast at lat. $40^{o}15'$ N.

redd counts

Most salmonids deposit their eggs in nests called **redd**s, which are dug in the streambed substrate by the female. Most redds occur in predictable areas and are easily identified by an experienced observer by their shape, size, and color (lighter than surrounding areas because silt has been cleaned away).

Spawning surveys utilize counts of **redd**s and fish carcasses to estimate spawner escapement and identify habitat being used by spawning fish. Annual surveys can be used to compare the relative magnitude of spawning activity between years.

river kilometer (RKm)

Distance, in kilometers, from the mouth of the indicated river. Usually used to identify the location of a physical feature, such as a confluence, dam, waterfall, or spawning area.

SASSI

A cooperative program by **WDFW** and **WWTIT** to inventory and evaluate the status of Pacific salmonids in Washington State. The SASSI report is a series of publications from this program and if referenced as "WDF et al. 1993” in this status review.

semelparous

The condition in an individual organism of reproducing only once in a lifetime.

smolt

verb- The physiological process that prepares a juvenile anadromous fish to survive the transition from fresh water to salt water.

noun- A juvenile anadromous fish that has smolted.

spawner surveys

Spawner surveys utilize counts of **redds** (nests dug by females in which they deposit their eggs) and fish carcasses to estimate spawner escapement and identify habitat being used by spawning fish. Annual surveys can be used to compare the relative magnitude of spawning activity between years. Surveys are conducted on a regular basis on **standard stream segments**, groups of which form a spawner **index**, and are occasionally conducted on **supplemental stream segments** (those that are not part of the standard surveying plan).

Several methodologies have been used to estimate trends in spawner abundance based on the results of redd counts or spawner surveys. The **peak count (PC)** methodology simply uses the largest number of fish observed during the peak of spawning activity. The **area under the curve (AUC)** approach estimates the number of “fish days” (one “fish day” is equal to one fish (spawner) present on the spawning ground for one day) for a given stream segment; AUC is calculated from the total number of spawners observed over the course of the season, divided by the average residence time of spawners on the spawning ground. **Stratified random sampling (SRS)** provides an estimate of the number of spawners in a given area based on spawner counts in both standard and supplemental surveys.

spawner-to-spawner ratio

Several measures are employed to estimate the productivity of salmon populations. The **spawner-to-spawner ratio** estimates the number of spawners (those fish that reproduced or were expected to reproduce) in one generation produced by the previous generation’s spawners. A spawner-to-spawner ratio of 1.0 indicates that, on average, each spawner produced one offspring that survived to spawn. The **recruit-to-spawner ratio** estimates the number of **recruits** (fish that are available for harvest in addition to those that bypass the fishery to spawn) produced by the previous generation’s spawners.

Strait of Juan de Fuca

The body of water separating the southern portion of Vancouver Island and the Olympic Peninsula in Washington. The strait extends from the Pacific Ocean east to the San Juan and Whidbey Islands.

Stream type

One of two races of chinook salmon (see Healey 1991). **Stream-type** chinook salmon populations emigrate to the ocean as one- and two-year-old smolts. As juveniles, **stream-type** fish exhibit behavioral and morphological characteristics consistent with establishing and maintaining territories in freshwater systems (aggressive behavior, and larger, more colorful, fins). Little is known about the oceanic migration patterns of **stream-type** chinook salmon. Based on a limited number of recovered tags, it appears that these fish move into the central North Pacific. Genetic differences between **ocean**- and **stream-type** populations are similar to those observed between coastal and inland steelhead and odd- and even-year pink salmon. **Stream-type** populations are most commonly found along the coast above 55°N longitude, and in headwater areas east of the Cascades.

terminal fisheries

Fisheries near freshwater (usually the mouth of rivers or bays or near a hatchery release site) where the targeted species is returning to spawn. This definition includes the **WDFW** term "extreme terminal fisheries" defined by Crawford (1997, p 24) as ". . . areas where hatchery fish can be harvested with minimum impact on wild stocks (e.g., the Tulalip tribal hatchery)."

west coast chinook salmon

For the purposes of this document, west coast chinook salmon are defined as chinook salmon originating from fresh waters of Washington, Oregon, California and Idaho.