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Status Review of Chum Salmon from Washington, Oregon, and California

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EXECUTIVE SUMMARY

In 1994, the Northwest Region of the National Marine Fisheries Service (NMFS) received three petitions to list distinct populations of chum salmon (*Oncorhynchus keta*) from Puget Sound and the Strait of Juan de Fuca as threatened or endangered species under the Endangered Species Act (ESA). In response to these petitions 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 of anadromous salmonids in the Pacific Northwest. These comprehensive reviews will consider all populations in the states of Washington, Idaho, Oregon, and California. This report summarizes the conclusions of the NMFS Biological Review Team (BRT) for the ESA status review of chum salmon.

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 (ESUs) of the biological species. Based on ecological, genetic, and life-history information developed during this status review from across the species range, the BRT identified four ESUs of chum salmon in the Pacific Northwest: 1) Puget Sound/Strait of Georgia ESU, which includes all chum salmon populations from Puget Sound, the Strait of Georgia, and the Strait of Juan de Fuca up to and including the Elwha River, with the exception of summer-run chum salmon from Hood Canal and the Strait of Juan de Fuca; 2) Hood Canal summer-run ESU, which includes summer-run populations from Hood Canal, Discovery Bay, and Sequim Bay on the Strait of Juan de Fuca; 3) Pacific coast ESU, which includes all natural populations from the Pacific coasts of California, Oregon, and Washington, west of the Elwha River on the Strait of Juan de Fuca; and 4) Columbia River ESU.

The BRT also evaluated patterns of abundance and extinction risk for chum salmon for all ESUs. The team concluded that the Puget Sound/Strait of Georgia ESU is not presently at risk of extinction, nor is it likely to become so in the foreseeable future. Current abundance is at or near historic levels, with a total annual run size averaging over 1 million fish during the past 5 years. The majority of populations within this ESU have stable or increasing population trends, and all populations with statistically significant trends are increasing.

The Puget Sound/Strait of Georgia ESU encompasses a great deal of diversity in chum salmon life-history patterns, including summer, fall, and winter runs. Only two populations of winter-run chum salmon were identified throughout the worldwide range of chum salmon, both of which are present in this ESU and spawn within a few miles of each other in southern Puget Sound. These winter-run populations are not large in size, and although they appear to be healthy with stable escapements, they represent a life-history pattern which is important to conserve. The BRT expressed concern that maintaining present population sizes of summer-run chum salmon in the Puget Sound/Strait of Georgia ESU may depend on supplementation programs. Concern was also expressed about effects on naturally spawning fish of high levels of supplementation and enhancement in the southern part of Puget Sound and Hood Canal and the high representation of non-native stocks in the ancestry of many hatchery stocks.

The BRT has concluded that the Hood Canal summer-run ESU is in danger of extinction. In 1994, petitioners identified 12 streams in Hood Canal that recently supported spawning populations of summer chum salmon. At the time of the petition, chum salmon runs in 5 of these streams may already have been extinct, and those in 6 of the remaining 7 showed strong downward trends. Similarly, summer chum salmon in Discovery and Sequim Bays were also at low levels of abundance. A variety of threats to the continued existence of these populations was identified, including degradation of spawning habitat, low river flows, possible competition among hatchery and naturally-produced juvenile chum salmon in Hood Canal, and high levels of incidental harvest in salmon fisheries in Hood Canal and the Strait of Juan de Fuca.

New information from state and federal agencies demonstrated substantial increases in returning summer chum salmon to some streams in Hood Canal and the Strait of Juan de Fuca in 1995 and 1996. However, serious concerns for the health of this ESU remain. First, the population increases in 1995 and 1996 were limited to streams on the west side of Hood Canal, especially the Quilcene River system, while streams on the south and east sides of Hood Canal continued to have few or no returning spawners. Second, a hatchery program initiated in 1992 was at least partially responsible for adult returns to the Quilcene River system. Third, the strong returns to the west-side streams are the result of a single, strong year class, while declines in most of these streams have been severe and have spanned two decades. Last, greatly reduced incidental harvest rates in recent years probably contributed to the increased abundance of summer chum salmon in this ESU. In Hood Canal, these reductions have been implemented because of greatly reduced abundance of the target species, coho salmon (*O. kisutch*), rather than as a specific conservation measure for summer chum salmon. If coho salmon in the area rebound, and fishery management policies are not implemented to protect summer chum salmon, these populations could again face high levels of incidental harvest.

The Pacific Coast ESU includes chum salmon from a large geographic area of considerable diversity. In the southern portion of the coastal ESU, neither the historic nor the present limit of spawning and distribution of chum salmon is known with certainty. Thus, it is unclear whether the historic range has been reduced. On the Oregon coast, almost all current production of chum salmon is natural, although abundance is low relative to historic levels. Habitat degradation appears to be the primary cause of the depressed status of these Oregon populations.

On the outer Washington coast, little information is available on the abundance of natural populations, although annual adult escapements to Grays Harbor and Willapa Bay number in the tens of thousands. The percentage of hatchery fish in these escapements is unknown. Throughout the ESU there has been considerable hatchery enhancement and some transfer of fish or eggs both within and outside of the ESU. However, hatchery production has been relatively minor compared to natural production, and hatchery programs have used primarily local populations. Therefore, although the BRT had several concerns regarding the paucity of information, the majority conclusion is that the Pacific coast ESU is not presently at risk of extinction nor likely to become so.

The Columbia River ESU historically supported commercial landings of hundreds of thousands of chum salmon, with annual landings of nearly half a million fish as recently as 1942. However, beginning in the mid-1950s, commercial catches declined drastically and now rarely exceed 2,000 per year (less than 50 fish per year have been caught since 1994). Historically, chum salmon also spawned in many Columbia River tributaries. Currently, the Washington Department of Fish and Wildlife (WDFW) recognizes and monitors only three natural populations in the Basin, one in Grays River and two in small streams near Bonneville Dam. All of these populations have been influenced by hatchery programs and fish transfers, including a hatchery on the Chinook River near the mouth of the Columbia River that had a return of 3,000 fish in 1993. Present-day populations in the Columbia River represent only a small portion of the historic chum salmon abundance and diversity. Substantial habitat loss in the Columbia River, its tributaries, and estuary was presumably an important factor in the decline and also represents a significant continuing risk for this ESU. Taking all of these factors into consideration, the BRT unanimously agreed that this ESU is at some risk. About half the members concluded that this ESU is at risk of extinction. The remaining members, citing population trends in recent years that indicate the monitored populations may be stable (albeit small), concluded that the ESU is not at substantial short-term risk of extinction but is likely to become so in the foreseeable future.

ACKNOWLEDGMENTS

This document represents the combined efforts of dozens of people who submitted information on chum salmon directly to the National Marine Fisheries Service, attended Biological and Technical Committee meetings, and answered seemingly endless questions from the authors and BRT members in person and by telephone. The authors particularly wish to acknowledge James Ames, Howard Fuss, Tim Tynan, and Stevan Phelps of the Washington Department of Fish and Wildlife, Nick Lampsakis and Dr. Robert Springborn of the Point No Point Treaty Council, and Carrie Cook, Tom Kane, and Dave Zajac of the U.S. Fish and Wildlife Service for generously sharing newly emerging data. We also wish to thank those who reviewed drafts of this and related documents.

Significant contributions to the compilation and analysis of data were made by Ted Parker, Steve Lambert, and Tod McCoy, from the NMFS, Northwest Fisheries Science Center (NWFSC). The Biological Review Team for chum salmon consisted of the following members from the NWFSC: F. William Waknitz; Drs. Stewart Grant, Jeffrey Hard, Robert Iwamoto, Orlay Johnson, Robert Kope, Conrad Mahnken, Michael Schiewe, Robin Waples, and John G. Williams; and from the NMFS, Alaska Fisheries Science Center, Dr. John Helle.

INTRODUCTION

The U.S. Endangered Species Act (ESA) is intended to conserve threatened and endangered species in their native habitats. Under the ESA, vertebrate populations are considered "species" if they are "distinct." On 14 March 1994, the National Marine Fisheries Service (NMFS) was petitioned by the Professional Resources Organization-Salmon (PRO-Salmon) to list Washington's Hood Canal, Discovery Bay, and Sequim Bay (Figs. 1-2) summer-run chum[1,2] salmon (*Oncorhynchus keta*) as threatened or endangered species under the ESA (PRO-Salmon 1994). A second petition, received 4 April 1994 from the "Save Allison Springs" Citizens Committee (1994), requested listing of fall chum salmon found in the following southern Puget Sound streams or bays: Allison Springs, McLane Creek, tributaries of McLane Creek (Swift Creek and Beatty Creek), Perry Creek, and the southern section of Mud Bay/Eld Inlet (Figs. 1-2). A third petition, received by NMFS on 20 May 1994, was submitted by Trout Unlimited (1994). This petition requested listing for summer chum salmon that spawn in 12 tributaries of Hood Canal (Figs. 1-3).

In response to these petitions and to the more general concerns about the status of Pacific salmon throughout the region, NMFS (1994) announced that it would initiate ESA status reviews for all species of anadromous salmonids in the Pacific Northwest. These comprehensive reviews will consider all populations in the states of Washington, Idaho, Oregon, and California. This proactive approach should facilitate more timely, consistent, and comprehensive evaluation of the ESA status of Pacific salmonids than would be possible in a series of reviews of individual populations.

Scope and Intent of the Present Document

This document reports results of the comprehensive ESA status review of chum salmon from Washington, Oregon, and California (chum salmon do not occur in Idaho). To provide a context for evaluating U.S. populations of chum salmon, biological and ecological information for chum salmon in British Columbia is also considered. This review thus encompasses, but is not restricted to, the populations identified in petitions for chum salmon received by NMFS in 1994.

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[1] Seasonal designations such as "summer-run," "summer chum salmon," or "summers" are used synonymously in this report.

[2] The terms "run," "stock," and populations" are used synonymously in this report and generally refer to a group of salmon that spawn at a particular place and time. These terms are problematical because they have been used in a variety of ways by salmon biologists and managers throughout the Pacific Northwest. For examples, WDFW (1997:A-4) uses the same definition for "stock" and "population" but defines "run" as "the sum of stocks of a single salmonid species which migrates to a particular region, river, or stream of origin at a particular time" (p. A-4).

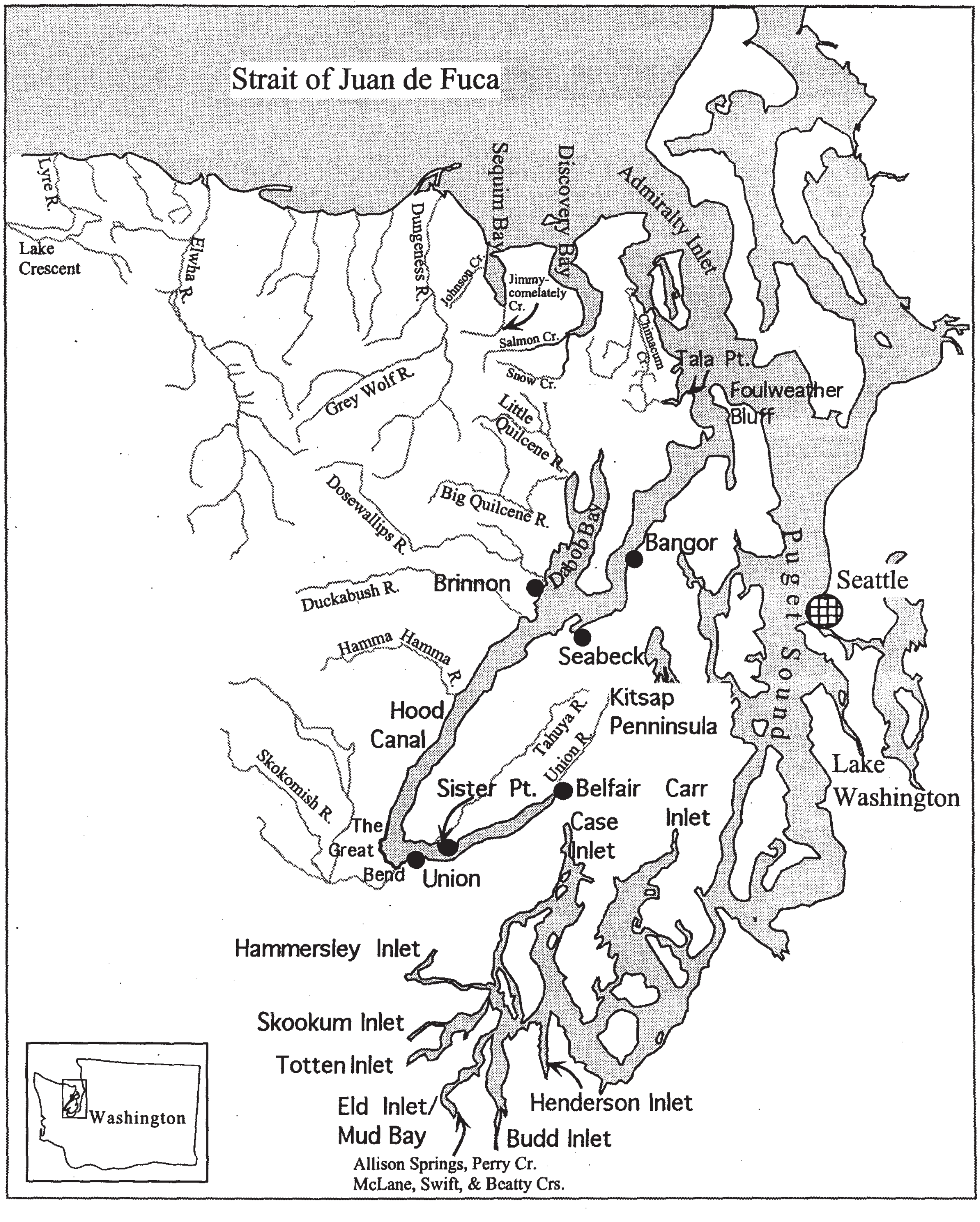

Figure 1. Major geographic locations in the southeastern Strait of Juan de Fuca, northeastern Olympic Peninsula, Kitsap Peninsula, Hood Canal, and southern Puget Sound.

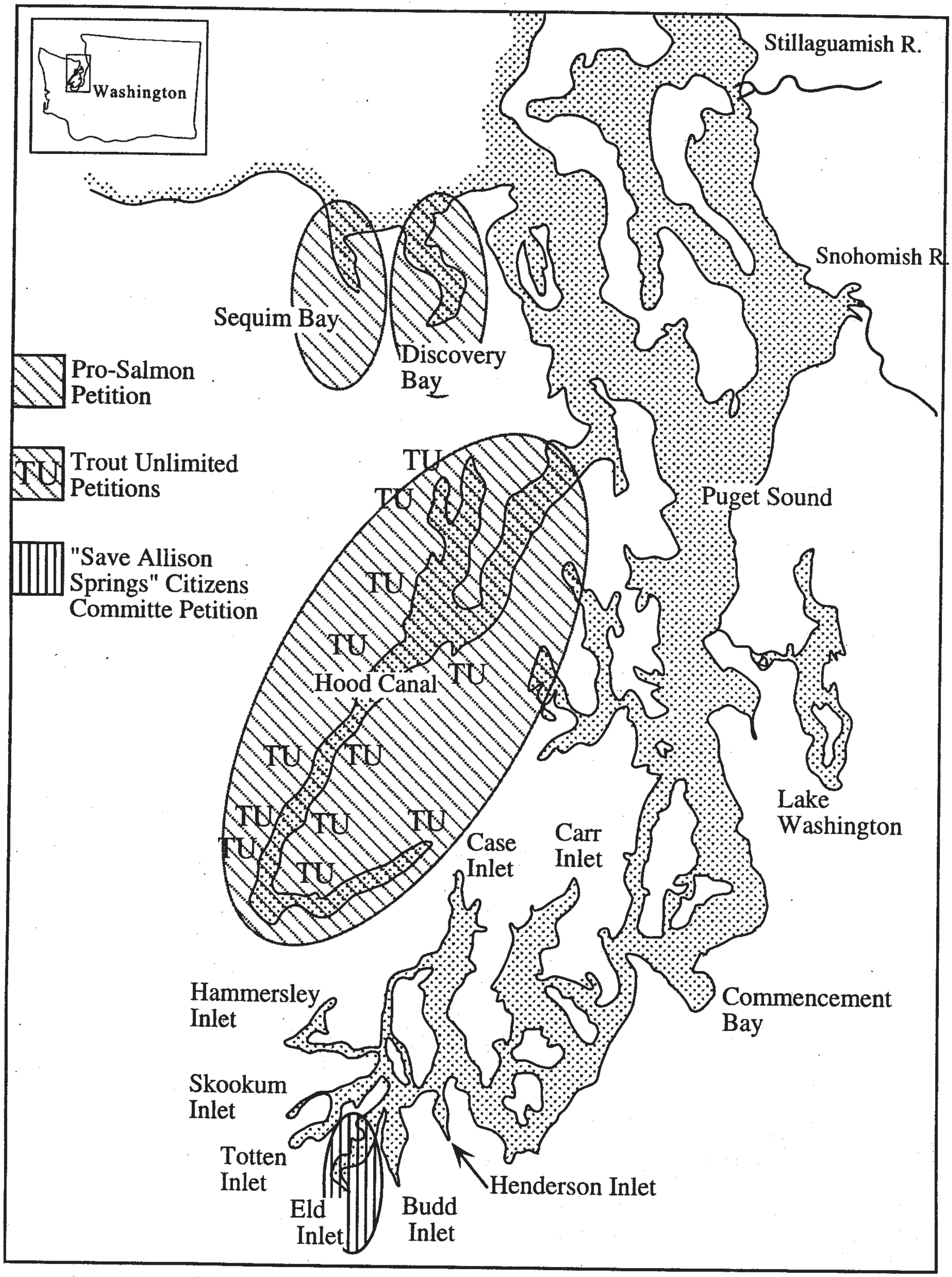

Figure 2. Locations of chum salmon petitioned in 1994 for listing under the ESA. Specific streams where chum salmon were petitioned for listing by Trout Unlimited are identified in Figure 3.

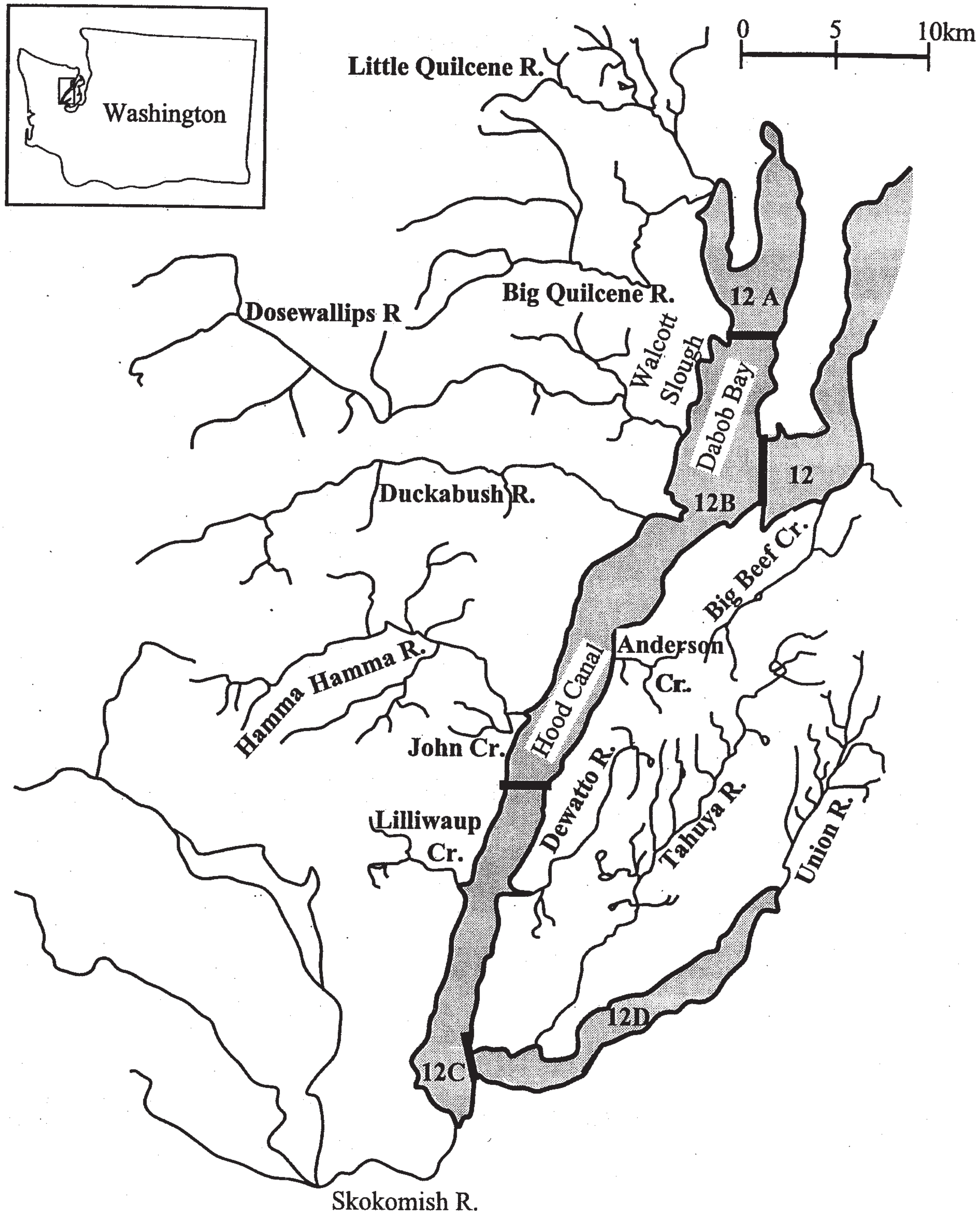

Figure 3. Map of Hood Canal with fishery management areas (12A - 12D) and major river drainages that produce chum salmon. Rivers in bold are where summer chum salmon were petitioned for listing by Trout Unlimited (1994). Modified from Tynan 1992 and Cook-Tabor 1994.

Because the ESA stipulates that listing determinations should be made on the basis of the best available scientific and commercial information, NMFS formed a team of scientists with diverse backgrounds in salmon biology to conduct this review. This Biological Review Team (BRT) reviewed and evaluated scientific information compiled by NMFS staff from published and unpublished literature. Information presented at public meetings held in Seattle in December 1994 and February 1995 was also considered. In addition, the BRT reviewed information submitted to the ESA administrative record.

Key Questions in ESA Evaluations

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 (NMFS 1996).

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 approaches for considering vertebrate populations. To clarify the issue for Pacific salmon, NMFS published a policy describing how the agency will apply the definition of "species" in the ESA to anadromous salmonid species, including sea-run cutthroat trout (*O. clarki clarki*) and steelhead (*O. mykiss*) (NMFS 1991). A more detailed discussion of this topic appeared in the NMFS "Definition of Species" paper (Waples 1991). 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 nonspecific 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.

For each of the two criteria (reproductive isolation and evolutionary legacy), the NMFS policy advocates a holistic approach that considers all types of available information as well as their strengths and limitations. 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 among populations. Data from protein electrophoresis or DNA analyses can be particularly useful for this criterion because they reflect levels of gene flow that have occurred over evolutionary time scales. Isolation does not have to be absolute, but it must be strong enough to permit evolutionarily important differences to accrue in different population units.

The key question with respect to the second 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.

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 et al. 1991). 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, transfers of fish from one area to another might change the genetic or life-history characteristics of 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. 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 “Assessment of Extinction Risk,” p. 144.) In contrast to most other types of risk for salmon populations, those arising from artificial propagation are often not reflected in traditional indices of population abundance. For example, to the extent that habitat degradation, overharvest, or hydropower development have contributed to a population's decline, these factors will already be reflected in population abundance data and accounted for in the risk analysis. The same is not true of artificial propagation. Hatchery production may mask declines in natural populations that will be missed if only raw population abundance data are considered. Therefore, a true assessment of the viability of natural populations cannot be attained without information about the contribution of naturally spawning hatchery fish. Furthermore, even if such data are available, they will not in themselves provide direct information about possibly deleterious effects of fish culture. Such an evaluation requires consideration of the genetic and demographic risks of artificial propagation for natural populations. The sections on artificial propagation in this report are intended to address these concerns.

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 "Extinction Risk" Question

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." 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 relative 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 recruit-to-spawner 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 in place. In this review, we do 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 Regional Offices in making listing recommendations.

Summary of Petitioners’ Arguments to List Chum Salmon

In 1994, NMFS received three petitions to list specific groups of chum salmon in Washington State under the ESA. The petitioners were PRO-Salmon, “Save Allison Springs” Citizens Committee, and Trout Unlimited. Below is a summary of their petitions.

PRO-Salmon Petition

The petition by PRO-Salmon (1994) requested protection of Hood Canal and Strait of Juan de Fuca summer chum salmon populations identified in the Washington State Salmon and Steelhead Stock Inventory (SASSI) reports (WDF et al. 1993) of the Washington Department of Fish and Wildlife (WDFW) and Western Washington Treaty Indian Tribes (WWTIT) (Figs. 1-2). The SASSI reports group all summer chum salmon spawning in Hood Canal, except those in the Union River, as one stock designated as Hood Canal summer chum salmon. The status of the Hood Canal summer chum salmon stock is listed in the SASSI reports as “critical” and the Union River stock as “healthy.” The origin of both stocks is listed as native and the production type as wild.

PRO-Salmon petitioners argue that these SASSI stocks meet the two criteria established by NMFS to define a “species” of Pacific salmon under the ESA: reproductive isolation and evolutionary significance. The petitioners claim that genetic data support distinctiveness from other fall/summer chum salmon populations, that the petitioned stocks are geographically isolated from other summer chum salmon, and that migrational and spawning timing differences isolate them from other fall chum salmon in Hood Canal.

With respect to the “evolutionary significance” criterion for species status under the ESA, the PRO-Salmon petitioners point out that summer chum salmon were historically present in Hood Canal and may have represented a larger portion of the overall chum salmon run to this basin than the fall-run type. They also point out that summer chum salmon in Washington are unique to the Puget Sound drainage area, inclusive of streams draining to the eastern Strait of Juan de Fuca, and that they were never present in Washington coastal drainages, the Columbia River Basin, or in Oregon or California. The petitioners further assert that summer chum salmon are unique among chum salmon run types in that they are found only in smaller, independent (not part of a large river basin) drainages of non-glacial origin and were absent historically in larger and/or glacial Puget Sound river systems. They also state that summer chum salmon, to a much greater extent than fall chum salmon, spawn within a short distance of tidal influence and do not require long estuarine transitions.

The petitioners claim that Hood Canal summer chum salmon meet the threshold criteria for protection under the ESA because, as detailed in the SASSI report, escapement goals for

Hood Canal summer chum salmon have not been met since 1968, and abundance has declined significantly through the 1980s.

The petitioners suggest that habitat loss (Lichatowich 1993) and overfishing are the major causes of the stock decline. They discuss in detail habitat losses due to channel excavations, dewatering, channelization, flood control, major water diversions, poor forestry practices, and bulkheading of nearshore marine habitats. The petitioners also state that not only has overfishing been a major cause of decline, but until recently no attempt has been made by WDFW or WWTIT to protect summer chum salmon. They conclude that summer chum salmon are severely overfished as incidental catch in mixed-fishery harvests of coho, sockeye, chinook (*O. tshawytscha)*, and pink salmon (*O. gorbuscha*).

The petitioners maintain that, as with Hood Canal summer chum salmon, summer chum salmon populations in the Strait of Juan de Fuca, Discovery Bay (Snow and Salmon Creeks), and Sequim Bay (Jimmycomelately Creek) are reproductively isolated by geographic distance from other summer chum salmon and have a different run timing from fall chum salmon found in the same region. The petitioners also claim that genetic studies published in the SASSI report (WDF et al. 1993) show these populations to be genetically different from other fall and summer chum salmon populations analyzed.

The petitioners claim that chum salmon in Discovery and Sequim Bays meet the criterion of “evolutionary significance” in the same manner as do Hood Canal summer chum salmon. The petitioners report that the abundance of summer chum salmon in Discovery and Sequim Bays has declined severely in recent years. Discovery Bay summer chum salmon escapement levels as reported in SASSI for the years 1968 to 1986 ranged from 3,700 to 4,500 fish per year. From 1989 to 1991, Discovery Bay escapements were less than 300 fish per year.

“Save Allison Springs” Citizens Committee Petition

The petition by the “Save Allison Springs” Citizens Committee requests ESA protection for southern Puget Sound fall chum salmon found in Allison Springs, McLane Creek, tributaries of McLane Creek (Swift Creek and Beatty Creek), Perry Creek, and the southern section of Mud Bay/Eld Inlet (Figs. 1-2). The petitioners present no specific information on reproductive isolation or evolutionary legacy, but contend that the fish are a conglomerate of a number of chum salmon populations in the area. They argue that these populations are genetically isolated from other chum salmon due to the ability of salmon to home and adapt to unique environments.

The petition states that although surrounding chum salmon populations are abundant and healthy, escapement of chum salmon to Allison Springs has been depleted due to damming and is presently only about 200 fish per year. Further, the petitioners argue that Allison Springs chum salmon are in imminent danger of extinction due to proposed land development, poor environmental regulations in the area, and a lack of understanding or response from local and state governments.

Trout Unlimited Petition

The petition by Trout Unlimited requests ESA protection for summer chum salmon spawning in 12 tributaries to Hood Canal, Washington (Figs. 1-3). The petitioners contend that these fish are reproductively isolated from other chum salmon populations in Washington, based on their life history and on genetic studies conducted by WDFW (Phelps et al. 1993, WDF et al. 1993). Life-history differences between summer and fall chum salmon in Hood Canal cited by the petitioners are based primarily on timing: time of return to natal streams, time of spawning, time of juvenile emergence from the gravel, and time of outmigration to Hood Canal and Puget Sound. The petitioners present data from the studies of Groot and Margolis (1991), Lichatowich (1993), and the WDF Chum Stock Assessment Unit (WDF et al. 1993) to support these timing differences. Based on these documents, they report that summer chum salmon in Hood Canal enter freshwater between mid-August and mid-October, with migration peaking in mid-September. Fall chum salmon enter the Canal from mid-November to mid-January, with peak entry about 20 November. Spawning is coincident with river entry. Summer-run fish emerge and outmigrate from mid-March through early April, but juvenile fall-run chum salmon do not emerge and outmigrate until mid-April, continuing through mid-May. Based upon this timing, the petitioners state that summer chum salmon outmigrate before naturally spawning fall chum salmon (Trout Unlimited 1994).

The petitioners also assert that distinct genetic differences exist between Hood Canal summer and fall chum salmon. This assertion is based on data developed by WDFW biologists (Phelps et al. 1994), who reported a Rogers genetic distance of 0.11 between sampled Hood Canal summer chum salmon and other chum salmon in Washington. The petitioners further contend, based on this and other data developed by WDFW (Phelps et al. 1994, Phelps[3]), that distinct genetic differences appear among summer chum salmon in each sampled river system in Hood Canal, except in Quilcene Bay and the Quilcene National Hatchery (Trout Unlimited 1994).

The petitioners believe summer chum salmon in Hood Canal meet the NMFS second criterion for ESU status (evolutionary and ecological diversity) because the "various runs of summer chum salmon are part of a unique race of chum salmon that has adapted to a specific niche in Hood Canal" (Trout Unlimited 1994).

The petitioners present data from WDF et al. (1993), Lichatowich (1993), and their own observations that address questions about declining abundance of summer chum salmon in Hood Canal. Based on this information, the petitioners claim that several individual runs of chum salmon from the Canal have disappeared and that others are in critical condition. As an example, they present the following general observations from WDFW and WWTIT (WDF et al. 1993). Escapement numbers were first reported for summer chum salmon beginning in the 1960s, and

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[3] S. Phelps, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., December 15, 1994.

these numbers peaked at 43,000 in 1968. From 1968 to 1978, escapement ranged from 10,000 to 43,000 fish. However, since 1978, escapement has not exceeded 5,500 fish per year, with a low of only 500 returning fish (for the entire Hood Canal Basin) in 1990. Some rivers and riverbasins, including Anderson and Big Beef Creeks, no longer have any returning summer chum salmon, and escapements of summer chum salmon to all Hood Canal tributaries, except those to the Union River, are severely depressed.

Data from two specific river systems are reported by petitioners from Trout Unlimited to support their general assertion that the abundance of the summer-run populations is critically depressed. In spawning surveys of the Big Quilcene River (northwestern side of Hood Canal), escapements were greater than 1,800 fish/mile in 1968 and 1,050 fish/mile in 1976. However, recent spawning surveys show that the run is “near extinction” (Trout Unlimited 1994), with only 25 fish/mile reported in 1991. Similar trends for the Little Quilcene River (escapements numbered 1,150 fish/mile in 1968 and 1,250 fish/mile in 1976, but only 100 fish/mile in 1991) were also used by the petitioners to support the claim that these fish are at critically low levels of abundance and warrant federal protection under the ESA.

The authors of this petition address what they believe are the causes for the decline of summer chum salmon in Hood Canal: overharvest, inadequate regulatory efforts, habitat degradation, predation, and other factors. Finally, the petitioners consider the recovery efforts now being implemented to be inadequate because there is no guarantee that ongoing recovery efforts will be continued, and the state-mandated recovery plan is not binding for Treaty Indian Tribes.

INFORMATION RELATING TO THE SPECIES QUESTION

In this section, we summarize biological and environmental information relevant to determining the nature and extent of chum salmon ESUs in the U.S. Pacific Northwest. The focus of this document is on populations in the contiguous United States; however, information from Asia, Alaska, and British Columbia was also considered to provide a broader context for interpreting results. Further, because ESU boundaries are based on biological and environmental information, they do not necessarily conform to state or national boundaries, such as the U.S./Canada border.

Biology of Chum Salmon

Chum salmon belong to the family Salmonidae and are one of eight species of Pacific salmonids in the genus *Oncorhynchus*. Chum salmon are semelparous, spawn primarily in freshwater, and apparently exhibit obligatory anadromy, as there are no recorded landlocked or naturalized freshwater populations (Randall et al. 1987). The species is best known for the enormous canine-like fangs and striking body color of spawning males (a calico pattern, with the anterior two-thirds of the flank marked by a bold, jagged, reddish line and the posterior third by a jagged black line). Females are less flamboyantly colored and lack the extreme dentition of the males.

The species has the widest natural geographic and spawning distribution of any Pacific salmonid, primarily because its range extends farther along the shores of the Arctic Ocean than other salmonids (Groot and Margolis 1991) (Fig. 4). Chum salmon have been documented to spawn from Korea and the Japanese island of Honshu, east, around the rim of the North Pacific Ocean, to Monterey Bay in southern California. The species' range in the Arctic Ocean extends from the Laptev Sea in the Russian Federation to the Mackenzie River in Canada (Fig. 4) (Bakkala 1970, Fredin et al. 1977). Chum salmon may historically have been the most abundant of all salmonids: Neave (1961) estimated that prior to the 1940s, chum salmon contributed almost 50% of the total biomass of all salmonids in the Pacific Ocean. Chum salmon also grow to be among the largest of Pacific salmon, second only to chinook salmon in adult size, with individuals reported up to 108.9 cm in length and 20.8 kg in weight (*Pacific Fisherman* 1928)[4]. Average size for the species is around 3.6 to 6.8 kg (Salo 1991).

In Asia, chum salmon are the most abundant and commercially valuable salmon. In Japan, mean annual harvest since 1952 has been around 25 million fish, compared to 6.9 million

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[4] The fish was caught in a Northwestern Fisheries Company trap on 12 July 1928 near the Quadra cannery in the Ketchikan district of southeast Alaska. It was photographed, weighed, and measured by the general manager of the company, P.H. McCue. The fish was a bright male in prime condition and scale data indicated it was 6 years old. The news article in *Pacific Fisherman* (1928) indicated that a number of similar-sized fish were caught by the trappers that summer.

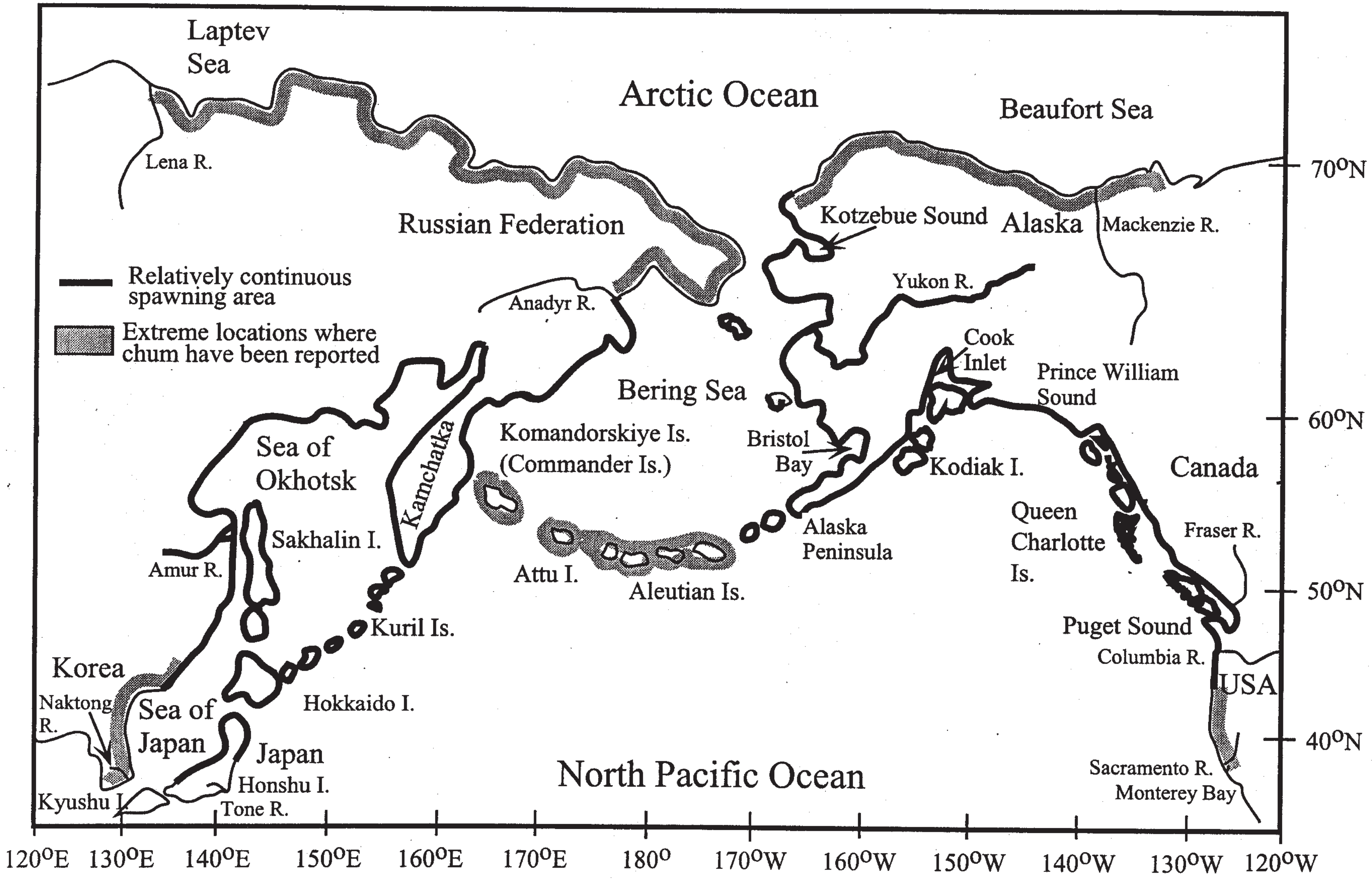

Figure 4. Geographic and spawing distribution of naturally occurring chum salmon. Modified from Salo 1991.

in the United States and 2.4 million in Canada (Bakkala 1970, Salo 1991). But even in North America, more chum salmon by weight are landed each year than any other salmon species (INPFC 1993). Major chum salmon fisheries in North America are located in southeast Alaska and British Columbia, but the commercial salmon catch north of Bristol Bay, Alaska is also primarily chum salmon (Hale 1981). While the low fat content of chum salmon makes it the least desirable of the Pacific salmon for canning, it is preferred for smoke curing among many native peoples. Chum salmon are primarily taken by gill net and purse seine and are usually sold fresh or frozen.

Chum salmon spend more of their life history in marine waters than other Pacific salmonids. Chum salmon, like pink salmon, usually spawn in coastal areas, and juveniles outmigrate to seawater almost immediately after emerging from the gravel that covers their redds (Salo 1991). This ocean-type migratory behavior contrasts with the stream-type behavior of some other species in the genus *Oncorhynchus* (e.g., coastal cutthroat trout, steelhead, coho salmon, and most types of chinook and sockeye salmon), which usually migrate to sea at a larger size, after months or years of freshwater rearing. This means that survival and growth in juvenile chum salmon depend less on freshwater conditions (unlike stream-type salmonids which depend heavily on freshwater habitats) than on favorable estuarine conditions. Another behavioral difference between chum salmon and species that rear extensively in freshwater is that chum salmon form schools, presumably to reduce predation (Pitcher 1986), especially if their movements are synchronized to swamp predators (Miller and Brannon 1982).

The family Salmonidae is generally thought to have had a freshwater origin (Tchernavin 1939; Hoar 1958, 1976; but see Thorpe 1982, 1987 for the opposing view), with chum and pink salmon considered the most derivative of the Pacific salmonid species, both because of their ocean-type life histories (McCormick and Saunders 1987, Salo 1991) and because of their positions in molecular genetic phylogenies (Utter et al. 1973, Thomas et al. 1986, Shedlock et al. 1992). Genetic studies also suggest that Pacific salmon (coho, chinook, sockeye, masou, pink, and chum salmon) and Pacific trouts (rainbow/steelhead, and cutthroat trout) are monophyletic. Analysis of mitochondrial DNA by Shedlock et al. (1992) indicates that extant Pacific salmon may have arisen 5 or 6 million years ago, and that pink and chum salmon diverged from each other 4.3 to 3.5 million years ago.

Chum salmon were first scientifically described from the Kamchatka River by Johann Julius Walbaum in 1792. The species' scientific name "*keta*" means "the fish" in the language of the Nanai people, who live in the borderlands of China and the Russian Federation along the Amur River. The species is perhaps best known for its unique breeding coloration and spawning morphology, as reflected in its two most widely used common names: "chum" and "dog" salmon. "Chum salmon" is the common name accepted by the American Fisheries Society, most likely derived from a word in the language of the Chinook peoples of the Columbia River area, *cam* (also translated as *sum* or *tzum*), which means calico (Lampsakis[5]). The name refers to the

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[5] N. Lampsakis, Fisheries Office, Point No Point Treaty Council, 7999 N.E. Salish Lane, Kingston, Washington 98346. Pers.commun., September 1995.

breeding coloration of the species and first came into general use around 1900 as a marketing name for the canned product (Tabbert 1991).

Early scientific and commercial records in Washington and Oregon often reported chum salmon as "kings" or "yellow kings." Chinook salmon are also called "kings" and this confusion in names makes historical estimates of abundance difficult for both species. In the Yukon River, fall-run chum salmon are called "silvers" or "silver salmon" because of their bright appearance (Tabbert 1991). The species is often sold in the United States as "Ocean" or "Silver Brite" salmon.

A second name, less marketable but more popular among native peoples in Alaska, is "dog salmon."[6] Tabbert (1991) suggested two possible origins for this name. It may have derived from the extremely large head, elongated upper jaw, and prominent, canine-like teeth on mature males, or from the practice of drying large quantities of this species as food for dogsled teams. Other common names include "dogfish" or just "dog," although these names usually refer only to the dried fish preserved for feeding dogs.

In Asia, where chum salmon have historically been the most abundant salmonid, many common names reflect the polytypic nature of the species (see "Life-History and Ecological Information," p. 34). For example, in the Russia Federation the standard common name for chum salmon is "keta," but summer-run fish are called "letnyaya keta" and fall-run fish "osennyaya keta" (Berg 1934). They are also called "Sil'cha" in the Amur Region and "Haiko" in Kamchatka. In Korea, "yon-o in" or "nyon-o" are common names for the species. In Japan, "skae" is the standard common name, but Hikita (1962) lists more than nine vernacular names from different regions of the country.

In Washington, chum salmon are managed jointly by the WDFW (formerly the Washington Department of Fisheries (WDF) and the Washington Department of Wildlife (WDW)) and the WWTIT. A variety of seasonal runs are recognized, including summer, fall, and winter populations. Fall-run fish predominate, but summer runs are found in Hood Canal, the Strait of Juan de Fuca, and in southern Puget Sound (WDF et al. 1993). Only two rivers have fish returning so late in the season that the fish are designated as winter-run fish, and both of these are in southern Puget Sound.

Environmental Information

Historically, chum salmon were distributed throughout the coastal regions of western Canada and the United States, as far south as Monterey Bay, California. Presently, major spawning populations are found only as far south as Tillamook Bay on the northern Oregon coast

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[6] Michael Morgan in an article published in *Alaska* magazine in 1975 entitled "The Middle Yukon, and Its Troublesome Tributary, Tanana" quoted a fish buyer who paid $1.25 per chum salmon as saying: "When I buy 'em, I call 'em dogs. When I sell 'em, I call 'em chums."

(Fig. 5). Climate and geological features vary markedly in this region, with diverse patterns of vegetation, weather, soils, and water quality. This section summarizes environmental and biological information that may be relevant to determinations of the nature and extent of ESUs for chum salmon in this region.

Physical Features

Physiography and geology

Chum salmon inhabit areas in Oregon and Washington (Fig. 5) that are represented by two major physiographic regions (McKee 1972). The first is the Coast Range Province, which in the United States extends from the Strait of Juan de Fuca south to the Klamath Mountains in northern California and from the Pacific Ocean east to Puget Sound. The second is the Puget-Willamette Lowland Province, which covers Puget Sound and the Willamette River Valley, Oregon. In southern British Columbia, chum salmon occur in three physiographic provinces: the Coast Mountains on the Mainland Province, the Coastal Trough (which covers the area surrounding Georgia and Johnstone Straits), and the Outer Mountains of Vancouver Island (McKee 1972). Although these regions appear quite diverse today, they are unified by their history of volcanic and glacial activity.

All of the physiographic regions have experienced volcanic eruptions, and volcanic rocks are a common feature in all regions. The Cascade Range is volcanic in origin and composed of a wide spectrum of igneous, metamorphic, and sedimentary rock types. The coastal mountains of both the Olympic Peninsula and British Columbia are composed of volcanic and nonvolcanic rock, with a foundation of marine basalt and marine sedimentary rocks. The massive foundation of marine basaltic flow on the Olympic Peninsula is unique in the region (McKee 1972).

Glaciers spread south from British Columbia at least four times during the Pleistocene Epoch, covering much of the Puget Lowland and pushing high against the flanks of the Olympic and the Cascade Ranges (McKee 1972). The effects of glaciation on the Puget Lowland were so great that a preglacial reconstruction of the topography is almost impossible (McKee 1972). Today, the area is covered by a thick layer of glacial sediment. Even regions not directly covered by the glaciers were structurally changed by the effects of ice dams, flooding, variation in sea levels, and climate changes (McKee 1972).

River hydrology

The timing of seasonal changes in river flow and water temperatures is perhaps the most critical factor in structuring the freshwater life history of anadromous salmonids. In general, the coastal region of the Pacific Northwest, including northern California, has a mild climate with warm, relatively dry summers and cool, wet winters. On average, it is cooler and wetter in the northern part of the region than in the southern part. There is also a seasonal north-to-south

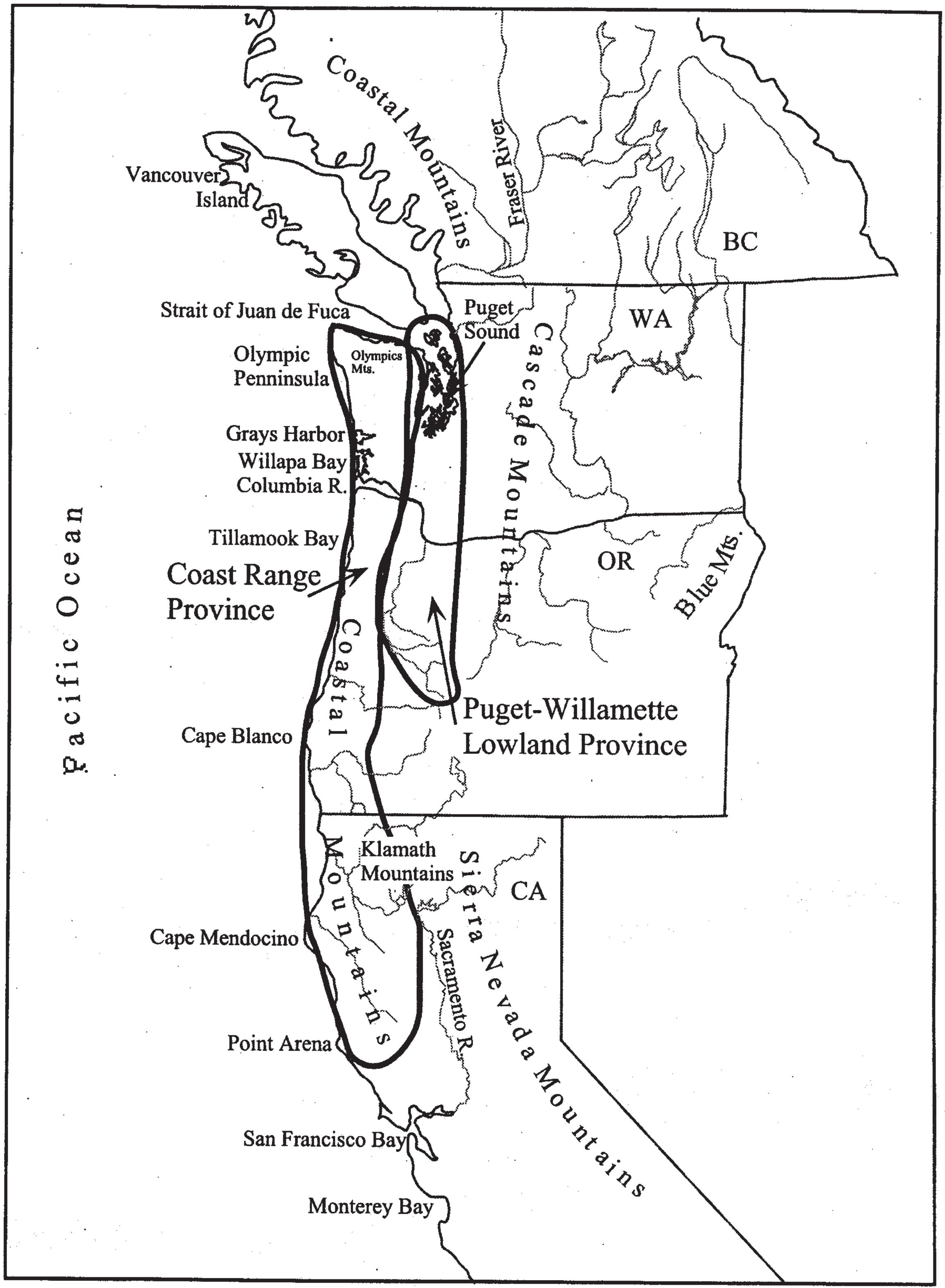

Figure 5. Major physiographic regions (Coast Range Province and Puget-Willamette Lowland Province) (McKee 1972) inhabited by chum salmon in the Pacific Northwest.

gradation in the timing of increases in winter precipitation and stream flows. In northern British Columbia, stream flows are lowest in July and August, with rising flows correlated with the onset of fall/winter rains in early September. Farther south on the Olympic Peninsula, minimal stream flows occur in August or September, with rising stream flows and decreasing temperatures beginning in early to mid-October (Table 1). Variation in run timing of chum salmon into and within individual river basins can often be correlated with these seasonal changes in stream flow and water temperature (Salo 1991, WDF et al. 1993, Hiss[7]).

Eight distinct regions of differing precipitation, temperature, and hydrology can be identified within the range of chum salmon in the Pacific Northwest (Franklin and Dyrness 1973). One of these regions, the eastern Olympic Peninsula, contains populations of chum salmon that are the subjects of two of the ESA chum salmon petitions received by NMFS in 1994; therefore, this region is more extensively discussed than other regions.

California and southern Oregon_It is difficult to determine whether spawning populations of chum salmon have been historically present in California (English et al. 1995) (Fig. 5). Presently, California Fish and Game biologists claim there are no viable spawning runs of the species in their state (English et al. 1995; see “Assessment of Extinction Risk,” p. 144), although spawned-out chum salmon carcasses (Moyle 1976) and juvenile chum salmon have been reported in California (Moyle 1976, English et al. 1995). In Oregon, chum salmon were reported to be widely distributed throughout coastal regions (Snyder 1908), with spawning populations at least as far south as the Coquille River Basin (Kostow 1995). Presently, chum salmon populations in Oregon are small and occur only sporadically south of the Tillamook Bay region (Nickelson et al. 1992, Cooney and Jacobs 1994, Kostow 1995). Nehlsen et al. (1991) reported that relic chum salmon populations may occur as far south as the Elk and Sixes Rivers.

Rivers in California (from Redwood Creek southward) that may support chum salmon drain the 500-1,000-meter-high Coast Range, an area underlain by easily eroded sedimentary rocks of the Franciscan Formation (California State Lands Commission 1993). To the north, the Rogue and Klamath River Basins cut through the Coast Range to drain the Cascade Mountains as well. Maximal elevations in this area are typically 1,000-2,000 m. Rivers from the Rogue River south to the Mattole River exhibit peak flow in late January or early February, whereas rivers farther south have peak flows in late February. Duration of peak flows in rivers south of the Mattole is much shorter than in those farther north, although both areas experience relatively low flows during the summer and early fall.

Northern Oregon coast_ Although chum salmon have probably never been as abundant south of the Columbia River as farther north, populations have been large enough for commercial and recreational exploitation have occurred in the Tillamook Bay region south to the Nestucca River (Cleaver 1951; see “Assessment of Extinction Risk,” p. 144) (Figs. 5-6). The species has been documented to occur as far south as Monterey, California (Fig. 5).

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[7] J. Hiss, U.S. Fish and Wildlife Service, Western Washington Fisheries Assistance Office, 2625 Parkmont Lane, Building A, Olympia, Washington 98502. Pers. commun., October 1994.

Table 1. Physical characteristics of selected rivers draining the Olympic Peninsula, Washington. (Hydrosphere Data Products, Inc. 1993)

Watershed	Size of drainage (km^2)	River length (km)	Linear stream length (km)	Avg. flow (m^3)	Avg. summer flow (m^3)	Avg. winter flow (m^3)	Extreme flows (m^3)	
							Max.	Min.
Rivers draining south into the Chehalis River and Grays Harbor								
Humptulips	635	98	515	42	7.08	113.24	934.23	2.32
Hoquiam	233	28	211	10	3.54	14.16	na	0.17
Wishkah	264	60	237	14	0.99	28.31	209.49	0.65
Wynochee	505	102	401	35	4.25	70.78	693.60	0.65
Satsop	774	46	568	58	8.49	118.90	1319.25	4.70
Cloquallium	168	33	191	11	0.99	16.99	103.33	1.70
Chehalis	6,734	204	5,395	198	24.06	481.27	1514.59	17.55
Rivers draining east into Hood Canal								
Skokomish	622	67	547	34	7.08	65.11	764.37	3.54
Hamma	220	29	177	10	2.83	14.86	36.24	1.70
Hamma								
Duckabush	174	39	191	12	4.25	16.99	253.66	1.27
Dosewalips	243	46	274	13	5.66	15.00	36.80	3.68
Rivers draining north into the Strait of Juan de Fuca								
Dungeness	513	51	410	11	5.10	11.61	193.07	1.84
Elwha	831	72	785	43	17.55	53.79	1,177.70	9.77
Hoko	132	40	169	12	1.13	26.05	399.17	0.34
Rivers draining west into the Pacific Ocean								
Ozette	228	21	135	14	1.42	33.97	368.03	1.42
Quillayute	1,629	113	1,208	126	28.31	342.27	2,881.96	7.67
Dickey	223	28	182	15	1.42	39.63	489.76	0.25
Soleduck	567	105	418	37	12.74	104.75	588.85	4.39
Calawal	334	50	315	30	3.40	76.44	639.81	0.42
Bogachiel	288	75	209	30	3.96	81.82	673.78	2.35
Hoh	774	90	502	62	30.01	90.59	1460.80	11.21
Queets	1,166	83	870	121	28.73	226.48	3,691.62	10.42
Raft	241	29	177	16	4.25	28.31	481.27	0.28
Quinault	1,124	111	899	105	30.57	178.35	2270.46	9.06
Moclips	101	20	58	6	1.13	14.16	120.60	0.28
Copalis	106	34	80	7	na	na	na	na

All coastal Oregon rivers north of Cape Blanco—with the exception of the Umpqua River—drain only the west side of the Coast Range (Fig. 6). The Oregon Coast Range is relatively low, with peaks at 500-1,000 m elevation, in contrast to most Cascade peaks which are 1,000-2,000 m high. Seasonal river flows in this region follow a fairly consistent pattern, with a single peak in December or January and relatively low flow in summer and fall. The Oregon coast has relatively high rainfall (120-240 cm/year) compared to areas east of the Coast Range (60-120 cm/year) or farther south (60-200 cm/year), but receives less rainfall than the extremely wet Olympic Peninsula farther north (>240 cm/year). Both air and stream temperatures are fairly consistent along the Oregon coast, with little latitudinal change. Minimal average winter air and stream temperatures are typically around 4^{o}C and 4-8^{o}C, respectively, whereas maximal average summer air and stream temperatures are typically around 21^{o}C and 15-21^{o}C, respectively. Because of the relatively low elevation, snowfall in the Coast Range is low, averaging 30-60 cm annually, while the higher Cascade Mountains receive 250-760 cm annually. On average, the Oregon coast receives more sunshine (1,800-2,200 hours/year) than the wetter Olympic Peninsula (<1,800 hours/year), but less than northern California and southern Oregon (2,000-2,200 hours/year).

Columbia River Basin_Small spawning populations of chum salmon are regularly found as far south as the lower Columbia River and Tillamook Bay (Figs. 5-6). The hydrology and flow patterns of rivers draining into the lower Columbia River are similar to those of coastal rivers immediately north and south of the Columbia River, with a single peak in December or January and relatively low flows in summer and fall. Columbia River tributaries, such as the Willamette or Cowlitz Rivers draining the Cascade Mountains, have proportionally higher flows in late summer and early fall than rivers draining the coastal range (e.g., Nehalem River and Tillamook Bay tributaries), reflecting the greater contribution of snow melt in these Cascade Mountain systems.

Southwest Washington_Rivers in southwest Washington drain the Willapa Hills, an area characterized by relatively low elevations (500-1,000 m), with moderate amounts of precipitation (200-240 cm/year) (Fig. 5). Rivers draining the Willapa Hills are relatively short and flow either south into the lower Columbia River or west into the Pacific Ocean through Willapa Bay and Grays Harbor (Table 1). These rivers display relatively low flows during late summer and early fall, increased river flows and decreased water temperatures beginning in early October, and a single flow peak in December or January. These temperature and water regimes are similar regardless of whether the rivers drain into the lower Columbia River or into other coastal bays.

There are also similarities between the Columbia River estuary, Willapa Bay, and Grays Harbor: All three are characterized by extensive intertidal mud and sand flats that are not found in estuaries to the north or south (Fig. 5). Part of this similarity results from the shared geology of the area: The Chehalis River Basin was the northernmost area that remained ice-free during the most recent glaciation (McPhail and Lindsay 1986), and the Chehalis and Columbia Rivers periodically had much higher flows during that time period, which greatly enlarged their respective valleys (Alt and Hyndman 1984, Allen et al. 1986). The Columbia River estuary,

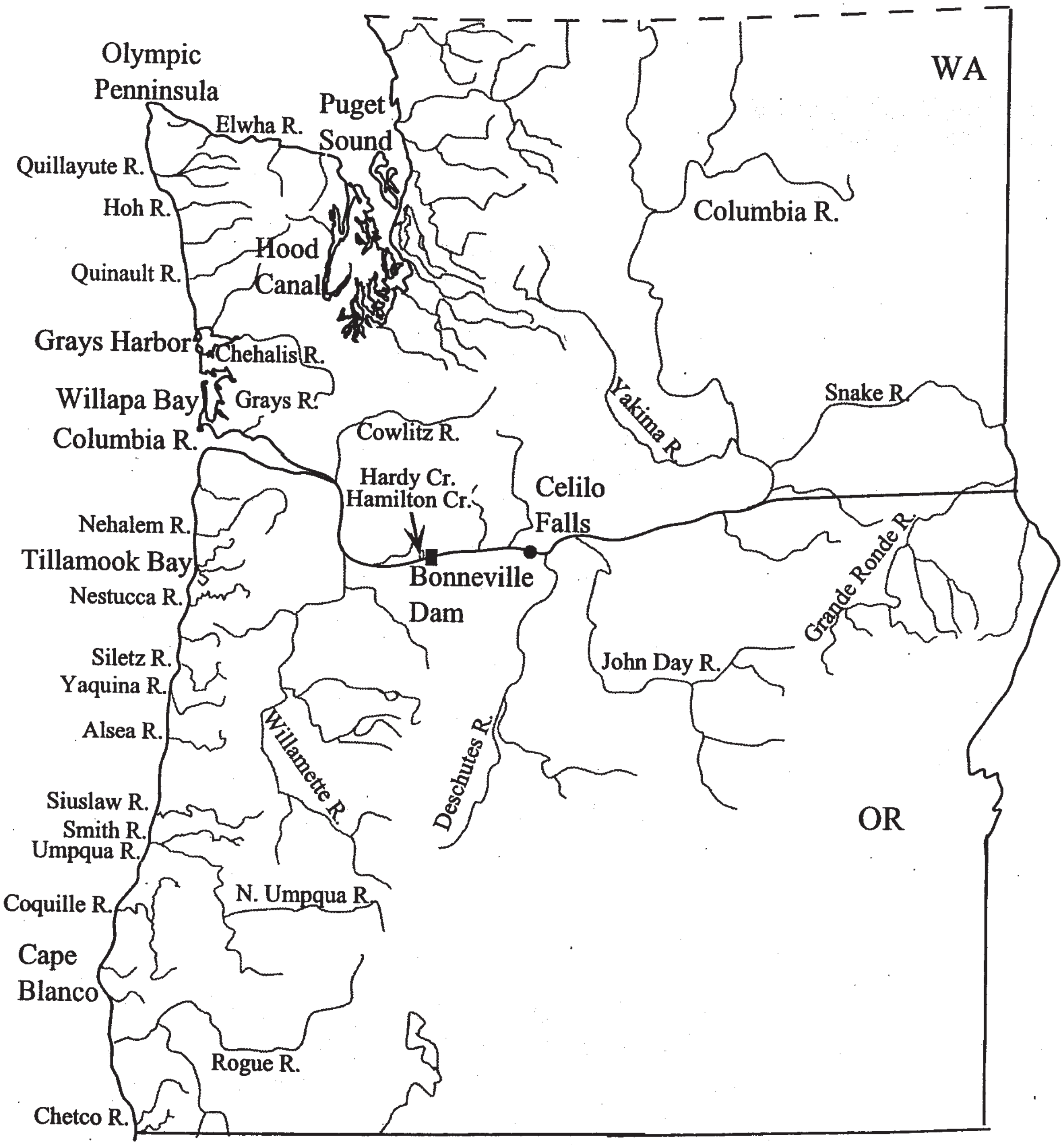

Figure 6. Major geographic features in Washington and Oregon cited in this Status Review.

Willapa Bay, and Grays Harbor were all inundated by seawater following the last ice age. Sediments carried by the Columbia River have slowly been filling the lower Columbia River and been transported northward along the coast to form Long Beach, which in turn has formed Willapa Bay, in addition to creating extensive sand beaches and dunes north and south of Grays Harbor (Alt and Hyndman 1984, Allen et al. 1986, Landry et al. 1989).

Life-history characteristics of chum salmon appear to follow the water flow and temperature regimes of these southwest Washington rivers. Fish enter freshwater spawning streams from early October to mid-November, with a peak return in early November. Spawning peaks in mid- to late November and is usually completed by early December (WDF et al. 1993; also see "Life-History and Ecological Information," p. 34).

Western Olympic Peninsula_ Farther north, the western coast of the Olympic Peninsula gradually becomes more rocky and steeply graded. Rivers along this coast may drain into Grays Harbor (e.g., Humptulips and Chehalis Rivers) or directly into the ocean (e.g., Hoh and Quillayute Rivers) (Table 1) (Fig. 5). While the Grays Harbor estuary is one of the largest on the west coast of North America, most western Olympic Peninsula rivers have small estuaries, and some abruptly enter the open sea.

There are two outstanding climatic characteristics of the Olympic Peninsula: In the winter it is one of the wettest places on earth (160-380 cm precipitation/year, with snowfall over 150 cm/year at higher elevations), but in the summer it is dry (Mathews 1988). The increased winter precipitation on the Olympic Peninsula is primarily caused by the high elevation of the Olympic Mountains (1,000-2,000 m) and the prevalence of water-laden air moving eastward off the Pacific Ocean (Franklin and Dyrness 1973, Mathews 1988). The summer drought results from a combination of the jet stream moving north in the summer, taking its rainy frontal systems with it, and a subtropical North Pacific high stabilizing off the Northwest coast. This high-pressure area produces an onshore airflow that is warmer than the sea surface (12.8°C, or 55°F), creating vast ocean fog banks, but little rain.

Tropical areas typically have well-defined wet and dry seasons, whereas temperate regions usually have precipitation year-round. The climate of the Olympic Peninsula is mid-way between California's Mediterranean climate (dry summers and warm temperatures) and Southeast Alaska's cold marine climate (heavy year-round rain, slightly reduced in summer, and cool temperatures year-round). Similar wet-dry temperate regions include southern Chile, western Scotland, northern Honshu, and coastal Norway. Precipitation in winter in these areas is around 1.5 times greater than it is in summer. On the Olympic Peninsula, precipitation is between 6 and 20 times greater in December than in June (Mathews 1988). Because of this winter precipitation, an extremely heavy snowpack at high elevations persists longer into the summer than in other mountains with equally mild or somewhat colder climates, such as the U.S. Rocky Mountains (Mathews 1988).

As a consequence of these climatic conditions, rivers originating in the Olympic Mountains derive much of their water from snowmelt and have relatively high flows even in summer. Most have a second flow peak during July or August. Rivers and streams that do not originate in the mountains have low or no summer flows. Because of the geological history of the region, the coastal plain of the Olympic Peninsula is narrow, with the Olympic Mountains thrusting upwards within a few kilometers of the ocean. Rivers in the region are typically swift, steeply graded, rocky, and short; this is true whether they drain directly into the ocean, such as the Copalis (34 km), Queets (83 km), or Ozette (21.4 km) Rivers, or whether they drain into Grays Harbor, such as the Humptulips River (98 km long). The largest river on the north coast is the Quillayute River, which, although only 113.5 km in length, drains four major basins with an area of over 1,012 km^2 (Storm et al. 1990).

Chum salmon from rivers draining the western Olympic Peninsula display an early- and late-fall return pattern coincident with increasing fall/winter river flows. In general, river entry occurs from September through December with spawning from October (late October in Grays Harbor) to January. Spawning tends to peak in mid-November. Chum salmon on the north coast are most abundant in Grays Harbor, perhaps because of the large estuary available for rearing and good spawning habitat of low-gradient streams.

Eastern Olympic Peninsula and Hood Canal_This region, the focus of two of the three petitions received by NMFS for chum salmon, lies on the eastern and northern Olympic Peninsula and has a different physical and climatic character from the western Olympia Peninsula (Figs. 1 and 6). It also has far more abundant and diverse runs of chum salmon than the north coast. The major geographic features of the region are Hood Canal and the eastern escarpment of the Olympic Mountains. Hood Canal is a 100-km-long, fjord-like, blind channel that extends to the west of Puget Sound (Figs. 1-2). Beginning at the northern tip of the Kitsap Peninsula between Tala Point and Foulweather Bluff (near Hansville, Washington), the Canal runs southward along the eastern side of the Olympic Mountains, takes a sharp eastward turn at the hook-like Great Bend, and ends only a few kilometers from southern Puget Sound (Fig 1). The western shore is on the Olympic Peninsula, with river headwaters high in the Olympic Mountains. The eastern shore is on the Kitsap Peninsula, with rivers much gentler and without headwater snowpack.

As with other regions of the Peninsula, the climate of Hood Canal is strongly influenced by the Olympic Mountains. Headwater areas of rivers draining western Hood Canal receive annual precipitation averaging 200-250 cm per year, and precipitation in the southern Canal averages between 150 and 200 cm annually. In the northern part of the Canal, the Olympic Mountains block major North Pacific storm systems from reaching Hood Canal, and this rain shadow reduces annual precipitation to about 75 cm annually in the Quilcene River Basin (Yoshinaka and Ellifrit 1974).

The primary force that has structured the unique hydrological characteristics of Hood Canal and the Strait of Juan de Fuca regions was the same general north-south uplift that formed the Olympic and Cascade Mountains. This uplift was accompanied by a downthrust between the two ranges that formed the Puget-Willamette Trough and allowed the intrusion of continental glaciers during the Pleistocene Epoch. It is estimated that the Vashon Glacier, present in the

Puget Sound area as recently as 15,000 years ago, cut and deepened many of the downthrust valleys as much as 900 feet below present-day sea level (Yoshinaka and Ellifrit 1974).

The result is a long channel that is relatively narrow and deep, with a sharp northeastward turn at the Great Bend near Union and Tahuya (Fig. 1). The Canal averages 2.4 km in width and is widest (6.4 km) at the mouth of Dabob Bay (between the towns of Brinnon and Seabeck) and narrowest (0.8 km) at Sister Point near the Great Bend. The average depth of the Canal is more than 152 m, and maximal depths may exceed 182 m near Dabob Bay. Water is shallower east of Great Bend, with shoaling continuing to the end of the Canal at the mouth of the Union River near Belfair (Yoshinaka and Ellifrit 1974).

The Quilcene, Dosewallips, Duckabush, Hamma Hamma, and Skokomish Rivers on the western side of the Canal drain the eastern slope of the Olympic Mountains (Table 1) (Fig. 3). These rivers tend to be steep, with cool water and high river flows even in summer. Big Beef Creek and the Dewatto, Tahuya, and Union Rivers drain the eastern shore of the Canal (Fig. 3). They are smaller, lowland-type streams on the Kitsap Peninsula. The Kitsap Peninsula, part of a glacial drift plain that covers much of Puget Sound, consists of low rolling hills usually less than 154 m high. The streams have very low flow levels in late summer and early fall. The greater Hood Canal watershed is approximately 2,331 km^2.

Hood Canal, along with similar long channels in southern Puget Sound, contains populations of summer-run chum salmon, a seasonal run more common in northern British Columbia and Alaska. The Canal also contains populations of fall chum salmon, classified by fishery co-managers in Washington State (WDF et al. 1993) as fall and late-fall stocks (Figs. 7a-d). Possible reasons for this diversity of chum salmon include the abundance of quality spawning grounds and the protected estuarine habitat afforded chum salmon smolts by this long inlet.

The topographic character of Hood Canal results in a unique hydrographic mosaic of weak tidal exchanges, seasonal nutrient loading, and low surface salinities. Although there is a constant but limited tidal exchange with Puget Sound, glacial sills at the Canal entrance greatly reduce water exchange and deepwater circulation. Only in late summer does cold, nutrient-rich upwelling water from the Pacific Ocean intrude into the Canal (Yoshinaka and Ellifrit 1974). Water exchange in the Canal is slow, because of strong tidal flows and significant water mixing only in the north, nearest the entrance to Puget Sound. The southern Canal and Dabob Bay experience weaker and less turbulent tidal exchanges, especially in the eastern arm (Friebertshauser et al. 1971).

Hood Canal also has an exceptionally large freshwater lens (> 3 m in depth), especially from December to June when river flows are high and tidal mixing is weak. The lens results in warmer spring/early summer temperatures (when juveniles are feeding) and colder fall temperatures (when adults return) than in more uniformly saline water (Phillips and Fleenor 1970).

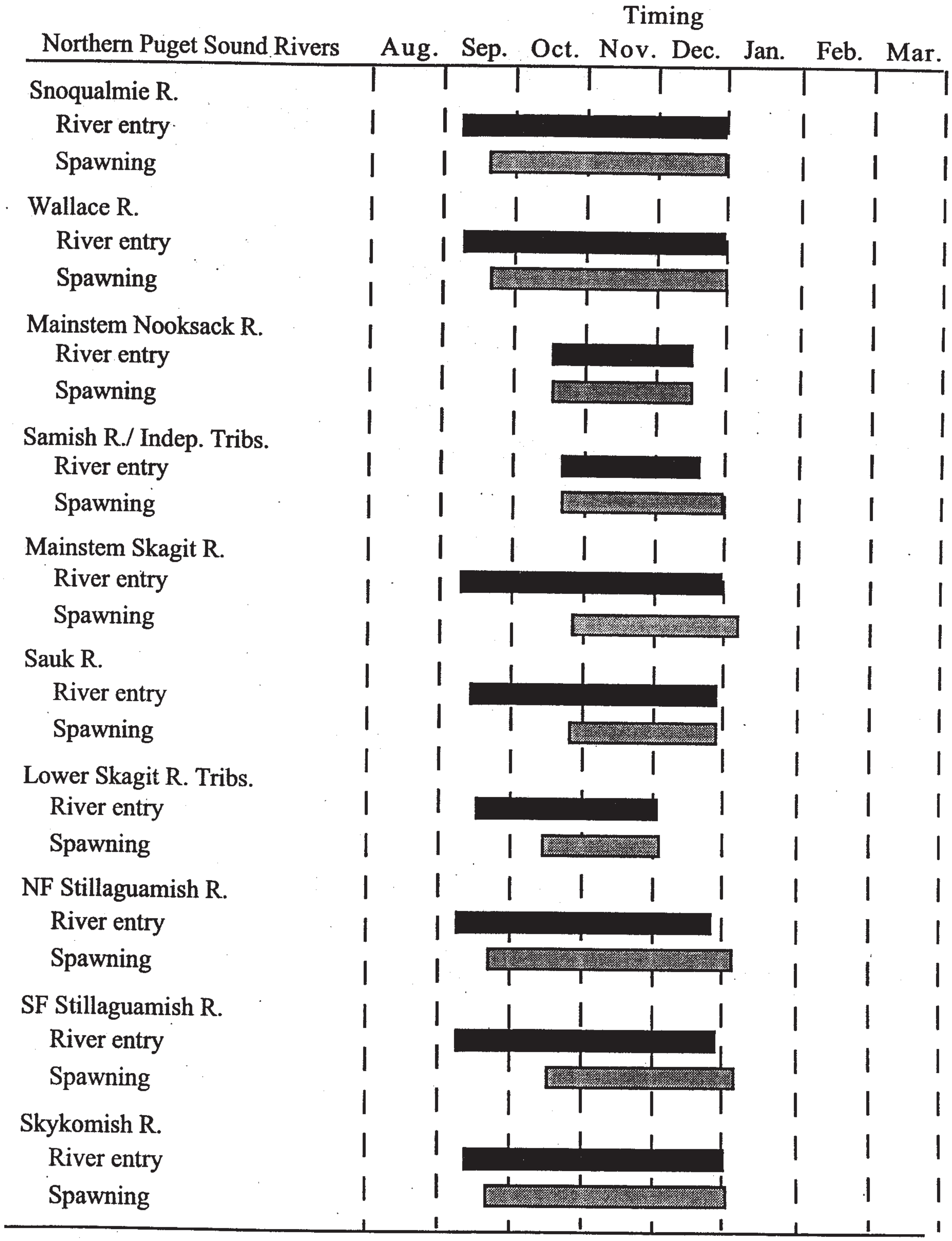

Figure 7a. River entry and spawn timing of chum salmon in tributaries to northern Puget Sound. All chum salmon entering rivers in northern Puget Sound are classified as fall-run fish by Washington State fishery co-managers. Data from WDF et al. (1993).

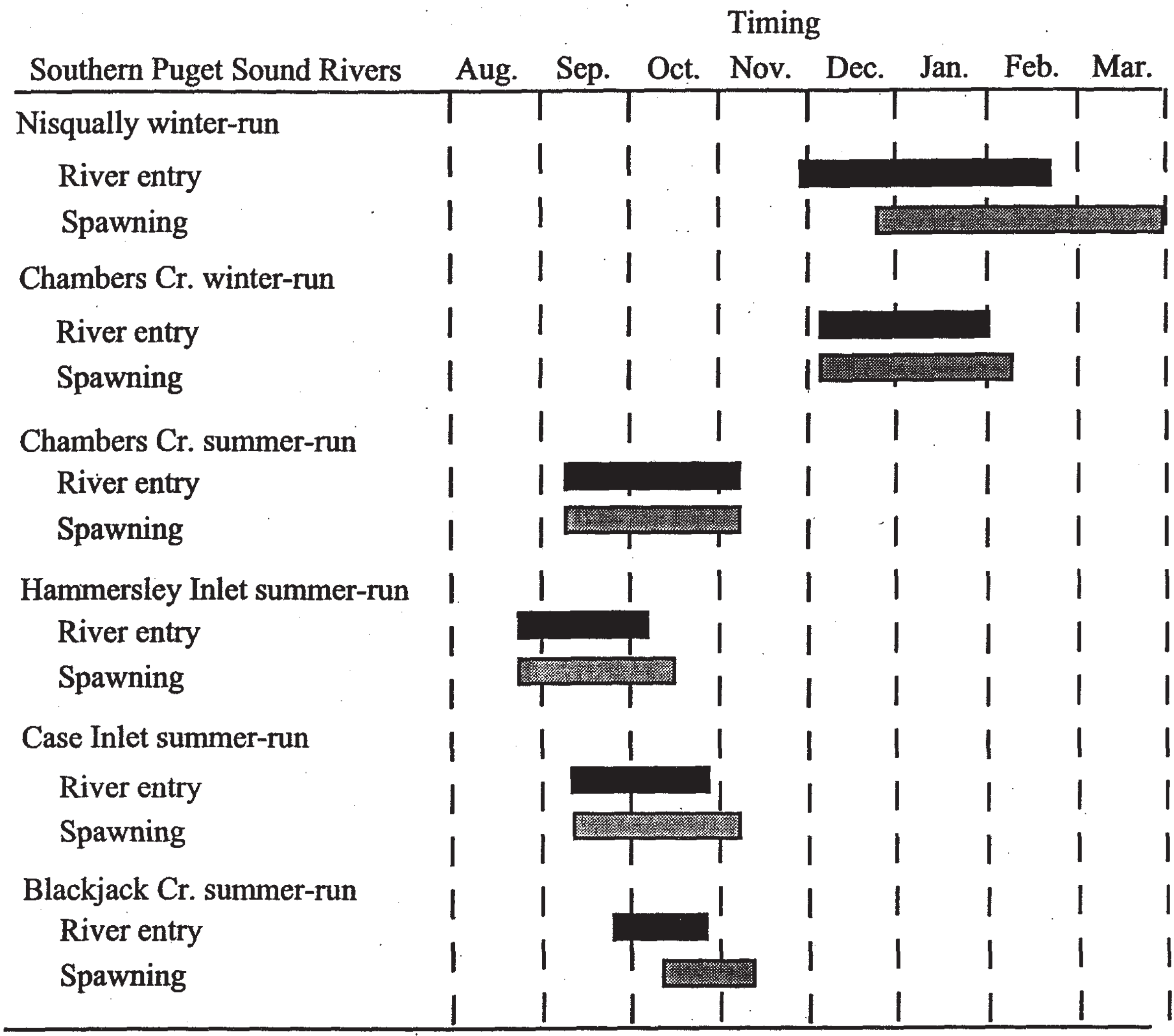

Figure 7b. River entry and spawn timing of chum salmon in tributaries to southern Puget Sound. All chum salmon entering rivers in southern Puget Sound are classified as summer-, fall-, and winter-run fish by Washington State fishery co-managers. Data from WDF et al. (1993).

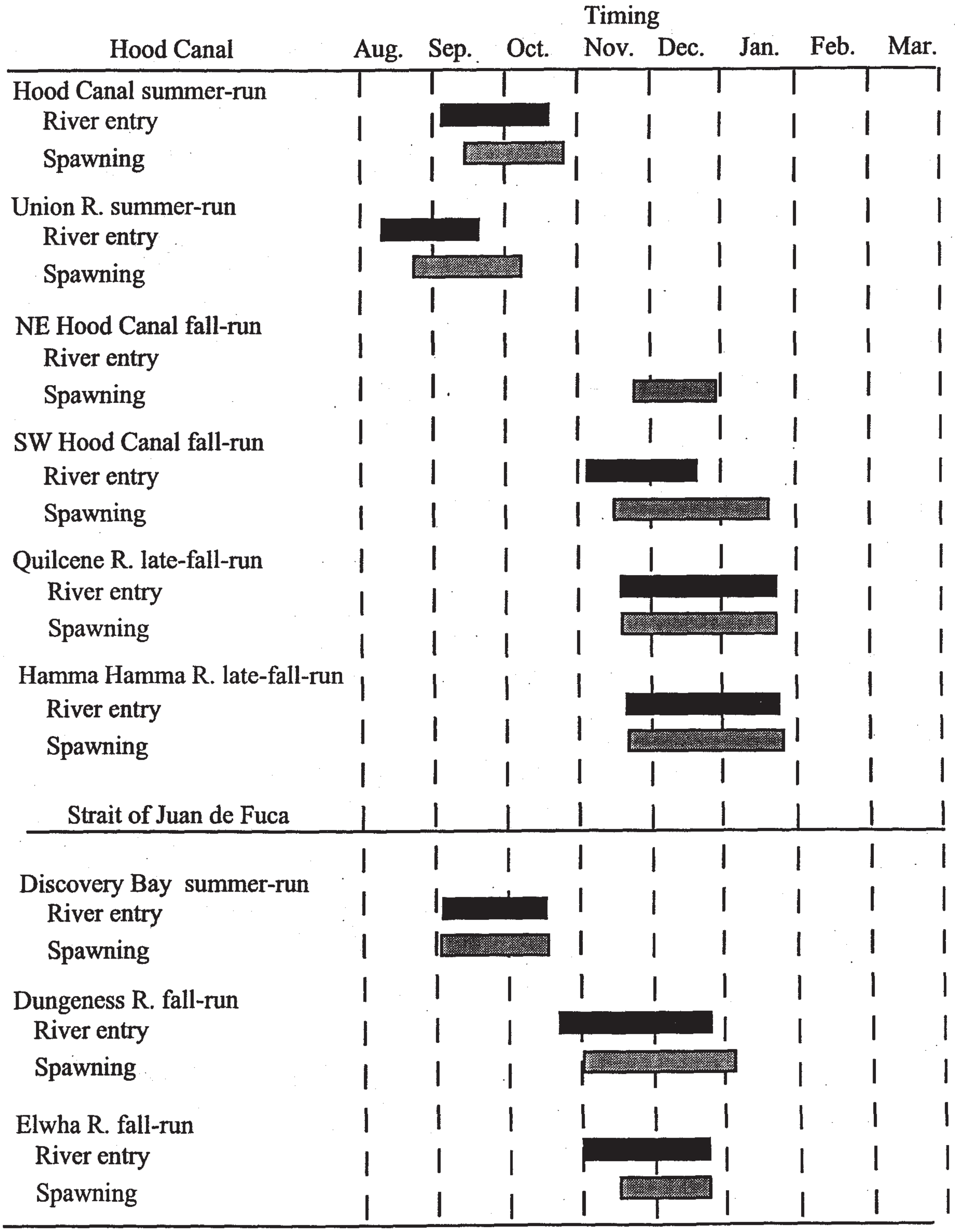

Figure 7c. River entry and spawn timing of chum salmon in tributaries of Hood Canal and the Strait of Juan de Fuca. Different groups of chum salmon in Hood Canal and the Strait are classified as summer-, fall-, and late fall-run fish by Washington State fishery co-managers. Data from WDF et al. (1993).

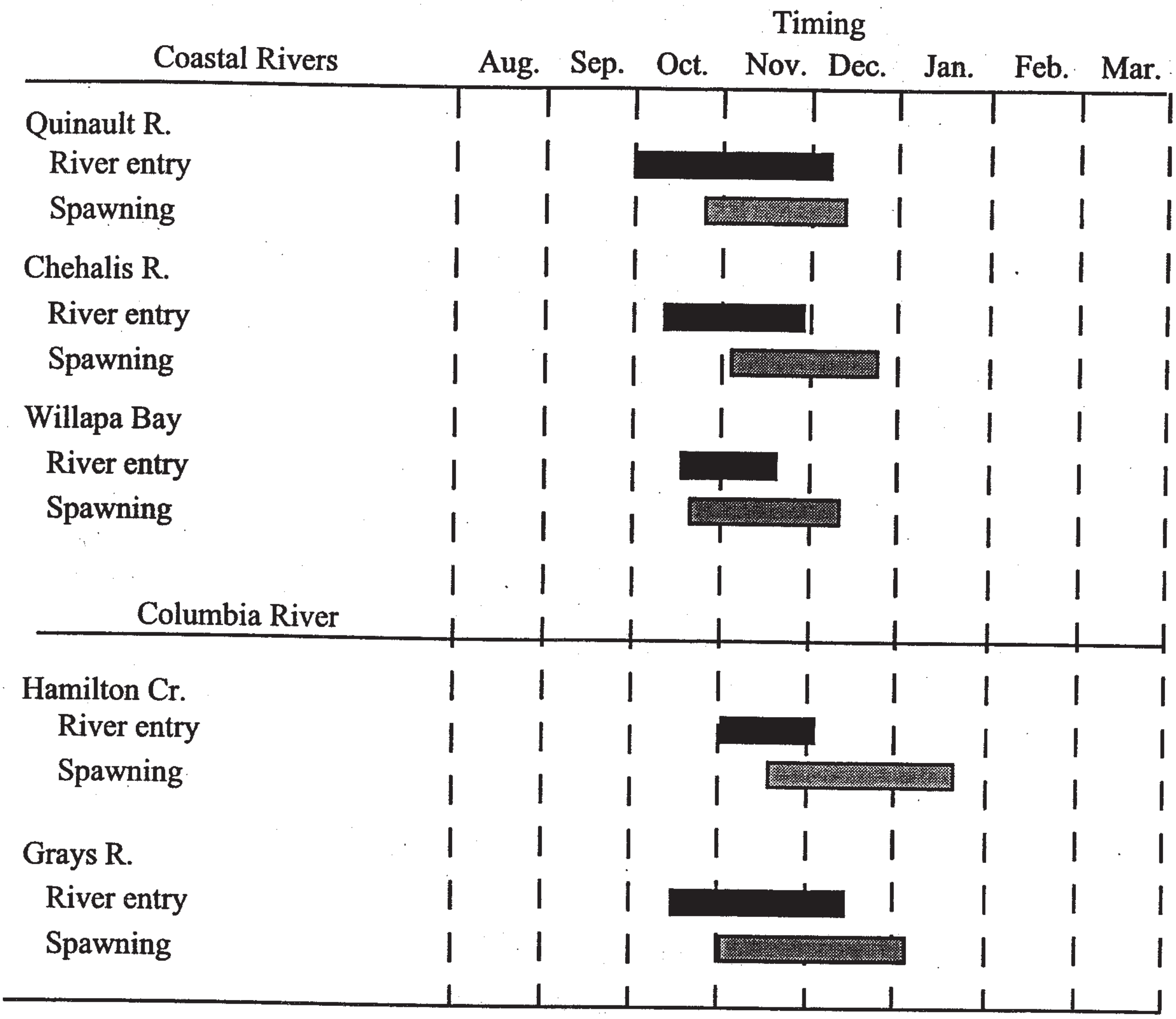

Figure 7d. River entry and spawn timing of chum salmon in tributaries along the Washington coast and in the Columbia River. All chum salmon spawning along the coast and in the Columbia River are classified as fall-run fish by Washington State fishery co-managers. Data from WDF et al. (1993).

Coastal British Columbia—The wet climate of the Olympic Peninsula continues north along the west coast of Vancouver Island and along the British Columbia mainland north of Vancouver Island (Fig. 5). Limited hydrographic data (Farley 1979) indicate that river flow patterns in this area are similar to those on the Olympic Peninsula, with relatively high flows throughout the year. Summer air temperatures generally decrease with increasing latitude—the Olympic coast is a few degrees warmer than the southwestern coast of Vancouver Island, which is a few degrees warmer than the northwestern coast and the mainland north of Vancouver Island.

Puget Sound and Strait of Georgia—A smaller gradient of decreasing average precipitation extends from west to east in northwestern Washington (Figs. 1 and 5). East of the Olympic Peninsula, precipitation rapidly decreases because of the rain shadow caused by the Olympic and Vancouver Island mountains to the north and the Willapa Hills to the south. The rain shadow continues through lowland Puget Sound, up the lowlands bordering the Strait of Georgia and to the south end of Queen Charlotte Strait. Most of the Washington streams that support chum salmon are in Puget Sound. This area receives less than 120 cm rain per year, with some areas receiving as little as 50 cm/year.

There is apparently a slight summer temperature cline within the northern rain shadow region; average maximal air temperatures in Puget Sound and Hood Canal (20-24^{o}C) are slightly higher than those in the Strait of Georgia (16-20^{o}C), which in turn are higher than those inside Vancouver Island farther north (14-16^{o}C). In contrast, winter air temperatures are more uniform, averaging 0-5^{o}C throughout the area. Stream temperatures in the area are generally cool, with a maximum of 12-20^{o}C in summer and a minimum of 0-4^{o}C in winter (Hydrosphere Data Products, Inc. 1993).

Coastal Upwelling

Upwelling along the coasts of British Columbia, Washington, and Oregon north of Cape Blanco is primarily wind driven (Smith 1983, Landry et al. 1989) and patterns are fairly consistent among regions (Bakun 1973, 1975; Thompson 1981) (Fig. 5). One exception to these patterns has been observed off the southwestern corner of Vancouver Island, where consistent and strong upwelling apparently occurs throughout the year (Denman et al. 1981). Upwelling south of Cape Blanco is thought to be caused by current-driven as well as wind-driven events, leading to relative temporal and spatial stability.

Oceanic and Climatic Variability

Historically, research into the survival, growth, and production of Pacific salmon has focused on the freshwater stages of their life cycles, with oceanic or climatic factors considered relatively unimportant (Hare and Francis 1995). Part of the reason for this is the vast scale and complexity of designing studies to investigate changes which may be local or global and occur over months or millennia. For example, in 1970, the North Pacific winter atmospheric circulation pattern shifted from previous years (Hollowed and Wooster 1992), but this discrete event lasted only a single season. By contrast, the "little ice age" and other long-term climate changes described in Chatters (1995) and Chatters et al. (1995) lasted for hundreds of years (1200 to 1770 A.D.).

Although numerous climatic and oceanic cycles have been identified on several time scales ranging from a few years (Kerr 1990, Hayward 1997), to hundreds (Kreutz et al.1997), to thousands (COHMAP members 1988), to tens of thousands (GRIP members 1993), it has been difficult to correlate these changes with salmon abundances. Physical and biological factors that influence salmonid survival are usually highly correlated with each other and exhibit such complex relationships that it is hard to separate cause from effect (Hare and Francis 1995). For example, a biological factor such as intraspecific competition is affected by other biological factors such as prey availability and predation, and these may be affected by climatic factors such as regional cooling and increased freshwater run-off.

Only in recent years with advances in data collection/storage technology and the increased availability of decadal-scale datasets, have comparisons between physical changes in the ocean or climate and biological production of salmon become possible. Long-term datasets of climatic factors—such as the Aleutian Low Pressure Index (ALP), Pacific Interdecadal Oscillation (PDO) Index or the Cold Tongue (CT) Index (Beamish and Bouillon 1993**,** Hare and Francis 1995, Francis and Mantua In press)—coupled with biological indices such as records of copepod abundance, and Alaska salmon catches have revealed correlated positive and negative trends (e.g., Francis and Sibley 1991, Beamish and Bouillon 1995, Hare and Francis 1995, Helle and Hoffman 1995**,** Francis and Mantua In press). These trends suggest that regional variability in biological production is caused in part by large-scale climate change reflected in North Pacific atmospheric-oceanic regime shifts (Hare and Francis 1995). These oscillating "warm" and "cool" regimes occur on decadal scales. The Pacific Northwest was warm from the early 1920s to late 1940s/early 1950s, cool from the early 1950s to mid-1970s, warm from the mid-1970s to the mid-1990s (Francis and Hare 1994) and appears to be presently shifting to a cooler, more productive regime in the late 1990s (Francis and Mantua 1997).

Food Production and Zooplankton

Beamish and Bouillon (1993) were the first to develop evidence showing that annual catches of chum, pink, and sockeye salmon in the North Pacific exhibit long-term parallel trends that corresponded to climatic indices, particularly the ALP. Their analysis indicated that increases in Alaskan salmon survival in the late 1970s occurred at the same time that year classes of other commercially important marine fishes also had exceptionally high marine survival (Beamish 1993). They hypothesized that this association was mediated in the late 1970s by large increases in food (zooplankton, particularly copepods) for larval fishes (Brodeur and Ware 1992, McFarlane and Beamish 1992, Beamish 1993). An alternative explanation was proposed by Meacham and Clark (1994), who argued that the dramatic increases in commercial catches of Alaskan salmon stocks since the 1970s are the result of sound management by the state of Alaska.

Climate and salmon production: Alaska versus Northwest

There is also increasing evidence that the climatic patterns and trends in catch data for the Pacific Northwest are opposite those for the Alaskan coast (Francis and Sibley 1991, Hollowed and Wooster 1992, Francis and Hare 1994). Francis and Mantua (In press) reported that the PDO was positively correlated with increased catches of

1) chum salmon in west and central Alaska and on west Vancouver Island and Puget Sound,
2) pink salmon in central and southeast Alaska and Oregon,
3) coho and sockeye salmon catches throughout Alaska,
4) coho salmon in Puget Sound,
5) sockeye salmon in West Vancouver Island, and
6) chinook salmon in Puget Sound and central Alaska.

Catches negatively correlated with the PDO include:

1) coho salmon in coastal Washington (but not Puget Sound), Oregon, and California, and
2) chinook salmon in west Vancouver Island, coastal Washington and California.

The mechanisms driving these changes are areas of intense research (reviewed in Francis and Hare 1994), but the periodic oceanic regime shifts are due, at least in part, to changes in the directions of the North Pacific Current, which splits in the eastern Pacific Ocean basin forming two currents (California and Alaska Currents) that are out of phase with each other (reviewed in Francis and Hare 1994).

Density Dependence

A second area of intense research is the question of whether density dependence or carrying capacity influences Pacific salmon abundance in the North Pacific Ocean. If changes in climate result in long-term changes in the survival and/or production of salmon in the North Pacific Ocean, evidence of density dependence or carrying capacity should be expected. Some evidence supports this contention. Helle (1979, 1984) and Helle and Hoffman (1995) rated a trend of decreasing size and older age at maturity for chum salmon from Alaska to Hood Canal, Washington, from the 1970s to the 1990s. Similarly, Ishida et al. (1993) showed significant decreases in mean body weight and increases in mean age of Japanese and Russian chum salmon during periods of increasing abundance in the 1970s and 1980s. Rogers (1980) and Peterman (1984) demonstrated density-dependent growth in North American populations of sockeye salmon. In Bristol Bay, Alaska, a highly productive natural system, Rogers and Ruggerone (1993) found changes in size and age structure in sockeye salmon populations during years of high abundance.

As noted by Beamish and Bouillon (1993), the primary evidence for density dependence in the 1980s was decreasing size. However, during that period, food in the northeastern Pacific Ocean apparently was increasing. They also noted that a density-dependent reduction in growth occurred only in coastal waters during the early and final periods of marine residence when fish compete primarily among themselves. They found little evidence of competitive interaction among groups of fish from distant regions.

Beamish and Bouillon (1993) also suggested that hatcheries, except in Japan, were not important contributors to the increase in chum salmon catches in the North Pacific during the 1970s and 1980s. They suggested that increases in Alaskan catches of chum salmon were so great in the 1970s that hatcheries could have contributed to them only slightly. However, they suggested that hatchery production strategies should take into account the interdecadal changes in the ocean conditions relative to salmon production.

Biological Features

Vegetation

Patterns of vegetation in Washington and southern British Columbia are strongly affected by precipitation. Coastal regions in Washington and British Columbia (Fig. 5) were historically forested with a Sitka spruce-dominated floral community, which includes western hemlock, western red cedar, red alder, and Douglas fir as major species. This vegetation type is restricted to coastal regions and river valleys, extending a few kilometers inland only over coastal plains, and to elevations above 150 m only in areas immediately adjacent to the ocean (Franklin and Dyrness 1973). Sitka spruce forests are replaced by western hemlock-dominated forests along the Strait of Juan de Fuca to the north and east. This vegetation type includes western hemlock, Douglas fir, red alder, and western red cedar as major species. The transition point between Sitka spruce and western hemlock along the Strait of Juan de Fuca appears to occur at about the Elwha River on the Olympic Peninsula and Sooke Inlet on Vancouver Island (Figs. 1 and 5). Because of Puget Sound’s lower precipitation and glacial soils, drought-tolerant pines, such as western white, lodgepole, and occasionally ponderosa, are more common here than elsewhere in the western hemlock zone.

Zoogeography

Only a few zoogeographic groupings of fishes, invertebrates, and amphibians have been identified along the east coast of the North Pacific Ocean within the range considered in this status review. There is a distinct faunal boundary for marine fishes off the northern tip of Vancouver Island (approximately 50°N lat.) (Allen and Smith 1988), but there is no apparent pattern of variation in marine fishes associated with chum salmon in southern British Columbia or in Washington and Oregon. There is only one distinct group of estuarine fishes in the Pacific Northwest, the Fjord group from Puget Sound and Hood Canal (Monaco et al. 1992). Other estuary groupings are less evident and seem to depend more on characteristics of individual estuaries rather than on geographic location. Regional differences are characterized not by unique variation within species (distinct subspecies or populations), but by presence or absence of species. Within the range of chum salmon in the Pacific Northwest, only one major freshwater ichthyogeographic region, the Columbia, has been described (McPhail and Lindsey 1986, Minkley et al. 1986).

The distributions of marine invertebrates show transitions between major faunal communities similar to those of marine fishes (Hall 1964, Valentine 1966, Hayden and Dolan 1976, Brusca and Wallerstein 1979). The primary cause of this zonation is attributed to temperature (Hayden and Dolan 1976), but other abiotic (Valentine 1966) and biotic (Brusca and Wallerstein 1979) factors may also influence invertebrate distribution patterns.

The distributions of many amphibian species appear to begin and end at several common geographical areas within the range of chum salmon in the Pacific Northwest. The Strait of Georgia and Vancouver Island are the northern extents of many amphibian distributions, such as tailed and red-legged frogs, as well as Pacific giant, western long-toed, western red-backed, Oregon, and brown salamanders (Cook 1984). In addition, several amphibians (Olympic torrent and Van Dyke’s salamanders) are restricted to the Olympic Peninsula, while other species (Pacific giant and Dunn’s salamanders) occur in most areas in western Washington and Oregon, except in the Olympic Peninsula (Leonard et al. 1993).

Ecoregions

The U.S. Environmental Protection Agency has developed a system of ecoregions based on patterns of factors such as land use, climate, topography, potential natural vegetation, and soils (Omernik and Gallant 1986, Omernik 1987). Under this system, the range of chum salmon in Washington covers two ecoregions that border on saltwater: the “Coast Range” ecoregion, which extends from the Strait of Juan de Fuca to Monterey Bay and from the ocean to approximately the crest of the coastal mountains; and the “Puget Lowland” ecoregion, which begins in Washington at approximately the Dungeness River near the eastern end of the Strait of Juan de Fuca and extends through Puget Sound to the British Columbia border.

Significance of Environmental Information for ESU Determinations

Based on the preceding physiographic, geological, climatic, and biological information, there appears to be evidence for an environmental distinction between the following three areas: the Columbia River and the coast, Hood Canal and the rest of the Olympic Peninsula, and the Olympic Peninsula and the rest of the Pacific Northwest. However, because the gradients in temperature and precipitation within the range of Northwest chum salmon are not sharp, and based on the physical and biological factors examined here, the precise location of an environmental “border” separating these areas is unclear.

Life-History and Ecological Information

Geographic Distribution

Chum salmon have a broader spawning distribution than any other species of Pacific salmon (Bakkala 1970, Salo 1991) (Fig. 4). In Asia, they commonly spawn as far south as the Naktong River in the Republic of Korea (35°N, 129°E) and the Tone River (36°N, 141°E) on Honshu Island, Japan (Walters 1955, Atkinson et al. 1967). In some years, small numbers of chum salmon occur in streams as far south as Nagasaki and Fukuoka Prefectures of Kyushu (about 33°N) (Sano 1966). Historically, the range of the fish extended as far as the Komandorskiye Islands (Smirnov 1975) and the area of present-day northeastern China, although these populations were also reportedly intermittent and sporadic (K. Chew and L. Donaldson[8], as cited in Salo 1991). The northern range of chum salmon in Asia extends along the edge of the Arctic Ocean, almost halfway across the Russian Federation to the Lena River (Laptev Sea) (73°N, 125°E) (Soldatov and Lindberg 1930). However, these populations are small and may occur only intermittently. Juvenile outmigration of these northern stocks often occurs beneath the ice of rivers draining the shores of the Arctic Ocean (Sano 1966, 1967).

Historically, the largest and most commercially important run of chum salmon in Asia was located in the Amur River, which flows more than 2,800 km along the border of China and the Russian Federation. The Amur River is also the only site in Asia that has large runs of both early (summer) and late (autumn) returning chum salmon within the same river basin (see "Spawning Migrations," p. 35). Other commercially important runs originate in Japan, on Sakhalin Island (the northernmost part of which is opposite the mouth of the Amur River), in the southern Kuril Islands, on the Kamchatka Peninsula north to the Anadyr River, and in continental streams emptying into the Sea of Okhotsk. Sano (1966) divided chum salmon in Asia into five geographic groups: West Kamchatka, East Kamchatka, Okhotsk, Sakhalin-Kurils, and the Amur River.

In North America, chum salmon have been observed as far south as the San Lorenzo River in Monterey, California (about 37°N, 122°W) (Scofield 1916), with spawning populations as far as 322 km upstream in the Sacramento River (37°50'N 122°W) (Hallock and Fry 1967) (Figs. 4-5). In recent years, chum salmon have been observed intermittently in northern California (Moyle et al. in press) and southern Oregon (Kostow 1995) (see "Assessment of Extinction Risk," p. 144, for information on the occurrence of chum salmon in Oregon and California). In North America, the northern range of the species extends to the shores of the Arctic Ocean (Wynne-Edwards 1952), east to the Mackenzie River (69°N, 135°W) (Dymond 1940), and west across the north Pacific Ocean to Attu Island in the Aleutian Archipelago (Holmes 1982).

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[8] K. Chew, School of Fisheries, University of Washington, Seattle, Washington 98195. Pers. commun., April 1995.

The geographic range of commercially important runs of North American chum salmon has shrunk in recent years. The northernmost runs that support large commercial fisheries return to Kotzebue Sound (Noatak and Kobuk Rivers) and the Yukon River (Buklis and Barton 1984) (Fig. 4). Before the 1960s, the southernmost commercially important run of chum salmon in North America occurred in Tillamook Bay, Oregon (45° 50' N) (Henry 1953, 1954) (Fig. 5). This was a highly lucrative annual fishery, with chum salmon landings exceeding that of any other salmonid in the Bay. However, Oregon closed this fishery in 1962 because of declining abundances of these fish (see "Assessment of Extinction Risk," p. 144, for further information). In the 1940s, an important fishery of chum salmon developed in the Columbia River, with commercial landings varying from 1 to 8 million pounds annually.

Since 1959, with a sharp decline in chum salmon abundance, commercial landings were gradually reduced, until presently there are neither recreational nor directed commercial fisheries for chum salmon in the Columbia River (ODFW and WDFW 1995). In the 1990s, the southernmost commercial run of chum salmon in North America was in Willapa Bay and Grays Harbor (Fig. 5). The harvest of chum salmon from these coastal fisheries averaged 96,000 fish from 1988 to 1992 (WDFW 1995).

Spawning Migrations

In both Asia and North America, chum salmon spawn most commonly in the lower reaches of rivers, with redds usually dug in the mainstem or in side channels of rivers from just above tidal influence to nearly 100 km from the sea. In some areas (particularly in Alaska and northern Asia), they typically spawn where upwelled groundwater percolates through the redds (Bakkala 1970, Salo 1991). Some chum salmon even spawn in intertidal zones of streams at low tide, especially in Alaska, where tidal fluctuation is extensive and upwelling of groundwater in intertidal areas may provide preferred spawning sites (Helle[9]). Bailey (1964) reported that chum salmon eggs in Olsen Creek, Alaska, could survive exposure to tidewater for up to 55% of the time during embryonic development.

Chum salmon are believed to spawn primarily in the lower reaches of rivers because they usually show little persistence in surmounting river blockages and falls. However, in some systems, such as the Skagit River, Washington, chum salmon routinely migrate over long distances upstream (at least 170 km in the Skagit River) (Hendrick[10]). In two other rivers, the species swims a much greater distance. In the Yukon River, Alaska and the Amur River, the Russian Federation, chum salmon migrate more than 2,500 km inland. Although these distances

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[9] J. Helle, NMFS Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, Alaska 99801. Pers. commun., April 1995.

[10] D. Hendrick, Washington Department of Fish and Wildlife, 333 East Blackburn Rd., Mt. Vernon, Washington 98273. Pers. commun., January 1996.

are impressive, both rivers have low gradients and are without extensive falls or other blockages to migration. In the Columbia River Basin, there are reports that chum salmon may historically have spawned in the Umatilla and Walla Walla Rivers, more than 500 km from the sea (Nehlsen et al. 1991). However, these fish would have had to pass Celilo Falls, a web of rapids and cascades, which presumably was passable by chum salmon only at high water flows.

Timing of Spawning Migrations

Spawning migration refers to the movement of adults from seawater into their natal rivers to spawn. Chum salmon may enter natal river systems from June to March, depending on characteristics of the population or geographic location. Groups of fish entering a river system at particular times or seasons are called “runs” (footnotes 1 and 2), and run timing has long been used by the fishing community to distinguish anadromous populations of salmon, steelhead, and sea-run cutthroat trout. Run-timing designations (e.g., summer versus fall or early-fall versus late-fall) are important in this status review, because two of the ESA petitions for chum salmon (PRO-Salmon 1994, Trout Unlimited 1994) used run timing as evidence supporting population distinction.

In ESA status reviews for anadromous Pacific salmonids, run timing, along with information for other biological and ecological characteristics, is evaluated from the perspective of two criteria for defining ESUs—reproductive isolation and contribution to ecological and genetic diversity (Waples 1991). Previous status reviews have shown that simply relying on traditional run-time designations is not sufficient for identifying ESUs; each case must be evaluated individually. For example, NMFS received petitions in 1990 to list three races of chinook salmon (spring-, summer-, and fall-run fish) in the Snake River as threatened or endangered species. The different runs were defined by fixed dates at which adults pass Lower Granite Dam on the lower Snake River. The BRT looked for other evidence to evaluate the biological significance of the nominal run-timing differences, because actual run timing in any given year is variable and may span the cutoff dates. Snake River fall-run chinook salmon spawn later and at a much lower altitude than do the other two forms, and also show substantial differences from spring- and summer-run fish in genetic and juvenile and adult life-history patterns. NMFS concluded on the basis of these differences that Snake River fall-run chinook salmon were in a separate ESU from spring- and summer-run chinook salmon (Waples et al. 1991). Conversely, spring- and summer-run chinook salmon in the Snake River spawn in similar habitats and cannot be reliably separated on the basis of genetic or life-history variation. Therefore, the two forms were considered to be a single ESU (or species under the ESA), i.e., Snake River spring-summer chinook salmon (Matthews and Waples 1991).

Asian run timing

Biologists in both Asia and North America have used run-timing differences to separate the species into early- or summer-run stocks and late- or autumn-run stocks[11] (Berg 1934, Sano 1966, Bakkala 1970, Salo 1991). Chum salmon return to natal spawning streams on both continents progressively later in southern areas. Chum salmon in northern Asia return only during summer months (June, July, and August); whereas farther south, both summer (July-August) and early autumn-run chum (September-October) salmon occur along the Amur River and streams on Sakhalin Island (Fig. 4). On Honshu Island in Japan in the far south, near the southern limit of their range, only autumn-run (October-November) chum salmon occur (Fig. 4).

The Amur River, which flows along the Russian-Chinese border, is almost 2,900 km in length and is the largest Asian river entering the North Pacific Ocean (Fig. 4). In addition to being the only major river in Asia with both seasonal runs of chum salmon, it has historically supported both the largest runs and runs that migrate farther inland than any other on the continent. Summer-run chum salmon enter the Amur River as early as July and spawn within 100 km of the sea. A second run of fish enters the system later in the fall, and some of these fish are known to migrate 1,000 to 2,500 km inland. The number of autumn-run chum salmon in the Amur River Basin has become so depressed in recent years that the run may be near extinction (Semenchenko and Augerot[12]).

In Asia, summer-run fish are considered distinct from autumn-run fish. Berg (1934), who first formally described Asian chum salmon, separated Asian chum salmon into seasonal races, and considered the "autumn" chum salmon an "infraspecies," *O. k. autumnalis*. However, while other Asian investigators have supported Berg's classification (Lovetskaya 1948; Grigo 1953; Birman 1951, 1956; Hirano 1958; Sano 1966), this taxonomy has not found wide support in North America, perhaps because North American chum salmon with different run timings are not as geographically separated as in Asia. Characteristics of autumn-run fish used by Berg (1934) and Sano (1966) to separate the seasonal runs include the following: 1) later entrance into spawning streams, 2) less developed gametes at time of entry into natal streams, 3) later spawning period, 4) larger size (≥3.5 kg versus ≤2.5 kg for summer-run fish), and 5) greater fecundity than summer-run chum salmon.

North American run timing

In North America, return timing of chum salmon also follows a general north-to-south cline of earlier to later returns, similar to that seen in Asia. Only summer-run chum salmon generally enter streams along the northern Bering Sea and Arctic coast; fall-run fish occur in

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[11] "Fall" is used synonymously with "autumn" to describe run times in this report. "Autumn" is most commonly used in the literature to refer to chum salmon in Asia, and "fall" refers to chum salmon in North America. Also see footnote 1.

[12] A. Semenchencko, Pacific Institute of Fisheries and Oceanographic Research (TINRO), 4 Shevchenko Alley, Vladivostok, 690600 Russia; and X. Augerot, Center for the Analysis of Environmental Change, Oregon State University, Nash Hall, Corvallis, OR 97331. Pers. commun., July 1996.

rivers bordering the southern Bering Sea and Gulf of Alaska; and both summer and fall runs commonly occur in southeast Alaska and northern British Columbia (Fig. 4). Fall-run fish occur primarily south of Vancouver Island (Bakkala 1970). Latitudinal changes in run timing occur in both Asia and North America. However, in Asia, geographic separation between fish with fall- and summer-run times appears to be distinct (Bakkala 1970), whereas in North America, many streams have both fall- and summer-run chum salmon populations. Also, in contrast to Asian summer-run chum salmon, many North American summer-run fish mature at older ages, are larger, and have higher fecundities than do fall-run chum salmon in the same region. Overall, the differences between summer and fall runs in North America are not nearly as distinct or well developed as those reported in Asia. This led Salo (1991) to suggest that most summer runs in North America should more accurately be called early fall runs, and that the only North American populations with the same distinguishing characteristics as the Asian summer chum salmon are in the Yukon River.

Alaska run timing—Chum salmon in northern Alaska tend to return earlier than do chum salmon farther south. Although this is similar to the pattern seen in Asia, Alaskan chum salmon in general show greater diversity in run timing than chum salmon across a similar range of latitude in Asia, with many Alaskan basins having runs that return from July through November. For example, tagging studies by Yanagawa[13], Bigler (1983, 1985), and Bigler and Burwen (1984) have shown a bimodal return timing of chum salmon in some rivers in the far north in Kotzebue Sound (around 67°N). The spawning run into Kotzebue Sound is primarily composed of fish that spawn in the Noatak and Kobuk Rivers, with the Noatak River supporting about three-quarters of the Sound’s total return (Bigler 1983) (Fig. 4). Kobuk River chum salmon enter Kotzebue Sound earlier than Noatak River chum salmon (Yanagawa footnote 12), and chum salmon in Kobuk River spawn in the lower tributaries from late July to late August and in the upper tributaries from late August well into October (Bigler and Burwen 1984). Spawning in the Noatak River showed a single peak in the lower 160 km of the river from mid-August to mid-October.

The Yukon River drainage (river mouth about 63°N) supports populations of chum salmon that not only have one of the most distinctive bimodal summer/fall-run patterns of return for chum salmon in North America, but also make the longest freshwater migration in the world (Buklis and Barton 1984) (Fig. 4). Chum salmon in the Yukon River share many similarities with those of the Amur River of Asia. Both of these large rivers have long (>2,500 km) stretches accessible to anadromous fish, and both have low gradients with no barrier falls (Buklis and Barton 1984, Brannian and Gnath 1988). Both Amur and Yukon River chum salmon consist of summer-run and fall-run fish, but unlike chinook salmon or steelhead trout in the contiguous United States, these run-time designations refer to time of spawning and not to time of river entry. In both rivers, summer-run chum salmon were historically more numerous (and in the Yukon still are more numerous), return in fuller spawning coloration, are less fecund, and are

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[13] C.M. Yanagawa. 1968. Kotzebue chum salmon tagging projects, 1966-1968. AYK Region Fishery Bulletin #7, cited in Bigler and Burwen 1984.

smaller than fall-run chum salmon (Berg 1934, Sano 1966, Buklis and Barton 1984). However, unlike the runs in the Amur River, the two runs in the Yukon River have an overlap in return times (Berg 1934, Buklis and Barton 1984). Yukon River summer-run chum salmon enter the river mouth from early May through mid-July, whereas some Yukon River fall-run chum salmon (e.g., Fishing Branch Creek in the upper river) enter as early as the beginning of June (Buklis and Barton 1984). Chum salmon returning to the Yukon River are considered predominantly fall-run fish that return from mid-July through early September (Brady 1983).

Summer-run chum salmon in both the Yukon and Amur Rivers spawn primarily in tributaries that empty into the lower part of the main stem, whereas fall-run fish spawn farther upstream in spring-fed streams and sloughs (Buklis 1981, Buklis and Barton 1984, Salo 1991). Some late-returning chum salmon in the Yukon River travel almost 3,200 km from the mouth of the river to its headwaters, near Teslin Lake in British Columbia. This freshwater migration is more than 700 km farther than the longest chum salmon migration on the Amur River.

Farther south, in rivers flowing into Bristol Bay (about 58°N), chum salmon return from mid-June through July, with a peak the first week of July (Salo 1991) (Fig. 4). On the Alaska Peninsula, return times are in July and August. In the Kuskokwim River, spawning is in late August and September. In central Alaska (e.g., eastern shore of Prince William Sound), some chum salmon first enter streams in mid-June, but the peak of spawning is primarily in late July and August. Throughout this area, run timing varies greatly between river basins, but is relatively consistent from year to year within basins (Helle[14]).

In Southeast Alaska, catch statistics from 1984 indicate that nearshore abundance peaked in the first 2 weeks in August, and that the median timing of the escapements occurred from late August to mid-September (Clark and Weller 1986). Spawning chum salmon are difficult to count in the many rivers and streams of this region, because of the large numbers of pink salmon also present in the streams (Helle footnote 14). However, it is clear that the run timings of these chum salmon are diverse, ranging from mid-June through December. As an example, Helle observed that chum salmon first entered some mainland streams in Behm Canal and Portland Canal in southern Southeast Alaska in mid-June, with peak numbers occurring in mid-August. Fish began to enter natal streams on islands in September, and the run did not peak until mid-October (Helle footnote 13). Spawning has also been observed in October near the mouth of the Alsek River in the Yakutat area (Salo 1991). An exceptionally late run of large, fall-run chum salmon return to the Chilkat River near Haines (Cline 1982), and the timing of this run appears to be influenced by upwelling groundwater in sloughs exposed after the glacial waters of the Klehini and Chilkat Rivers recede in the fall (Helle footnote 13). Large numbers of bald eagles congregate in these sloughs in late fall and early winter to feed on the chum salmon carcasses (Helle footnote 13).

British Columbia run timing_Tables 2 and 3 list rivers in British Columbia that support escapements greater than 5,000 chum salmon annually and show run timings (start, peak, end)

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[14] J. Helle, NMFS Alaska Fisheries Science Center, Auke Bay Laboratory, 11305 Glacier Hwy., Juneau, Alaska 99801. Pers. commun., November 1995.

Table 2. Estimated average escapements of chum salmon to British Columbia streams with spawning times beginning in August or September, 1951 to 1962 (modified from Aro and Shepard 1967). Statistical area refers to fishery management regions designated by WDFW and Canadian Department of Fisheries and Oceans (see Aro and Shepard 1967 for maps showing locations of numerical areas).

Statistical area	Stream	Average escapement in thousands of fish	Spawning times		
			Start	Peak	End
12	Ahnuhati River	10 - 20	Aug.	Sept.	Nov.
12	Ahta Valley Creek	5 - 10	Aug.	Sept.	Nov.
12	Kakweiken River	5 - 10	Aug.	Oct.	Nov.
12	Kingcome River	10 - 20	Aug.	Oct.	Nov.
12	Quatse River	5 - 10	Aug.	Oct.	Oct.
12	Waterfall River	5 - 10	Aug.	Sept.	Oct.
15	Toba River	20 - 50	Aug.	Nov.	Dec.
12	Glendale Creek	5 - 10	Sept.	Oct.	Nov.
12	Keogh River	2 - 5	Sept.	Sept.	Oct.
12	Klinaklini River	20 - 50	Sept.	Oct.	Nov.
12	Viner Sound River	20 - 50	Sept.	Oct.	Oct.
12	Wakeman River	5 - 10	Sept.	Oct.	Nov.
13	Orford River	5 - 10	Sept.	Oct.	Nov.
13	Salmon River	2 - 5	Sept.	Oct.	Nov.
13	Southgate River	5 - 10	Sept.	Oct.	Nov.
15	Theodosia River	10 - 20	Sept.	Oct.	Nov.
17	Nanaimo River	20 - 50	Sept.	Oct.	Jan.
23	Toquart River	20 - 50	Sept.	Oct.	Nov.
25	Burman River	5 - 10	Sept.	Oct.	Nov.

Table 3. Estimated average escapements of chum salmon to British Columbia streams with spawning times beginning in October or November, 1951 to 1962 (modified from Aro and Shepard 1967). Statistical area refers to fishery management regions designated by WDFW and Canadian Department of Fisheries and Oceans (see Aro and Shepard 1967 for maps showing locations of numerical areas).

Statistical area	**Stream**	**Average escapement in thousands of fish**	**Spawning times**		
			Start	**Peak**	**End**
12	Nimpkish River	1Yr>100 11yr 20 - 50	Oct.	Nov.	Dec.
13	Heydon Creek	5 - 10	Oct.	Nov.	Nov.
13	Homathko River	10 - 20	Oct.	Nov.	Nov.
13	Phillips River	2 - 5	Oct.	Oct.	Nov.
13	Englishman River	5 - 10	Oct.	Nov.	Dec.
13	Little Qualicum River	20 - 50	Oct.	Nov.	Dec.
13	Puntledge River	20 - 50	Oct.	Nov.	Dec.
13	Qualicum River	20 - 50	Oct.	Dec.	Jan.
13	Tsable River	5 - 10	Oct.	Nov.	Dec.
15	Sliammon Creek	5 - 10	Oct.	Nov.	Dec.
16	Deserted River	5 - 10	Oct.	Nov.	Dec.
16	Tzoonie River	10 - 20	Oct.	Nov.	Dec.
17	Bush Creek	2 -5	Oct.	Oct.	Dec.
17	Chemainus River	20 - 50	Oct.	Oct.	Jan.
17	Holland Creek	5 - 10	Oct.	Oct.	Dec.
18	Cowichan River	1Yr>100 11yr 20 - 50	Oct.	Dec.	Jan.
18	Koksilah River	2 -5	Oct.	Dec.	Jan.
19	De Mamiel Creek	10 - 20	Oct.	Nov.	Dec.
19	Goldstream River	5 - 10	Oct.	Nov.	Dec.
19	Sooke River	20 - 50	Oct.	Nov.	Nov.
22	Nitinat River	20 - 50	Oct.	Oct.	Nov.
23	Nahmint River	1Yr>100 11yr 20 - 50	Oct.	Oct.	Nov.
3	Sarita River	20 - 50	Oct.	Oct.	Nov.
23	Toquart River (left fork)	5 - 10	Oct.	Oct.	Nov.

Table 3 (Continued).

Statistical area	Stream	Average escapement in thousands of fish	Spawning times		
			Start	Peak	End
24	Megin River	5 - 10	Oct.	Nov.	Nov.
24	Moyeha River	5 - 10	Oct.	Nov.	Nov.
24	Tranquil Creek	10 - 20	Oct.	Nov.	Nov.
25	Inner Basin River	10 - 20	Oct.	Oct.	Nov.
25	Tahsis River	5 - 10	Oct.	Oct.	Nov.
26	Clanninick River	5 - 10	Oct.	Oct.	Nov.
26	Malksope River	5 - 10	Oct.	Nov.	Nov.
26	Tahnish River	5 - 10	Oct.	Oct.	Nov.
28	Cheakamus River	10 - 20	Nov.	Dec.	Jan.
28	Indian River	10 - 20	Oct.	Nov.	Nov.
28	Squamish River	1Yr>175 10yr 20 - 50	Nov.	Dec.	Jan.
29	Chehalis River	20 - 50	Oct.	Oct.	Oct.
29	Chilliwack River*	20 - 50	Oct.	Dec.	Jan.
29	Fraser River below Hope	75.1	Nov.	Dec.	Dec.

*Includes Vedder River and Sweltzer Creek.

for each population (Aro and Shepard 1967). Escapements were estimated from catches in inside passages and inlets close to spawning areas. Spawning times were estimated from a variety of stream surveys (e.g., foot, plane, photographs), although Aro and Shepard (1967) cautioned that the dates of runs were approximate because information from different surveys was not always comparable. Since chum salmon spawning areas are spread more evenly over a large number of moderately sized streams in British Columbia, the species is more difficult to survey in spawning areas than are sockeye and pink salmon. Nonetheless, surveys have shown that chum salmon spawn in the lower reaches of more than 880 streams in British Columbia and that this population is fairly well distributed among the streams. Aro and Shepard (1967) calculated that the most productive 58 streams produced only 50% of the estimated total chum salmon escapement, while 75% of the total pink salmon run in British Columbia occurred in the most productive 58 streams, and 75% of the sockeye salmon escapement occurred in only 29 streams.

In general, there is a distinct north-to-south cline of early-to-late return and spawning times in British Columbia, similar to the clines for these variables in Asia and Alaska. Chum salmon pass through inshore fishing areas near the northern mainland of British Columbia in July and August (summer runs), and catches peak in August along the coast of north-central British Columbia, near Bella Bella and Bella Coola. Catches are made primarily in August and September around the Queen Charlotte Islands. Return times of chum salmon into northern rivers around Johnstone Strait and the Strait of Georgia are usually earlier (early October) than they are in southern rivers, such as the Cowichan River (late December). Peak catches north of Vancouver Island occur from mid-July to mid-September, and southern British Columbia peak catches are in October (Beacham 1984).

Aro and Shepard (1967) also found a marked cline for spawning time. They found 64 rivers with “major stocks” of chum salmon north of Vancouver Island (Statistical Area 13), and all but two of these runs appear to spawn in August or September. Farther south (Statistical Area 13 and higher), 47 major runs were listed, but only one spawned as early as August (Toba River, Section 15), and only eight spawned in September. All other runs began spawning in October or November. Most southern runs completed spawning by the end of December, but six apparently continued to spawn into January. In the north, all but six runs completed spawning by the end of October, and these six finished spawning by November.

Canadian biologists do not classify chum salmon runs into “summer” or “fall” categories. However, spawning in southern British Columbia occurs principally from October to January (Tables 2 and 3). Early spawning and summer runs of chum salmon are rare in southern British Columbia, and no July spawners have been reported. Rivers on northern Vancouver Island and those opposite on the mainland with late-summer or August spawning times include the Ahnuhati, Keogh, Kingcome, Quatse, and Waterfall Rivers, and Ahta Valley Creek. Spawning peaks in October in most of these rivers, but continues into November. Farther south, midway down Vancouver Island and on the opposite mainland (Toba River), chum salmon spawning begins in August and continues through December. Spawning peaks in mid-November, not in October as it does to the north. On southern Vancouver Island, chum salmon spawn in the Nanaimo River (average escapement 20,000-50,000 per year) from September to January, with a peak in October. On the outer southern coast of Vancouver Island, chum salmon run from

September to November into the Toquart River (20,000-50,000 escapement) and peak in October. Similarly, on the middle outer coast of Vancouver Island, fish in the Zeballo River (5,000-10,000 escapement) spawn from September to November (Aro and Shepard 1967). No data are available to indicate whether there is a break between the early and late portions of the run, but the runs appear to be continuous (Beacham[15]).

Washington run timing—Most chum salmon in Washington are classified as fall-run fish and generally return to their natal streams from October to November, although distinct summer and winter runs of chum salmon are recognized. WDFW and WWTIT (SASSI: WDF et al 1993) listed return times for 72 runs of chum salmon: 62 are classified as fall runs, 2 as winter runs (both in southern Puget Sound), and 8 as summer runs (4 in southern Puget Sound and 4 in Hood Canal/Strait of Juan de Fuca) (Table 4; and Fig. 7a-d).

Puget Sound run timing—Only fall (October to late November) runs have been observed in the rivers of northern Puget Sound (Nooksack, Skagit, Stillaguamish, Skykomish, and Snohomish Rivers) (Atkinson et al. 1967; Hiss et al. 1982a; WDF et al. 1993). However, there is a greater variability in river entry and spawning time within these fall runs than runs in British Columbia. Salo (1991) suggested this regional difference was due to the presence of a larger number of moderate-to-large rivers in Washington than in British Columbia, and to the fact that chum salmon spawn farther upstream in Washington rivers. For example, chum salmon were tagged at the mouths of the Stillaguamish and Nooksack Rivers, and spawn timing was calculated from tagged carcasses counted on spawning grounds (Hiss et al. 1982a, 1982b). In the Stillaguamish River, the average time between tagging and spawning-area recovery was 31 days, and some fish spent more than 6 weeks in freshwater before spawning. Also, different parts of the river basins had different spawning times; in general, return times to spawning areas higher in the river basin were progressively later than return times to spawning areas lower in the basin (Tables 5-7) (Hiss et al. 1982a, 1982b).

All three seasonal runs (summer, fall, and winter) occur in Puget Sound (Table 4; Fig. 7a-b) (WDF et al. 1993). Summer-run chum salmon spawn from September to mid-October, and WDFW has identified three summer chum salmon runs: Case Inlet, Hammersley Inlet, and Blackjack Creek. A fourth run into Chambers Creek, north of the Nisqually Delta, in summer was listed as extinct (SASSI: WDF et al. 1993). Existing runs exhibit a wide range of spawning times that extend from late August to mid-October (Hammersley Inlet), through mid-September to early November (Case Inlet), to mid-October and mid-November (Blackjack Creek near Port Orchard, Washington). With the exception of Blackjack Creek, these runs have been supplemented with fry from local spawners, which were reared at Johns Creek Hatchery (Hammersley Inlet) and at Coulter Creek Hatchery (Case Inlet).

Chambers Creek, a southern Puget Sound stream that empties into the Tacoma Narrows, also once contained a run of summer fish (WDF et al. 1993). The existence of the run was

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[15] T. Beacham, Department of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station, Nanaimo, B.C., Canada V9R 5K6. Pers. commun., September 1995.

Table 4. Chum salmon stocks identified in Washington State by WDF and WWTIT in the SASSI report (WDF et al. 1993). The definitions for stock origin (Origin) and production type (Type) are described in the text and in WDF et al. (1993).

Drainage	River	Run time	Origin/Type
U.S./Canada Border	Sumas/Chilliwack River	Fall	Native/Wild
Nooksack/Samish	Mainstem/Sf Nooksack River	Fall	Native/Wild
	NF Nooksack River	Fall	Native/Wild
	Samish/Independent River	Fall	Mixed/composite
Skagit	Lower Skagit River Tributaries	Fall	Unknown/Wild
	Sauk River	Fall	Native/Wild
	Mainstem Skagit River	Fall(Even)	Native/Wild
	Mainstem Skagit River	Fall(Odd)	Native/Wild
Stillaguamish	SF Stillaguamish River	Fall	Native/Wild
	NF Stillaguamish River	Fall(Even)	Native/Wild
	NF Stillaguamish River	Fall(Odd)	Native/Wild
Snohomish	Snoqualmie River	Fall	Native/Wild
	Skykomish River	Fall(Even)	Native/Wild
	Wallace River	Fall(Even)	Native/Wild
	Skykomish River	Fall(Odd)	Native/Wild
	Wallace Rover	Fall(Odd)	Native/Wild
Duwamish/Green	Crisp Creek	Fall	Non-native/Cultured
	Duwamish/Green River	Fall	Mixed/composite
Puyallup	Fennel Creek	Fall	Unknown/Wild
	Hylebos Creek	Fall	Unknown
	Puyallup/Carbon River	Fall	Native/Wild
Nisqually	Nisqually River	Winter	Native/Wild
South Sound	Car Inlet	Fall	Mixed/composite
	Case Inlet	Fall	Native/Wild
	Dyes Inlet/Liberty Bay	Fall	Native/composite
	Eld Inlet	Fall	Native/Wild
	Gig Harbor/Ollala River	Fall	Mixed/composite
	Goldsborough/Shelton Creeks	Fall	Native/Wild

Table 4 (Continued).

Drainage	River	Run time	Origin/Type
	Henderson Inlet	Fall	Mixed/composite
	John/Mill Creeks	Fall	Mixed/Wild
	Sinclair Inlet	Fall	Native/Wild
	Skookum Inlet	Fall	Mixed/composite
	Totten Inlet	Fall	Native/Wild
	Upper Skookum Creek	Fall	Native/Wild
	Blackjack Creek	Summer	Native/Wild
	Case Inlet	Summer	Native/composite
	Chambers Creek	Summer	Native/Wild
	Hammersley Inlet	Summer	Native/composite
	Chambers Creek	Winter	Native/Wild
Hood Canal	Dewato River	Fall	Mixed/composite
	Dosewallips River Late	Fall	Native/Wild
	Duckabush River Late	Fall	Native/Wild
	Lower Skokomish River	Fall	Mixed/composite
	NE Hood Canal	Fall	Mixed/composite
	Quilcene River Late	Fall	Mixed/composite
	SE Hood Canal	Fall	Mixed/composite
	Upper Skokomish River Late	Fall	Native/Wild
	West Hood Canal	Fall	Mixed/composite
	Hamma Hamma River Late	Fall	Native/Wild
	Hood Canal	Summer	Native/Wild
	Union River	Summer	Native/Wild
Strait of Juan de Fuca	Deep/E & W Twin Creeks	Fall	Native/Wild
	Dungeness River/E Strait of Juan de Fuca Tributaries	Fall	Native/Wild
	Elwha River	Fall	Native/Wild
	Hoko/Clallam/Sekiu	Fall	Native/Wild
	Lyre River	Fall	Native/Wild
	Pysht River	Fall	Native/Wild
	Discovery Bay	Summer	Native/Wild

Table 4 (Continued).

Drainage	**River**	**Run time**	**Origin/Type**
	Sequim Bay	Summer	Native/Wild
Sooes/Ozette	Ozette River	Fall	Native/Wild
	Sooes River	Fall	Non-native/Cultured
Quillayute	Quillayute River	Fall	Native/Wild
Hoh	Hoh River	Fall	Unknown
Queets	Queets River	Fall	Unknown
Quinault	Quinault River	Fall	Mixed/composite
Grays Harbor	Humptulips River	Fall	Native/Wild
	Chehalis River	Fall	Native/Wild
Wallapa Bay	Bear River	Fall	Native/Wild
	Naselle River	Fall	Mixed/Wild
	Nemah River	Fall	Native/Wild
	North River	Fall	Native/Wild
	Palix River	Fall	Native/Wild
	Wallapa River	Fall	Native/Wild
Lower Columbia	Grays River	Fall	Native/Wild
	Hardy Creek	Fall	Native/Wild
	Hamilton Creek	Fall	Native/Wild

Table 5. Estimated run timing for chum salmon in southern Puget Sound based on live fish counts (Cole et al. 1986).

Tributary	**Duration of spawning**
Nisqually River	
Clear Creek	Late Dec. - Early March
Yelm Creek	Late Dec. - Early March
Southern Puget Sound	
McAllister Creek	Mid Dec. - Late Feb.
Red Salmon Creek	Late Dec. - Late Feb.

Table 6. Spawn timing for chum salmon in the Stillaguamish River Basin based on surveys of live tagged fish on spawning grounds (Hiss et al. 1982a).

Tributary	**River km**	**Spawning distance from mouth (km)**	**Duration of spawning**	**Peak spawning**
NF Stillaguamish		25.0 - 54.0		
Grants Creek	not given	0.0 - 0.5	Nov. 3 - Dec. 16	Dec. 8 - 12
Placid Creek	42.6	0.0 - 0.5	Nov. 24 - Dec. 29	After Dec. 5
Squire Creek	50.7	0.0 - 1.9	Oct. 27 - Dec. 16	Nov. 24 - 27
Furland Creek	Tributary to Squire Creek	0.0 - 0.8	Oct. 20 - Dec. 16	Nov. 24 - 28
Ashton Creek	Tributary to Squire Creek	0.0 - 0.8	Oct. 20 - Dec. 20	Nov. 24 - 29
SF Stillaguamish		29.0 - 37.0		
Jim Creek	16.9	0.0 - 6.6	Oct. 10 - Dec. 1	Nov. 11 - 14
Siberia Creek	Tributary to Jim Creek	0.0 - 0.8	Nov. 3 - Dec. 8	Nov. 11 - 15

Table 7. Estimated spawn timing and duration of spawning for chum salmon in the North Fork Nooksack River based on carcass counts of tagged spawners (Hiss et al. 1982b).

Tributary	**River km**	**Duration of spawning**	
		1978 - 79	**1979 - 80**
NF Nooksack	58 - 83.2		
0411 and Slough	77.9	Late Dec. - Late Feb.	Mid Jan. - Late Feb.
Slough at Belis Creek	no data	Late Dec. - Late Feb.	Early Jan. - Late Feb.
Rutsatz Slough	59.1	Mid Dec. - Late Feb.	Late Dec. - Late Feb.
Bear Creek	72.6	Early Dec. - Late Feb.	no data
Bear Creek Slough	no data	Mid Dec. - Late Feb.	Late Dec. - Late Feb.
Maple Creek	80	Early Jan. - Late Feb.	Late Dec. - Late Feb.
Pipeline Crossing	no data	Early Jan. - Late Feb.	Late Dec. - Late Feb.

inferred from weir counts in the 1970s and 1980s at the Garrison Creek Hatchery, which is located on a tributary of Chambers Creek. Hood Canal chum salmon with November return timing were introduced into Chambers Creek in the 1970s. Until the SASSI review, chum salmon returning to Chambers Creek before 10 December were assumed to be a mix of the "early native stock" and introduced fish (Crawford 1997); fish returning after 10 December were considered natural winter-run chum salmon. However, analysis of weir counts at the hatchery revealed an earlier run beginning about the third week in September and peaking about the third week in October. The early run was considered to be extinct by about 1983 when only three fish were observed in the creek. November-returning fish of Hood Canal origin have not been observed in Chambers Creek since 1986, but winter-run chum salmon still return to the creek (see below).

The Chambers Creek winter-run fish enter the river from early December to late January (Table 4) and are reported in SASSI to be geographically and temporally isolated from other Puget Sound runs (WDF et al. 1993). As reported by Crawford (1997:5), "The issue of spawner overlap with winter chum is moot, since summer and 'fall' chum are no longer present."

Winter-run chum salmon (defined in the SASSI report [WDF et al. 1993] as fish with an average peak of spawning after 10 January) also occur in the Nisqually River in southern Puget Sound (Table 4) (WDF et al. 1993). This winter run and the winter run in Chambers Creek may be the latest returning chum salmon in the world. Tagged chum salmon caught by purse seines in the Nisqually River estuary between late November and mid-January from 1974 to 1980 were recaptured from mid-December to late February/early March at weirs on two spawning ground tributaries, Muck and Yelm Creeks (Cole et al. 1986). Small numbers of fall-timed chum salmon are caught in a tribal fishery in the Nisqually River basin, but WDFW does not believe these fish represent a self-sustainable fall run (Turner 1995). Stream surveys or other data for these fall fish are not available. These fall fish may be strays or they may be from hatchery programs in the Nisqually River Basin. These hatchery programs have primarily reared winter-run fish, but summer-run fish from Johns Creek and fall-run fish from Kennedy Creek, Hood Canal, and Bonneville Hatchery Complex on the Columbia River have also been propagated (see Appendix).

Nine groups of natural fall-run chum salmon in southern Puget Sound were identified in the SASSI report (WDF et al. 1993) (Table 4). One of these, the Eld Inlet fall-run chum salmon, contained fish that return to Allison Springs, which was the focus of the petition submitted by the "Save Allison Springs" Citizens Committee (1994). These southern Puget Sound chum salmon spawn from mid-October to late January, with the long duration of spawning apparently caused by differences among the populations. These fish are reported in the SASSI report (WDF et al. 1993) to be isolated by distance, and to some degree by run timing differences, from other groups of chum salmon in Puget Sound.

Eld Inlet is located between Totten and Henderson Inlets, near the southern end of Puget Sound (Fig. 2) and is fed by freshwater streams near its terminus. The primary tributaries emptying into Eld Inlet where fish spawn are McLane, Swift, and Perry Creeks. Chum salmon returning to Eld Inlet enter southern Puget Sound (WDF et al. 1993) from late October to mid-

December, with river entry and spawning from late November to early January. Although this is a broad spawning time compared to other fall chum salmon in Puget Sound, WDFW points out that it is "much later than the Puget Sound summer stocks" (WDF et al. 1993, Appendix 1—Hood Canal and Strait of Juan de Fuca, p. 259), the only other chum salmon spawning in the region. Spawn timing of other fall-run chum salmon in southern Puget Sound are shown in Table 4.

***Hood Canal summer chum salmon run timing*—**Co-managers in Washington have classified chum salmon in Hood Canal as summer- and fall-returning stocks (Fig. 7). Run-timing and other life-history characteristics for the SE populations have been extensively reviewed by Tynan (1997). Information recorded from 1913 to 1914 (Fig. 8) at the Quilcene National Fish Hatchery on the Big Quilcene River in northern Hood Canal (Fig. 3) indicated a separation of almost a month between the end of the summer chum salmon run and the beginning of the fall run (Cook-Tabor and Zajac). The SASSI report (WDF et al. 1993) states that, at present, the "summer" spawning of the early run occurs from early-September to mid-October, while the "fall" run spawns from early November to late December (Table 4, Fig. 7c). Graphs of spawning survey data collected by WDFW (Fig. 9) and catch survey patterns developed by the Point No Point Treaty tribes (Figs. 10 and 11; Lampsakis[6]) also show nearly a month's separation between peak catches of summer-run chum salmon and natural, fall-run chum salmon in Hood Canal (Fishery Management Area 12).

Summer-, but not fall-run, chum salmon also occur in two bays on the eastern end of the Strait of Juan de Fuca (Fig. 1). These fish have run times similar to those of summer-run fish in Hood Canal (Table 4, Fig. 7c). A run of early-returning chum salmon was recently observed in the Dungeness River, but no life-history, abundance, or other data for the run are available (Johnson[7]).

***Hood Canal fall chum salmon run timing*—**Co-managers in Hood Canal (WDF et al. 1993) identified 10 naturally spawning Hood Canal fall chum salmon stocks: Northeast Hood Canal, Dewatto, Southeast Hood Canal, Lower Skokomish, Upper Skokomish Late, West Hood Canal, Hamma Hamma Late, Duckabush Late, Dosewallips Late, and Quilcene Late. Fall-run chum salmon in the SASSI report are defined as fish that enter the terminal area in Hood Canal (terminal areas are Fishery Management Areas 12A, B, C, and D) (Fig. 3) between the first week

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[16] C. Cook-Tabor and D. Zajac, U.S. Department of Interior, Fish and Wildlife Service, Western Washington Fishery Resource Office, 2625 Parkmont Lane, Bldg. A, Olympia, Washington 98502. Pers. commun., March 1995.

[17] N. Lampsakis, Fisheries Office, Point No Point Treaty Council, 7999 N.E. Salish lane, Kingston, Washington 98346. Pers. commun., March 1995.

[18] R. Johnson, 133 LipLip Land, Nordland, Washington 98358. Pers. commun., May 1995.

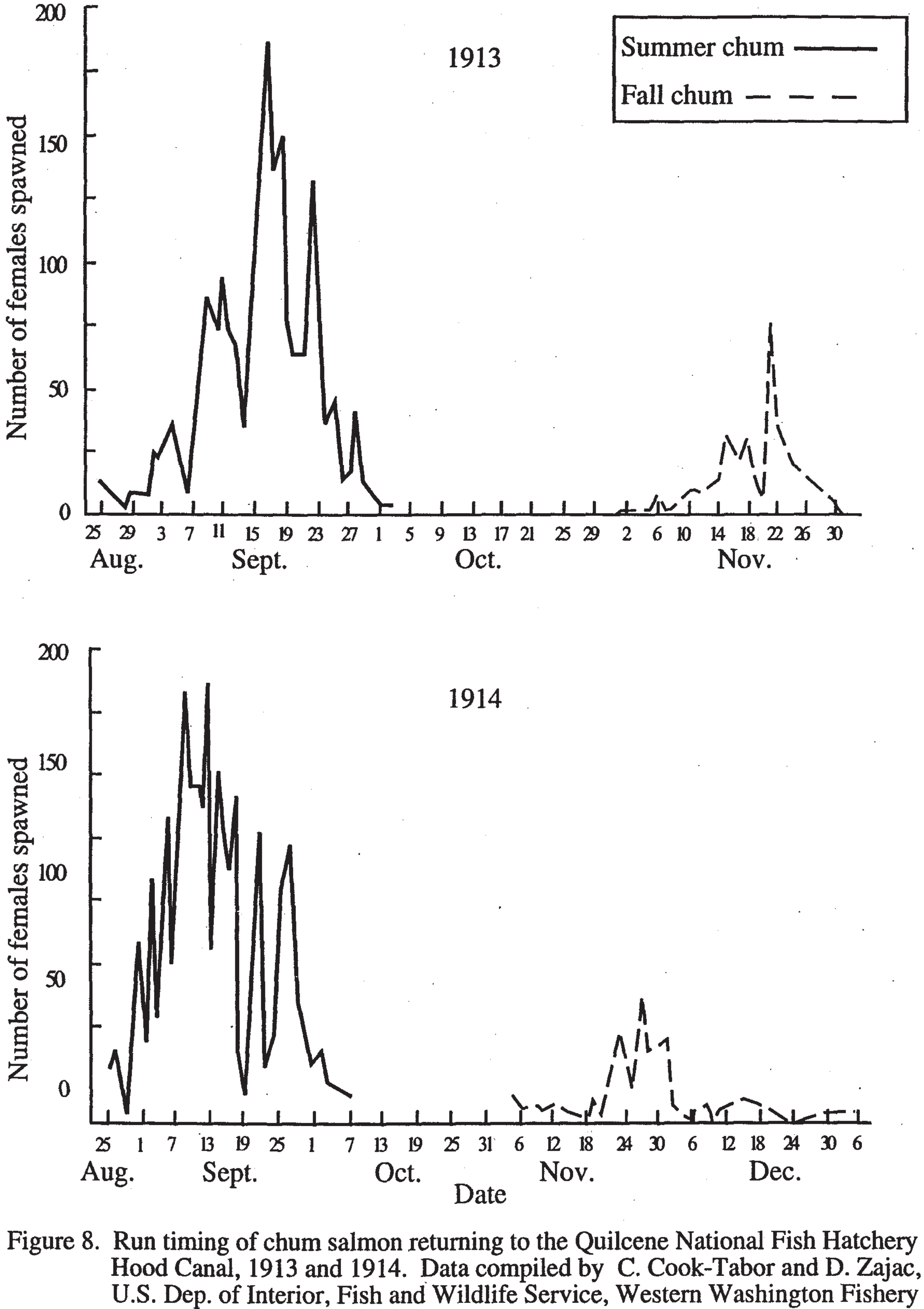


Figure 8. Run timing of chum salmon returning to the Quilcene National Fish Hatchery on Hood Canal, 1913 and 1914. Data compiled by C. Cook-Tabor and D. Zajac, U.S. Dep. of Interior, Fish and Wildlife Service, Western Washington Fishery Resource Office, 2625 Parkmont Lane, Bldg. A, Olympia, WA 98502, March 1995.

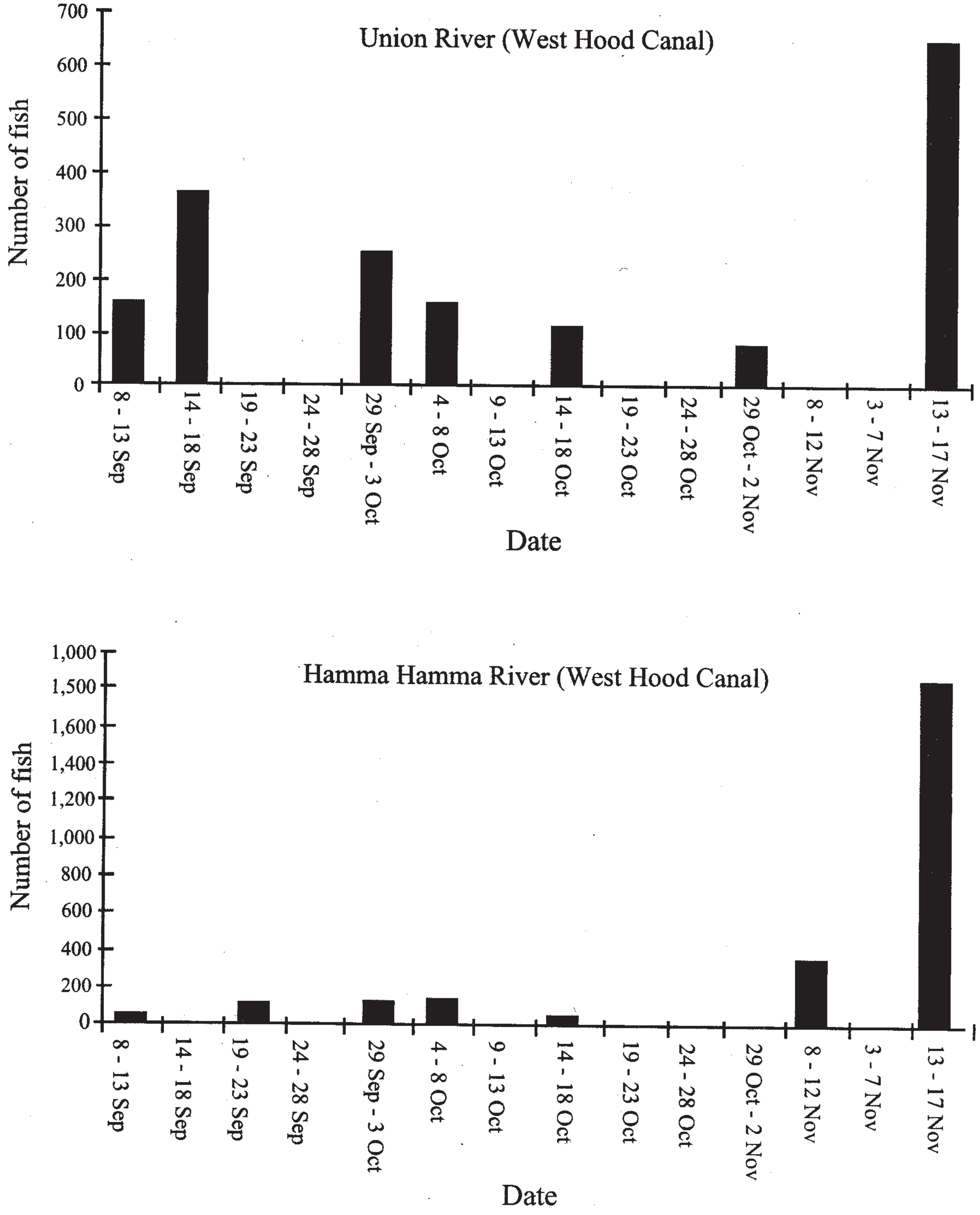


Figure 9. Total survey counts of live and dead chum salmon spawners conducted in 1994 in western tributaries of Hood Canal (Duckabush, Dosewallips, Union, Hamma Hamma, and Big Quilcene Rivers) and the Strait of Juan de Fuca (Salmon Creek in Discovery Bay and Jimmycomelately Creek in Sequim Bay). Each bar represents counts from a single day from the range of dates given. Dates have been grouped to standardize river data. Data provided by J. Uehara, Washington Department of Fish and Wildlife, P. O. Box 43151, Olympia, WA 98504, January 1995.

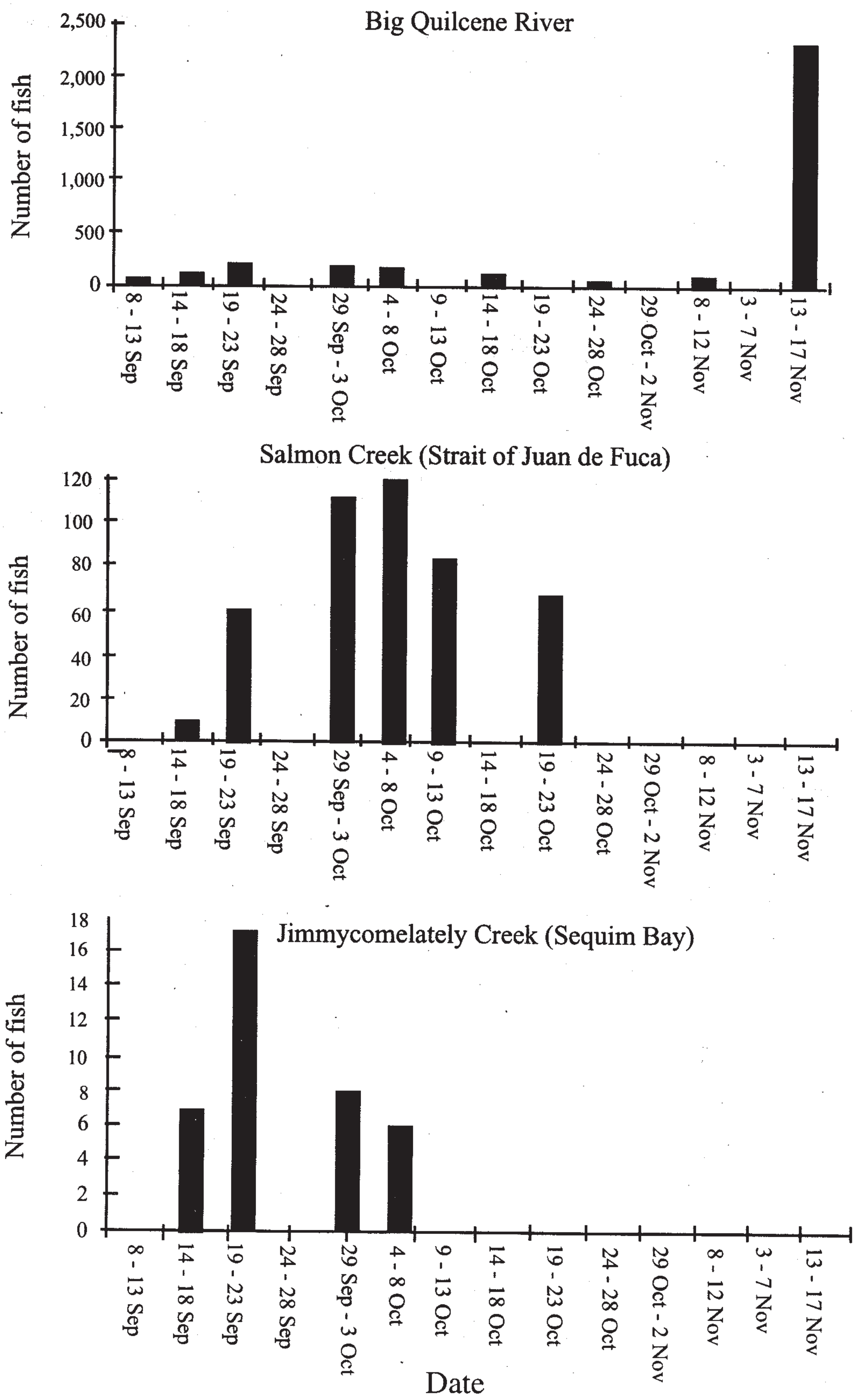
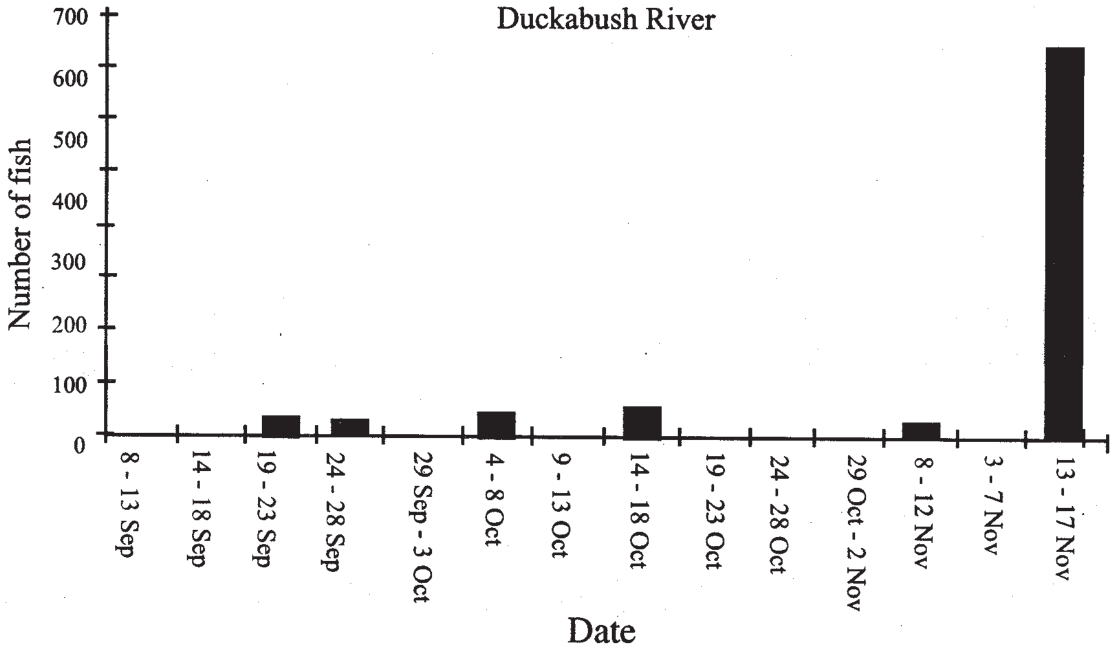


Figure 9. Continued.



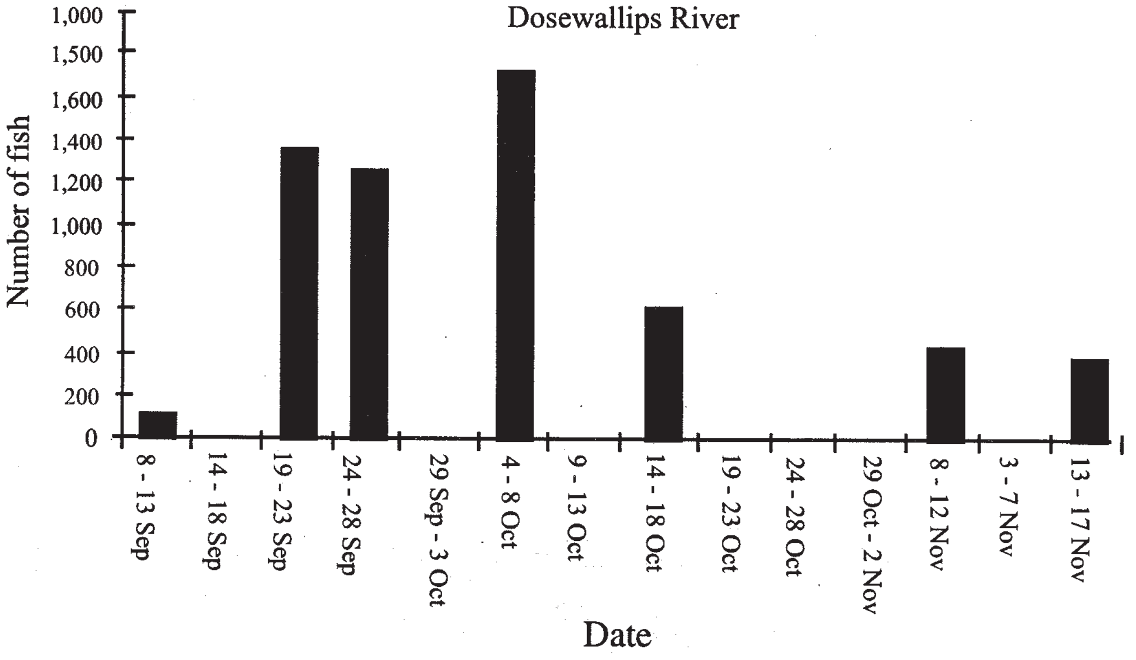


Figure 9. Continued.

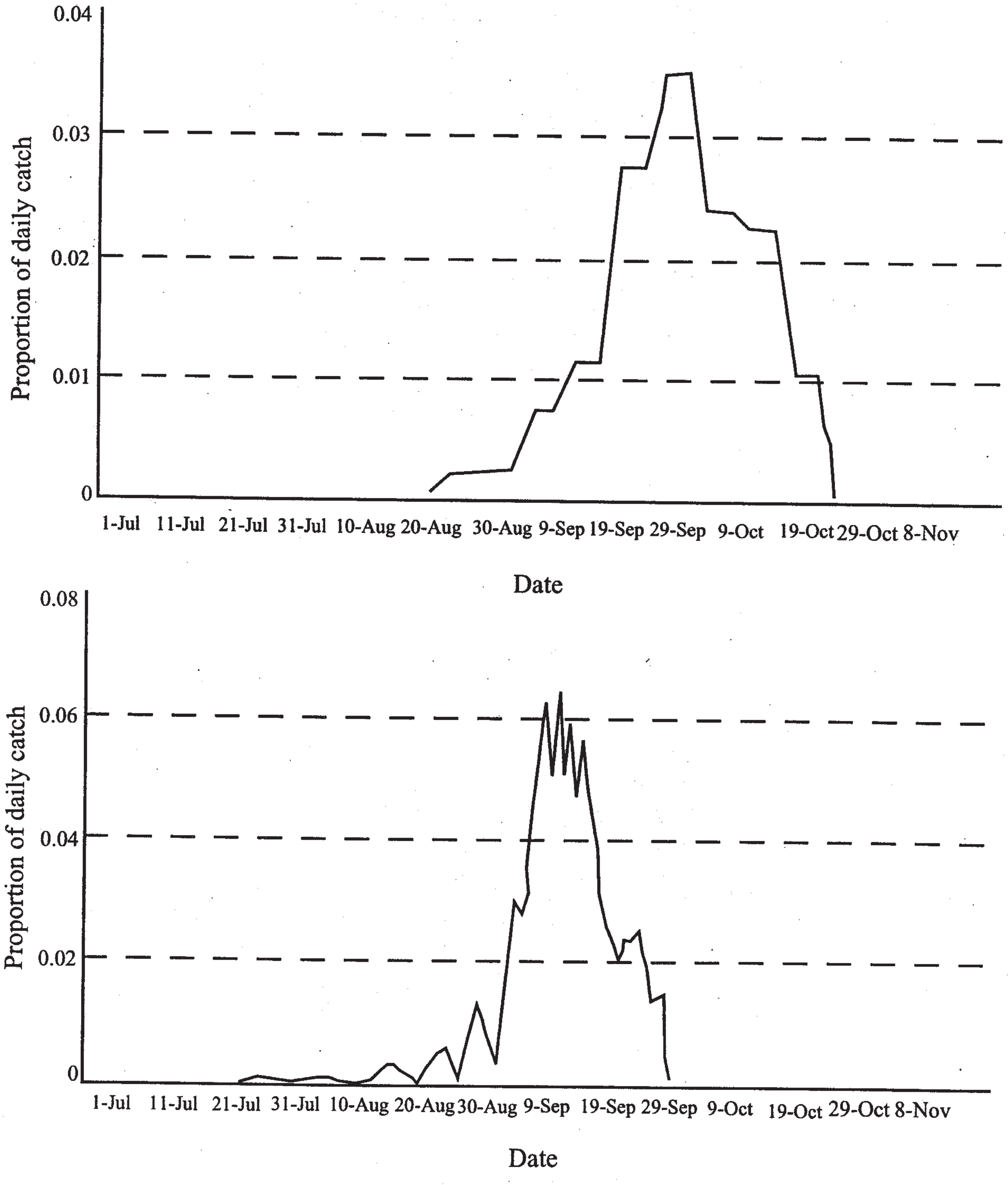
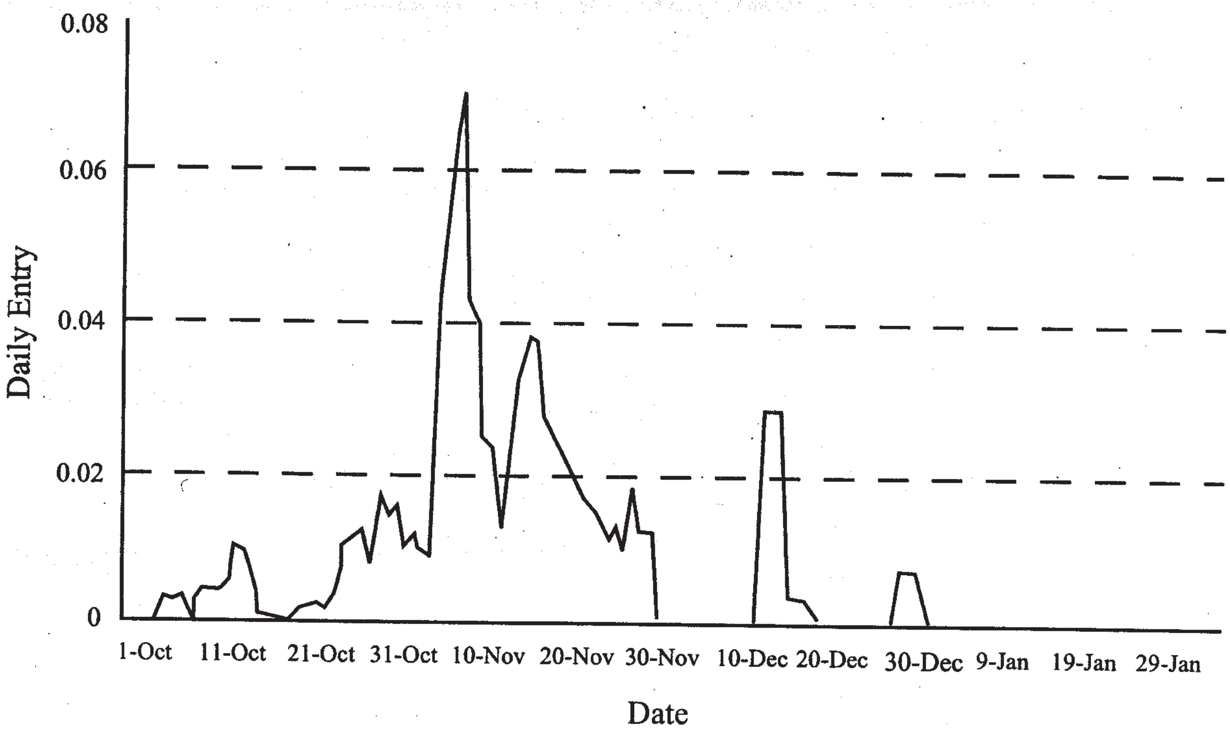


Figure 10. Summer chum salmon catch patterns in Big Quilcene River (top) and Hood Canal (bottom). Graphs provided by N. D. Lampsakis, Point No Point Treaty Council, 7999 N. E. Salish Lane, Kingston, WA 98346, 23 March 1995.



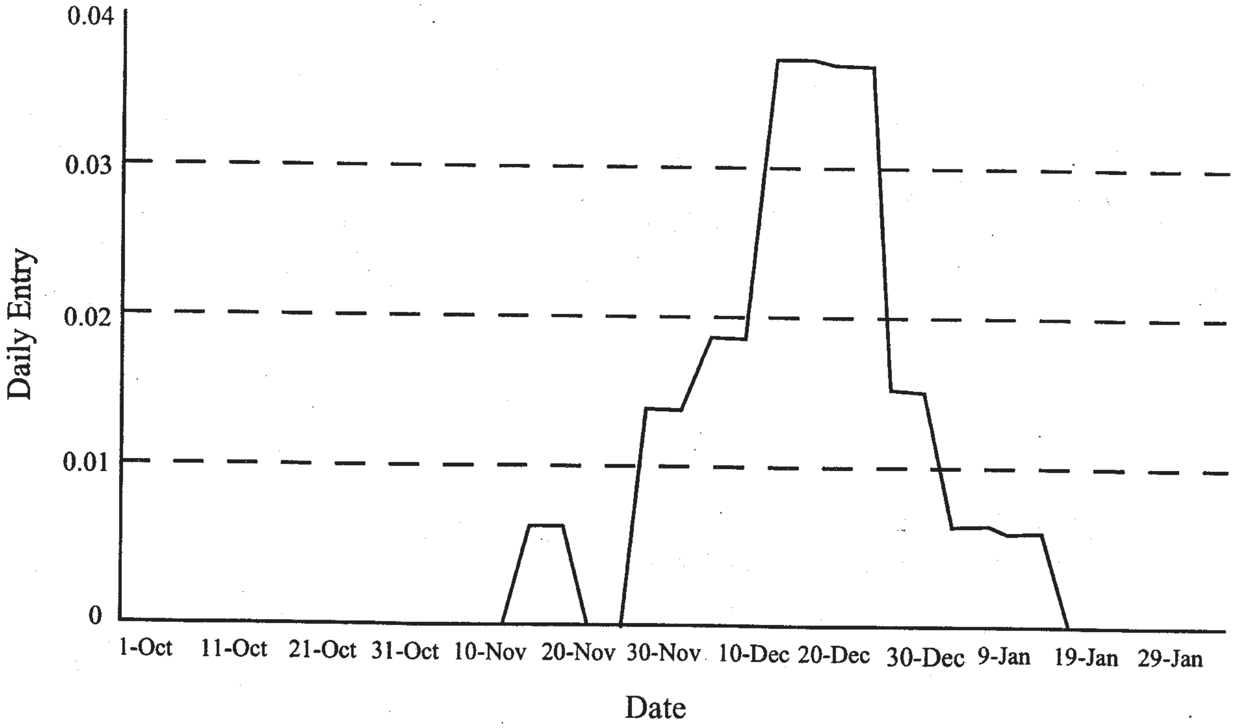


Figure 11. Fall chum salmon catch patterns in the Strait of Juan de Fuca, Dungeness River (top) and the Lyre River (bottom). Graphs provided by N. D. Lampsakis, Point No Point Treaty Council, 7999 N. E. Salish Lane, Kingston, WA 98346, 23 March 1995.

in October and the first week in January. These stocks are separated by the co-managers based on two criteria: geographic separation of spawning grounds and differences in run timing (WDF et al. 1993, Appendix 1—Hood Canal and Strait of Juan de Fuca, p. 43):

> Spawning [of fall-run chum salmon] begins about the third week in October and may continue through January. This long duration is a result of timing differences among the nine fall chum stocks in the area which are classified for management purposes as "early fall" and "late fall" stocks.
>
> Fall chum spawning in this region is isolated from other Puget Sound chum stocks primarily through geographic separation. Hood Canal summer chum are separated by a clear difference in the spawning seasons from the fall stocks. Hood Canal fall chum were separated into 10 stocks based primarily on geographic separation of the spawning grounds. However, in some cases run-timing differences were also large enough to consider separation of stocks.

However, this does not mean fall chum salmon in Hood Canal were classified in SASSI by run timing "primarily for management purposes." Crawford (1997:6) argues that

> Differences in run timing of Hood Canal fall chum stocks was considered but in all cases there was significant timing overlap, and none of the fall timed stocks would have been identified as a distinct stock based solely on timing differences. The timing difference criterion was only used in support of spawning distribution, and was always characterized in the individual stock reports as "to some degree by differences in run timing." The reference to SASSI characterizing stocks based on "management differences in run timing" is not correct. Fishery management elements were not a part of the SASSI stock identification or stock rating process. The confusion here probably arises from the fact that WDFW staff feel that because there is so much overlap in timing among the Hood Canal fall chum stocks, the distinction between fall timing and "late" fall timing is only useful in a management sense; to fine tune management dates for fisheries.

Hatchery production of fall chum salmon in Hood Canal is large compared to other locations in Washington or British Columbia. This hatchery production also had an effect on the identification of some fall chum salmon stocks in SASSI (WDF et al. 1993, Appendix 1—Hood Canal and Strait of Juan de Fuca, p. 42):

> The West Hood Canal fall chum stock is comprised of chum spawning in small, independent tributaries located on the west side of the canal. These fish were identified as a single stock for two reasons: 1) The proximity of many of these streams allows for the possibility of commingling of the spawners on the spawning grounds, and 2) large hatchery plants and/or major egg box projects using Hood Canal (Hoodsport) Hatchery stock are ongoing in these streams and have established runs with a similar genetic makeup. The Hood Canal Hatchery stock originated from Finch Creek, one of the west-side independent tributaries. Accordingly, these fish were identified as a mixture of native and non-native fish.

Less run-timing information is available on early fall-run chum salmon in Hood Canal (Table 4, Fig. 7c) (WDF et al. 1993) than for most other chum salmon populations. The SASSI report provided "terminal run," "river entry," and "spawning" timings when available for each stock listed in the survey; however, for early fall-run fish in Hood Canal, this information was reported in SASSI for only one of the five early-returning groups reported. For late fall-run fish, all groups have timing reported for all three factors. The early-run group with the most complete record of run timing is the West Hood Canal fall-run chum salmon. These fish are reported to enter the terminal areas between mid-October and late November, begin up-river migrations between early November and mid-December, and spawn between mid-November and mid-December. Only spawn timing is reported for all other early fall-run fish, which is thought to occur from mid-October to about mid-December (WDF et al. 1993). Based upon this reported time of spawning, there is often no clear distinction between "spawn time" in early- and late-run fall chum salmon in Hood Canal. All late fall-run chum salmon begin to enter terminal areas in mid-October and spawn from mid-December to late January (WDF et al. 1993). For example, "Dosewallips Late Fall Chum" stock (WDF et al. 1993, Appendix 1—Hood Canal and Strait of Juan de Fuca, p. 80) reach the entrance to Hood Canal (Terminal Area 12) from mid-October to mid-December, but do not enter the river to spawn until mid-November to mid-January. An early fall run of chum salmon ("Northeast Hood Canal Fall Chum") (WDF et al. 1993), which spawns in a broad swath approximately opposite the mouth of the Dosewallips River, is reported to spawn between mid-November and mid-December (WDF et al. 1993). Clearly, the spawning times of these early and late fall-run fish can overlap.

Washington and Oregon coast run timing—Chum salmon appear to return to tributaries on the Washington and Oregon coasts in October and November and to spawn as late as December, but data are limited (WDF et al. 1993, Kostow 1995). Long-term run times for coastal Oregon chum salmon are available only for Tillamook Bay, which fish enter in October and November. However, spawning may continue into late December, as it does on the Washington coast (Henry 1954, Cooney and Jacobs 1994). Smaller runs of chum salmon are reportedly found farther south in Netarts Bay, Nestucca River, Yaquina River, Siuslaw River, and Coos Bay, although run times for these fish are not available.

Columbia River run timing—Chum salmon are limited to tributaries below Bonneville Dam, with the majority of fish spawning on the Washington side of the Columbia River. Chum salmon have been reported in October in the Washougal, Lewis, Kalama, and Cowlitz Rivers in Washington and to the Sandy River in Oregon (Salo 1991). Only three Washington runs (Grays River, Hamilton Creek, and Hardy Creek) were listed in the SASSI report, and all return in about October (the peak is mid-November), a run time similar to that of chum salmon in rivers along the Washington coast (Table 4) (WDF et al. 1993). Grays River chum salmon enter the Columbia River from mid-October to mid-November, but apparently do not reach the Grays River until late October to early December. These fish spawn from early November to late December. Fish returning to Hamilton and Hardy Creeks begin to appear in the Columbia River earlier than Grays River fish (late September to late October) and have a more protracted spawn timing (mid-November to mid-January). The Oregon Department of Fish and Wildlife (ODFW) cited 25 locations in that state where chum salmon spawn in the lower Columbia River, but run times for these fish are unavailable (Kostow 1995).

Marine Travel Time to Spawning Grounds

Chum salmon in different runs may swim at different speeds during their return migrations from oceanic feeding grounds (Salo 1991). However, an insufficient number of studies have been conducted to determine run-specific travel times. For example, Lyamin (1949) found that chum salmon tagged at different locations migrated between 300 km in 15 days (20 km/day) and 1,200 km in 15 days (80 km/day), whereas Shmidt (1947, cited in Lyamin 1949) reported maximal speeds of 43-63 km/day. Fish tagged in British Columbia traveled at a rate of 14 km/day from Johnstone Strait to the mouth of Fraser River (Anderson and Beacham 1983).

An additional complication in calculating stock-specific timing of freshwater entry is “milling” (Hunter 1959, Koski 1975): All species of anadromous salmonids may delay their entry into freshwater or into terminal spawning areas as they approach the mouths of their natal rivers at the end of the marine phase of their life cycle. For example, some tagged chum salmon in Skagit Bay remained in the estuary for up to 21 days (Eames et al. 1981). Also, as noted above, the average time between tagging at the mouth of the Stillaguamish River and recovery of marked carcasses on the spawning grounds was 31 days (Hiss et al. 1982a, b). Some of these tagged fish spent more than 6 weeks in freshwater before spawning (Hiss et al. 1982a, b).

Chum salmon are particularly vulnerable to fisheries and natural predation during this period of milling. For example, Evenson and Calambokidis (1993) found that the number of harbor seals at Dosewallips State Park in Hood Canal, Washington, was highest when adult chum salmon were present. Fisheries aimed at other species or more plentiful hatchery stocks of chum salmon (as described by Tynan (1992) and Cook-Tabor (1995) for Hood Canal) can also incidentally harvest fish milling in Hood Canal. Adult chum salmon concentrate in such large numbers in estuaries and off the mouths of small streams that their dorsal fins break the water’s surface. The cause of milling is unclear, although maturation may play a role, but often fish will move into a river only after a period of rain, when water flow increases. For whatever reason, the period of milling becomes shorter as the spawning season progresses (Salo 1991).

Straying

In the past, observations of chum salmon behavior have suggested to some that the species may have a greater tendency to stray than other species of *Oncorhynchus* (reviewed in Lister et al. 1981). There are a number of reasons why this perception could have developed. 1) *O. keta* spawn near the mouths of streams, and their young do not conduct the long, downstream, freshwater migrations that are common in some salmonid species. It has been hypothesized that juvenile salmonids who do conduct long, freshwater migrations may sequentially imprint on a chain of migratory cues that assist them as adults in returning to their natal streams (Lister et al. 1981). 2) Observations of the reluctance of adult chum salmon to surmount small falls or rapids have suggested to some that they may go upstream as far as they can toward natal areas, but once they reach a barrier, they spawn. 3) Adult chum salmon also are more sexually mature when they enter freshwater than most species of anadromous salmonids and may not be able to endure delays in reaching their natal areas; if delayed, they may be forced to spawn at the first available location. 4) It has been observed (McNeil 1969, Lister et al. 1981) that, when spawning densities of chum salmon become high in some rivers (especially those with hatchery runs), straying to nearby streams may increase.

Only a few experimental studies have directly addressed this issue (Lister et al. 1981; Quinn 1984, 1993; Salo 1991; Altukhov and Salmenkova 1994; Tallman and Healy 1994), and these studies have concluded that under normal circumstances, straying in chum salmon is no greater than in any other species of *Oncorhynchus*. Lister et al. (1981) reviewed experimental studies on straying in all species of Pacific salmon, but found only a few unpublished reports that used chum salmon as the study species (Table 8). In a review of the life history of chum salmon, Salo (1991) found that the only information relevant to straying in chum salmon was collected incidentally from studies designed for other purposes. Genetic studies of straying for all species of Pacific salmon are limited (reviewed in Quinn 1984, 1993, 1997), and only one experimental study of chum salmon straying has been published (Smoker and Thrower 1995).

Mark-release and recapture studies—The first reported experimental mark-release study to document straying in chum salmon was conducted in Japan by Sakano (1960, cited in Okazaki 1982a). In this study, over 2 million native, fin-clipped chum salmon fry were released into the Tokoro River on northern Hokkaido Island and into the Chitose River on the southern part of the island. Both the Tokoro and Chitose Rivers are large rivers that empty directly into the sea, and “straying” in this study is defined as the portion of fish that were captured in a river system other than their native Tokoro or Chitose Rivers. The straying rate was estimated to be only 2% for fish released into the Tokoro River, with most of the fish recovered in their natal stream. However, some strays were recovered as far as 350 km away in the Teshio River on western Hokkaido Island. Fish released into the Chitose River strayed at a rate as high as 10%, with marked fish recovered as far as 2,000 km away on Honshu Island. However, this rate of straying among fish released into the Teshio River has perhaps been underestimated, due to an inadequate geographic sampling range; most of the rivers monitored were on Hokkaido Island, while many strays were incidentally recovered far to the south on Honshu Island (Okazaki 1982a).

Salo (1991) collated information on straying and homing in chum salmon from studies designed to gather other kinds of information. For example, Salo and Noble (1952a, b; 1953) marked juvenile (dorsal fin marks) and adult chum salmon (fin clips) at the mouth of Minter Creek, Washington for 2 years and found no marked adults in nearby streams. In another study cited by Salo (1991), Wolcott (1978) released fry from the Quilcene National Fish Hatchery into Walcott Slough, near Brinnon on Hood Canal, and found no strays in nearby streams. The authors concluded that adults returned “unerringly” to traps on the slough, even though a natural run did not exist there. In his own studies, Salo (1991) observed that adult chum salmon returned to a weir trap set at the outlet of a small stream from which the fish had emigrated as fry and not to a nearby trap set on the mainstream. These results were taken by Salo (1991) as support for strong homing behavior in chum salmon.

Table 8. Summary of juvenile marking and adult recovery studies used to estimate stray rate in chum salmon (Lister et al. 1981).

Date of study	Brood years marked	Type of mark	Brood source	Rearing site	Life stage released	Release site	Number of fish marked	Estimate of straying	Reference
1951-55	1?	fin-clip	unknown	hatchery	unknown	Tokoro R., Japan	2 million total	2%	Sakano 1960
1951-55	1?	fin-clip				Chitose R., Japan		10%	
1974-76	2	fin-clip	Disappearance Cr., Prince of Wales I., AK	hatchery	fed fry	Disappearance Cr.	109,303	0%[a]	Freitag and Ward 1981 (reported in Lister et al. 1981)
1975-77	2	fin-clip	Disappearance Cr., Prince of Wales I., AK	hatchery	fed fry	Beaver Falls Hatchery, Revillagigedo I., AK	101,463	8.80%	Freitag and Ward 1981 (reported in Lister, et al. 1981)
1976-79	1	fin-clip	Inches-Barnes Cr., Fraser R., B.C.	on site	unfed fry	Inches-Barnes Cr.	275,305	0.072%[b]	Foye 1981 (reported in Lister et al. 1981)
1973-78	2	fin-clip	Blaney Cr., Fraser R., B.C.	on site	unfed fry	Blaney Cr.	252,900 in 1973	45.7%	Harding 1981 (reported in Lister et al. 1981)
							190,033 in 1974	9.3%	
1981-88	2	coded micro-wire tags	2 stocks from Juneau, AK	hatchery	age-0 fry	Juneau, AK	20,000 per yr.	0%	Smoker and Thrower 1995

[a] Only 17 fish were recovered at release site.

[b] Only age-3 fish recoveries examined; normally age-4 returns comprise 60% of escapement.

In their review of straying in Pacific salmon, Lister et al. (1981) identified one unpublished mark-and-release study on chum salmon in Alaska and two studies from the Fraser River in Canada. These studies were summarized in a common format and published as appendices by Lister et al. (1981). In the Alaskan study, Freitag and Ward (reported in Lister et al. 1981) (Table 8) designed a study to evaluate imprinting in off-site rearing facilities: They reared chum salmon to the fry stage in two hatcheries, then released some into their natal stream and others from a hatchery. Straying was defined as occurring when fish were captured at sites other than where they had been released as juveniles. None of the fish released into their natal stream were found in nearby streams. However, these results were inconclusive, because only 17 of 100,000 marked fish returned over the 2 years of the study. An 8.8% straying rate, based on returns of 56 fish (0.12% of the total release), was reported for the fish released from the hatchery.

The two studies identified by Lister et al. (1981) on straying in chum salmon in the lower Fraser River did not involve transfers of fish from one area to another. Straying was also defined in these studies as occurring when fish were captured in streams other than where they had been released as juveniles. In the first study, fish from Inches-Barnes Creek, a tributary to the Fraser River, were spawned and eggs reared in a hatchery on the creek (Foye, reported in Lister et al. 1981). Juveniles were fin-clipped as fed fry and released into the creek. The returning adults strayed at a rate of 7.2% to streams within 2 km of the natal stream. In another study, adults from Blaney Creek, a tributary to the North Alouette River on the lower Fraser River, were spawned and their eggs incubated at a facility on-site (Harding, reported in Lister et al. 1981). Juveniles were fin-clipped and released into Blaney Creek (252,900 were released in 1974 and 190,033 in 1975). A large difference in adult straying was found between the 2 years, with 45.7% straying in 1977 but only 9.3% in 1978 (Harding 1981, cited in Lister et al. 1981). Harding hypothesized that the high straying rate in 1977 resulted from a large escapement that saturated available spawning sites in Blaney Creek, forcing many fish to seek other areas to spawn. Blaney Creek had a spawning density of 1.7 females/m^2 in 1977, but only 0.2 females/m^2 in 1978 (Banford and Bailey 1979). While spawner densities vary greatly among spawning areas, the density in 1977 was more than twice the optimal density for chum salmon suggested by McNeil (1969).

Lister et al. (1981) reviewed almost 400 studies on straying in Pacific salmon, including the ones above on chum salmon, and found a small but measurable straying rate in almost every study. They concluded that the average straying rate of adults released as smolts from the hatchery where they had been reared was 2.6% across species. However, straying rates varied widely under different conditions (such as site of release or life-history stage of fish at release). Lister et al. (1981:39) concluded that "relatively large adult returns (of chum salmon) to sites with hatchery facilities could result in increased straying to nearby streams. This pattern was evident from chum salmon marking studies conducted to evaluate hatchery operations."

In Washington, Eames et al. (1981, 1983) tagged adult chum salmon in 1976 and 1977 in northern Puget Sound near Port Gardner, Bellingham Bay, and Skagit Bay. However, the primary purpose of these studies was to estimate run-size, not straying. In this study, "strays" were defined as "tagged fish which moved to other river systems or which were taken in the various [out of basin or nonreported] fisheries" (Eames et al. 1981:147). However, the fish tagged in this study were caught in the estuary, and it is unlikely that all the fish tagged were native to the drainage. With these caveats, the researchers estimated straying rates between 6.9% and 63.2% for the fish in their study.

Also in Washington, observations by WDFW biologists (Fuss and Hopley 1991), during a study of five consecutive broods of coded-wire tagged chum salmon released from the Hood Canal Hatchery, revealed very few stray fish in streams located in Hood Canal.

Other observations have shown that chum salmon periodically appeared in some southern Oregon and California streams, with few if any known chum salmon spawning at locations nearby (Moyle et al. in press). It therefore appears that chum salmon either stray thousands of kilometers from the nearest spawning areas in some years, or they maintain spawning populations in California and southern Oregon in areas that have been poorly surveyed.

Genetic studies on straying—Bams (1976) published a study on pink salmon that suggested impaired homing in transplanted fish and in hybrids between populations. This hypothesis was tested with chum salmon by Smoker and Thrower (1995). For two years they crossed fish from two populations of chum salmon, tagged the offspring with coded microwire tags, and released about 20,000 age-0 fry per year from control and treatment groups up to 65 km from their natal streams (Table 8). Recoveries were monitored for 3 years per brood year. None of the 611 tagged fish that were recovered strayed from the native (non-hybridized) group, and only one stray was recovered from the hybridized group. Although the number of fish released was small, the results support the hypothesis that straying rates for native and transplanted hatchery chum salmon are not necessarily great.

However, even small straying rates from large hatchery releases may result in a high proportion of hatchery fish in small, natural populations. This can substantially affect natural populations, particularly if the stray fish are of non-native origin. (Jacobs 1988, Thorpe 1994). Many small populations of summer-run chum salmon in southeast Alaska have escapements of less than 5,000 adults, and hatchery programs in some areas (see "Artificial Propagation," p. 108) have released more than 100 million fry per year, producing returns approaching 1 million fish per year. In recent years, otolith marking has been used on many of these hatchery releases, with extensive monitoring of local wild populations for hatchery-marked fish. While no results have yet been published, early returns indicate that only a small proportion of the total return of hatchery fish is straying into local streams, although strays may represent up to 50% of the fish in some of these streams (Thrower[19]).

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[19] Frank P. Thrower, NMFS Auke Bay Laboratory, 11305 Glacier Highway, Juneau, Alaska 99801-8626. Pers. commun., November 1995.

Spawning behavior

In freshwater, a variety of population-specific reproductive behaviors have been described for chum salmon in Asia (e.g., Sano and Nagasawa 1958) and North America (e.g., Johnson et al. 1971; Tautz and Groot 1975; Duker 1977, 1982; Helle 1981; and Schroder 1973, 1982) that may act to isolate populations. For example, Duker (1982) described a model for the pre-spawning phase of courtship that involved mate recognition based on a variety of auditory, tactile, and visual clues (e.g., species-specific body coloration, the black and white pigmentation pattern inside the mouth) (Schroder 1981, Duker 1982). However, studies to determine whether these behaviors or characteristics act to reproductively isolate particular populations or runs of chum salmon from one another have not yet been made.

Spawning Ground and Redd Characteristics

There is extensive literature on selection of spawning sites and redd characteristics for chum salmon (reviewed in Bakkala 1970, Smirnov 1975, Salo 1991), which indicates that under specific circumstances chum salmon spawn in a wide variety of locations. In general, chum salmon are reported to spawn in shallower, slower-running streams and side channels more frequently than do other salmonid species, perhaps to avoid competition with pink salmon (Bakkala 1971, Smirnov 1975, Salo 1991). In Asia, there are also extensive differences reported between seasonal run types, with summer chum salmon reported to spawn in deeper waters and higher velocities than fall chum salmon (Sano and Nagasawa 1958, Soin 1954, Smirnov 1975, Salo 1991), even though Smirnov (1975:50) reported that the “autumn chum is larger than the summer one and its redds are also larger.”

Smirnov (1975) suggests that the differences in physical parameters between the two run times of chum salmon in the Russian Federation may be caused by interactions with pink salmon. Fall chum salmon migrate farther inland than pink salmon, but summer chum and pink salmon spawn in similar areas. Both species spawn within about 100 km of seawater, although in most years, the spawning grounds of the two are widely separated: Summer chum salmon spawn in the lower and middle reaches of rivers, whereas pink salmon usually migrate into the upper reaches. But even in years when both pink and summer chum salmon are abundant, and their spawning grounds are close together in the middle reaches, the two species maintain separation by choosing different locations for their redds. Smirnov reported that in these circumstances, summer chum, unlike pink salmon, spawn in deep, lower-velocity pools, away from riffles and closer to river banks.

The velocity of water in spawning areas has been a widely studied area of research. In the Amur River Basin, water velocities of 10-80 cm/sec were measured over summer chum salmon spawning sites, and velocities of 10-30 cm/sec in riffles over fall chum salmon spawning grounds. However, fall chum salmon also spawned in pools in this region where the velocity was reported to be quite insignificant (Soin 1954, Smirnov 1975). On Hokkaido Island, Sano and Nagasawa (1958) also found that fall chum salmon selected spawning areas with lower water velocities (10-20 cm/sec) than did summer chum salmon in the Amur River area. These differences in the physical characteristics of spawning areas may act to isolate populations or runs in the same river (Salo 1991).

In Washington, Johnson et al. (1971) measured water velocities near 1,000 chum salmon redds and found that velocities where fish spawned varied from 0.0 to 167.6 cm/sec and that over 80% of the fish spawned in velocities between 21.3 and 83.8 cm/sec. This range is similar to that found in other species of salmon. For example, velocities of streams where chinook salmon spawn are reported to range from 10 to 150 cm/sec. Johnson et al. (1971) also attempted to correlate abundance indices of chum salmon in Washington with environmental variables such as stream discharge, velocity, and surface water temperatures, but found no relationship between run size and these variables. He concluded that he was unable to measure or to isolate the critical areas in which environmental factors influence run size.

Subgravel flow (upwelled groundwater) may also be important in the choice of redd sites by chum salmon. Salo (1991:240) reported that “chum salmon prefer to spawn immediately above turbulent areas or where there was upwelling.” Sano (1966:46), in a summary of available information on Far Eastern chum salmon, reported that throughout the Russian Federation and on Hokkaido Island in Japan, autumn chum salmon “utilize mostly spring areas of upper tributaries, [as] damage by freezing and other severe winter conditions is relatively minor in most years.” However, Sano also notes (p. 46), based on studies by Smirnov in the 1940s, that “summer chum salmon spawn earlier in the season, and they do not particularly choose spring areas.”

Smirnov (1975) noted that “the summer spawning chum from Kamchatka gravitates towards the places of emergence of ground water” (p. 50) and that in the redds “of the summer Amur and Sakhalin chum the eggs are mainly flushed by the so-called subterranean water, replenished by the infiltrating streams water” (p. 49). Smirnov further noted that the summer chum salmon in the Amur River area began to spawn from August to September during the warmest time of the year when water temperatures fluctuated from 9.8 to 13.6°C. He reported that incubation remained above 3°C through October and then dropped to zero.

Smirnov (1975:50) also noted that in many areas of the Russian Federation and on the Islands of Hokkaido and Honshu in Japan, fall chum salmon reproduced in localities supplied with groundwater even when temperatures did not go below freezing: “In limnocrenes, or spring-fed spawning creeks on the basin of the Amur, the summer temperatures do not exceed 11-12°C; in the winter they fluctuate within the limit 2.5-5°C (on Hokkaido spawning grounds, sometimes higher).”

Biologists at WDFW reported that chum salmon in Washington do not preferentially choose areas of upwelling groundwater for redd construction; rather they suggest that chum salmon in Washington “most commonly” use “areas at the head of riffles” (Crawford 1997:4). As reported in Turner (1995) and repeated in Crawford (1997:4):

> We [WDFW] are unaware of any evidence that Washington chum salmon specifically select spawning sites with upwelling ground water. . .Washington chum salmon would not seem to need this particular adaptation. Upwelling ground water would be an advantage for summer chum . . .

> but most of the streams involved do not seem to match the definition of ‘streams with cool, upwelling ground water.’ The summer chum streams of the Strait of Juan de Fuca and the Kitsap Peninsula are characterized by low summer/fall flows and likely experience elevated stream temperatures during the summer chum spawning period. In fact, a **lack** of ground water influence may pose a particular problem for summer chum during periods of summer drought as has occurred in western Washington in recent years. A more likely reason that summer chum spawn where they do is the low flow condition of spawning streams at the time of return, confining these fish to the lower reaches of the streams.

Fecundity and egg size

Fecundity and egg size of chum salmon have been extensively reported in the literature (reviewed by Bakkala 1970 and Salo 1991); however, in most cases, comparative regional or run-type information by age, size, or relative survival rates are lacking. Salo (1991:244) considered fecundity data unreliable for comparison among regions and among runs, because it was “not certain how representative the samples [were] for the reported geographical regions and rivers of origin.”

Nevertheless, some latitudinal and run-type trends were evident for absolute fecundities (number of eggs/female) and relative fecundities (number of eggs/cm of length) (Salo 1991). One pronounced trend was that the ranges of absolute fecundity for both individual and annual means were higher and larger among Asian chum salmon runs than among North American runs. For example, individual fecundities from numerous studies, summarized by Salo (1991), varied from about 900 to 8,000 eggs per female in Asian chum salmon, but only from 2,000 to 4,000 eggs per female in North American chum salmon. The annual mean of these fecundities ranged from about 1,800 to 4,000 eggs per female in Asian chum salmon and from 2,000 to 3,600 eggs per female in North American chum salmon. Differences also existed among northern and southern populations in the two regions. Rivers in northern Asia had generally higher relative fecundities than rivers in southern Asia. However, in North America the opposite was true: Fall-run fish from southern rivers tended to have higher relative fecundities than fall-run fish from northern rivers. The different regional trends are difficult to interpret because the various studies were not always comparable. However, Salo (1991) suggested that differences may be related to decreasing survival rates from south to north in Asia, and from north to south in North America.

Fecundity differences between run times—Differences in both relative and absolute fecundities have been extensively documented in fish with different run times (summer- and fall-run chum salmon) in the Amur River (Lovetskaya 1948; Birman 1951, 1956; Svetovidova 1961; Sano 1966; Kulikova 1972), and to a lesser extent in the Yukon River (Andersen 1983, Trasky 1974) and in Hood Canal (Koski 1975). Summer-run chum salmon generally spawn within 100 km of the mouths of both the Amur and Yukon Rivers, whereas some stocks of fall-run fish historically migrated hundreds of kilometers upriver to spawn. Interestingly, summer-run fish in the Amur River have higher fecundities on average than do fall-run fish spawning in the lower river, although in the Yukon River the opposite trend appears. However, the difference between runs in the Yukon River is not large, and few data are available to compare fecundities between the two run times (45.5 eggs/cm, N=23 for summer-run fish; and 41.2 eggs/cm, N=24 for fall-run fish).

Fecundity and egg size for summer- and fall-run chum salmon in Hood Canal were measured in Big Beef Creek by Koski (1975) in 1967-69. He found that summer- or early-run females were smaller for a given age than in late-run fish (males were of similar size), but early-run fish had slightly larger fecundities per body length and per weight. Early-run fish had on average 50 eggs per cm of body length compared to 46 eggs/cm in fall-run fish. Early-run fish also averaged about 526 g less than later-returning fish, but had about 100 more eggs. Koski also found that early-run fish had larger eggs than late-returning fish of the same body size.

Incubation and time of emergence

The rates of chum salmon embryonic and juvenile development tend to decline at high latitudes in both Asia and North America, but vary among populations within an area, apparently because of adaptation to local environmental conditions (e.g., summer-, fall-, and winter-run chum salmon in southern Puget Sound or Hood Canal) (Bakkala 1970, Salo 1991). One of the earliest detectable differences between chum salmon in different areas is the time of hatching of eggs and the emergence of alevins from gravel. Differences between areas are caused by physical factors such as stream flow, water temperature, dissolved oxygen, and gravel composition, and by such biotic factors as genetics, spawning time, and spawning density, all of which can affect survival (reviewed in Bakkala 1970, Salo 1991).

The rate of embryonic development in chum salmon is influenced most by water temperature (reviewed in Bakkala 1970, Koski 1975, Salo 1991). The amount of heat, measured in thermal units (TUs), required by fertilized chum salmon eggs to develop and hatch is about 400-600 TUs, and the heat required to complete yolk absorption is about 700-1,000 TUs. Lower water temperatures can prolong the time required from fertilization to hatching by 1.5-4.5 months. For example, fertilized eggs hatch in about 100-150 days (400-600 TUs) at 4°C, but hatch in only 26-40 days at 15°C.

The time to hatching also varies among populations and among individuals within a population (Salo 1991). Koski (1975) found differences in the time to hatching between early- and late-returning chum salmon at Big Beef Creek, a tributary to Hood Canal. For 2 years (1968-1969 and 1969-1970), early-returning (peak September) and late-returning (peak late November or December) fish spawned and their offspring were reared in spawning channels in the creek. Fry emerged from February to June, but the timing of fry emergence differed between early- and late-returning fish by an average of 35 days each year. Early-run fish took longer to hatch, and this difference between the two runs was consistent from year to year. However, the longer hatching time of early-returning spawners led to fry with lower average weight and less lipid content than fry of late-returning spawners. Lower weight and fewer food reserves in early-

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[20] Thermal or temperature units (TUs) are the average number of degrees above 0°C during a 24-hour period.

return fry may decrease their chances of survival during early life history. The difference in incubation times for eggs from these early- and late-returning fish suggested a genetic difference between the two runs, and Koski (1975) concluded that natural selection apparently acted on hatching times: Fry tended to emerge when they had their best chances of surviving in streams and estuaries.

Changes in hatching times due to adaptation to cold water have also been found for chum salmon in the Susitna River, Alaska (Wangaard and Burger 1983) and in the Amur River in Asia (Disler 1954, cited in Bakkala 1970). In these populations, low incubation temperatures resulted in faster embryonic development than for embryos in other populations at the same temperature. In Canada, however, Beacham and Murray (1986) failed to find differences in hatching times among eggs from adults with early, middle, and late spawning times that had been incubated at constant temperatures of 4, 8, and 12°C. Nevertheless, the time of emergence in that study depended on the timing of spawning: Earlier-spawning fish laid larger eggs that took longer to develop than did smaller eggs from later-spawning fish.

Other factors, such as dissolved oxygen, gravel size, salinity, nutritional condition, and even the behavior of alevins in the gravel, can also influence the time to hatching, emergence from the gravel, or both (reviewed in Bakkala 1970, Schroder et al. 1974, Schroder 1977, Salo 1991). For example, Fast and Stober (1984) found that developing chum salmon embryos in small coastal streams required less oxygen than had been reported for either coho salmon (*O. kisutch*) or steelhead (*O. mykiss*), but it is unknown to what extent chum salmon in different areas vary in their oxygen requirements. The relative importance of various factors influencing early development in different populations has not been evaluated.

However, despite a large amount of variability in incubation environments, even over short distances, chum salmon display a variety of developmental responses that result in similar emergence and outmigration times among fry within an area. Variability in some of these responses appears to reflect differences among individual fish, but it also reflects differences among populations in adult run and spawning times, egg size, and temperature-development requirements.

Downstream movement

Observations of chum salmon fry are often more difficult to make than are observations of juveniles of other salmonids because chum salmon outmigrants 1) are smaller than outmigrants of other salmonids, 2) migrate at night, 3) usually have shorter distances to migrate to reach saltwater than do other species, and 4) do not school as tightly as some other salmonids (e.g., pink and sockeye fry) (Salo and Bayliff 1958, Beall 1972, Koski 1975, Seiler et al. 1981, and reviewed in Salo 1991). Moreover, some chum salmon fry outmigrate in conditions less conducive to scientific observation. For example, observation of outmigrating chum salmon fry in northern Russian rivers draining into the Arctic Ocean is obscured by ice on the rivers at that time of year (Sano 1966, 1967).

Nonetheless, several key facets of fry outmigration are known (Table 9). Downstream migration may take only a few hours or days in rivers where spawning sites are close to the mouth of the river, or it may take several months, as in the Yukon and Amur Rivers, where spawning sites are located hundreds of kilometers upriver. The timing of outmigration is usually associated with increasing day length, warming of estuarine waters, and high densities of plankton (Walters et al. 1978). Juvenile chum salmon at southern localities, such as those in Washington and southern British Columbia, migrate downstream earlier (late January through May) than do fry in northern British Columbia and southeastern Alaska (April to June) (Table 9).

In the Yukon and Noatak Rivers in northern Alaska, chum salmon fry migrate downstream beginning in late May, with the breakup of river ice. Outmigration continues until fall, with peak movement in June and July (Martin et al. 1986) (Table 9). However, several exceptions to this general pattern can be found. For example, Koerner (1993) reported that in Fish Creek, a tributary of the Salmon River near Hyder, Alaska, chum salmon fry outmigrated over an extended period from late February through May. Chum salmon in this creek also spawned over an extended period from mid-June through October, which may have contributed to the long period of emergence from the gravel and outmigration (Helle, footnote 14).

Several cues influence the timing of downstream migration, resulting in considerable variability in migration timing. These cues include time of adult spawning, stream temperatures during egg incubation and after hatching, fry size and nutritional condition, population density, food availability, stream discharge volume and turbidity, physiological changes in the fry, tidal cycles, and day length (Simenstad et al. 1982, Salo 1991). In the Russian Federation, Soldatov (1912, cited in Smirnov 1975) found that chum salmon outmigrations did not always immediately follow emergence; juveniles in many rivers remained up to 3-4 months in the river and grew to a considerable size before outmigration (Kostarev 1970, as cited in Salo 1991). In Washington, chum may reside in freshwater for as long as a month (Salo and Noble 1953, Bostick 1955, Beall 1972). Juvenile residence times in freshwater longer than a month have also been reported in the mainstems of the Skagit (Dames and Moore 1976) and Nooksack (Tyler 1964) Rivers.

Estuarine Life History

Chum salmon juveniles, like other anadromous salmonids, use estuaries to feed before beginning long-distance oceanic migrations. However, chum and ocean-type chinook salmon usually have longer residence times in estuaries than do other anadromous salmonids (Dorcey et al. 1978, Healey 1982).[21] The period of estuarine residence appears to be the most critical phase

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[21] Healey (1982) found that chinook salmon (of all salmonid species) depend most on estuarine habitat, since all chinook life-history types feed and grow for some time in estuaries (unlike stream-type fry, ocean-type chinook fry move quickly to salt water after emerging and depend on estuaries for nursery habitats). Lake-type sockeye and pink salmon depend on estuaries the least of anadromous salmonids.

Table 9. Seasonal timing of chum salmon fry migration from freshwater streams to seawater in Asia and North America.

Location	Beginning of run	End of run	Peak of run	References
Kamchatka	early April	June	late April to early May	Semko 1954
Okhotsk area	May	July	late June	Volobuyev 1984
Hokkaido area	March	June	April to late May	Kobayashi and Ishikawa 1964, Kobyashi et al. 1965, Sano 1966, Kobayashi and Kurohagi 1968
Yukon River	late spring	autumn	June and July	Martin et al. 1986
Noatak River	late spring	autumn	mid-summer	Merritt and Raymond 1983
Olsen Creek, Prince William Sound, Alaska	May	June	mid-May	Kirkwood 1962
Taku River, southeast Alaska			early May	Meehan and Siniff 1962
Skeena River, BC	mid-March	mid-April		McDonald 1960
Hooknose Creek, BC	late April	early May		Hunter 1959
Fraser River, BC	February	June	mid-March and late April	Todd 1966, Beacham and Starr 1982
Nooksack, River, WA	April	June		Tyler and Bevan 1964
Skagit River, WA	early Feb.	late May	March/April	Stober et al. 1973
Skagit River, WA	April	June		Davis 1981
Duwamish River, WA	Jan.-Feb.	Late May	April	Bostick 1955
Minter Creek, southern Puget Sound, WA	late January to early Feb.	late April to late May	mid-March	Salo and Noble 1953, 1954
Big Beef Creek, Hood Canal, WA	February	June	April and May	Koski 1975
Satsop River, Grays Harbor, WA			late April	Brix 1981
Humptulip River, Grays Harbor, WA			late April	Brix 1981

in the life history of chum salmon and appears to play a major role in determining the size of the subsequent adult run back to freshwater (Mazer and Shepard 1962, Bakkala 1970, Mathews and Senn 1975, Fraser et al. 1978, Peterman 1978, Sakuramoto and Yamada 1980, Martin et al. 1986, Healey 1982, Bax 1983a, Salo 1991). Bax (1983b) determined that the extent of juvenile mortality within 4 days after a hatchery release into the Hood Canal estuary was 31-46%. The most important determinant of estuarine survival may be the timing of entry into saltwater because of the strong seasonality of plankton in estuaries (Gunsolus 1978, Helle 1979, Gallagher 1979, Simenstad and Salo 1982).

For these reasons, the estuarine life-history phase has been the most intensely studied period of chum salmon early life history. In all countries with large chum salmon hatchery programs, research has focused on determining the optimal size and time for release of juvenile chum salmon to enhance adult returns. How changes in estuaries affect the use of estuaries by chum salmon, and how such changes influence the time of seawater entry, run and spawn timing, and growth and maturation, may be important in delimiting ESUs.

Smoltification

This term denotes the life-history stage in which juvenile salmonids lose their parr marks, turn silvery, and migrate from freshwater into seawater. In summary, smoltification is perhaps the most intensively studied aspect of salmonid life history. Groot et al. (1995) contains an extensive review of both historical and recent studies on this process. Coho, stream-type chinook, lake-type sockeye salmon, and steelhead have a distinct “smolt” stage that can be identified visually among fry, parr, and fingerlings (Hoar 1958). Chum and pink salmon, however, do not have clearly defined smolt stages, but are nonetheless capable of adapting to seawater soon after emerging from gravel. Chum salmon also usually retain parr marks when they first enter seawater. In Japan, chum salmon fry weighing less than 2 g maintained normal levels of plasma sodium (Na^+) when they moved from freshwater into seawater (Iwata 1982). This ability, however, declines slightly with continued residence in freshwater. The capability of chum salmon fry for early osmoregulation in seawater may be important for adult homing back to natal streams. For example, hatchery coho salmon were 10 times less likely to stray within a river system if they were released into the river as fingerlings rather than as smolts (McHenry 1981, cited in Lister et al. 1981).

Timing of entry into estuary

Chum salmon fry from various spawning populations and adult runs in a river system tend to enter seawater at a similar time, one that maximizes their chance of survival. The most critical factor for survival of fry within an estuary appears to be fish size (Healey 1982). Similar entry timing into an estuary by fish from different rivers may be an adaptation to temporally variable food resources because plankton abundance in estuaries is highly seasonal (Gunsolus 1978, Helle 1979, Gallagher 1979, Simenstad and Salo 1982). Walters et al. (1978) developed a model of optimal timing for downstream migration and entry into estuaries to maximize early marine survival. The parameters for this model included 1) zooplankton production, 2) diet and growth of young salmon, 3) size-dependent survival, and 4) timing of fry outmigration into saltwater. For juvenile chum salmon in the Fraser River estuary, this model demonstrated a close correlation between timing of seawater entry and early chum salmon survival.

Duration of estuarine residence

Chum salmon juveniles of early-returning adults tend to enter estuaries before juveniles of late-returning fish (Koski 1975). Unlike some other species—sockeye salmon, for example, which move immediately into deep water after entering an estuary—chum salmon tend to remain in shallow eelgrass beds or other productive areas within the estuary from January to July (Healy 1982). Residence times are known for only a few estuaries, even though residence timing has been studied since the 1940s (reviewed in Congleton 1979, Healey 1982, Simenstad et al. 1982, Bax 1983a). Observed residence times range from 4 to 32 days, with a period of about 24 days being the most common (Table 10).

Migratory patterns within estuaries

Migration patterns of juvenile chum salmon have been studied intensively in areas such as Hood Canal by following marked juveniles from hatchery populations of fall-run chum salmon and by monitoring outmigration (Bax 1982, 1983a,b; Bax et al. 1979, Bax et al. 1980; Bax and Whitmus 1981; Schreiner 1977; Whitmus and Olsen 1979; Whitmus 1985; Salo et al. 1980). Some fry remain near the mouth of their natal river when they enter an estuary, but most disperse within a few hours into tidal creeks and sloughs up to several kilometers from the mouth of their natal river. In the Nanaimo and Fraser River estuaries, juveniles spend up to 3 weeks feeding in the inner estuary, with little local movement (Healey 1979, Levy et al. 1979). Chum salmon juveniles in the Nanaimo, Yaquina, Cowichan, and Courtenay estuaries are most abundant in nearshore areas during April and May, but are most abundant in the outer estuary during May and June (Myers 1980, Healey 1982).

Chum salmon fry show daily tidal migrations in the Fraser and Nanaimo Rivers, which have large deltas and marshlands (Healey 1982). However, fry in Hood Canal have not been observed to display daily tidal migrations (Bax 1983a), most likely because rivers entering Hood Canal do not have extensive delta or tidal marsh systems (with the exceptions of the Quilcene and Skokomish Rivers).

Although in general, movements of chum salmon fry in Hood Canal appear to follow a pattern that depends on the time of release from hatcheries, release time is not the only causative factor influencing migratory patterns (Bax 1982, 1983a). Chum salmon fry released into Hood Canal in early February and March have spread out over a large area, but fish released in April and early May tended to remain inshore initially, moving offshore in summer. These movements were apparently associated with prey availability. Fish initially fed inshore on epibenthic organisms, then offshore on plankton later in the season. Foraging success (growth), as well as

Table 10. Residence times (weeks) of juvenile chum salmon and other salmon species in Washington State estuaries. Maximum individual residence in days is indicated in parentheses. Average residence time per estuary for chum salmon is 10 weeks; average individual residence time is 24.5 days (from Simenstad et al. 1982).

Estuary	**Chum**	**Pink**	**Coho**	**Chinook**	**Reference**
N. Puget Sound					
nearshore	6	4	12	6	Miller et al. 1978
Bellingham Bay					
offshore	11+	---	11+	11+	Tyler 1964
offshore	7+	---	7	6+ (»20)	Sjolseth 1969
nearshore	6	4	6	6	Miller et al. 1978
					Fresh 1979
Skagit Bay/Port					
Kiket Island	13	13	12	15(50)	Stober et al. 1973
saltmarsh	14+, (4)			16+. (6)	Congleton et al. 1982
Elliott Bay					
lower Duwamish	9	---	5	8,(42)	Bostik 1955
estuary	---	---	---	8	Salo 1969
lower Duwamish	12	---	14+	16+	Meyer et al. 1981b
Commencement Bay					
estuary	8	16+	9	9+	Puyallup Indians unpubl. (cited in Simenstad et al. 1982)
Hylebos Waterway	9	---	---	8+	Meyer et al. 1981a
Nisqually Reach	17+	12	15,	11+	Fresh et al. 1979
Hood Canal	23(32)	18	15, (6)	13	Salo et al. 1980
Strait of Juan de Fuca	14	14	14	16+	Simenstad et al. 1982
Quillayute River	5, (32)	---	---	18+	
Grays Harbor	10	---	---		Wendler et al. 1954
Grays Harbor	10+,(»30)	---	12	29+,(»189)	Simenstad and Eggers 1981

age, appeared to be the major factors in offshore movements of chum salmon juveniles in the Strait of Georgia in early June and July (Healey 1980).

A seasonal change in the swimming speed of juvenile chum salmon was also observed in Hood Canal (Bax 1982). In February and March, chum salmon fry (<40 mm fork length) usually moved 8-14 km/day, but in May and June they moved 3-7 km/day. Fish released from the Hood Canal Hatchery at Hoodsport in June took 3 weeks to arrive at the mouth of Hood Canal (Bangor Annex), but arrived after only 1 week when released in April. However, this pattern may not be consistent from year to year: Bax (1982) found that in 2 of the 3 years of a study (1977-1979), average migration speed was lower in February than in March. Larger fish tended to move faster than small fish, but the overall rate of movement decreased as the season progressed (Bax 1983a).

Larger fish also tended to move out of an area first when both large and small chum salmon fry were simultaneously released from hatcheries on the Skokomish River in southern Hood Canal (Bax and Whitmus 1981, Whitmus 1985). In southern British Columbia, larger fish also tended to migrate offshore first, but by mid-July all chum salmon juveniles had left the estuaries, regardless of size (Healey 1980). A similar timing of outmigration was observed in the Yaquina River estuary in Oregon, except that most chum juveniles had moved out of the estuary by mid-May (Myers 1980).

Reasons for the differences in movement patterns among areas are unclear. One reason may be that genetically based physiological differences between runs produce different behavior patterns (Whitmus 1985). Migration may be facilitated by both active swimming and passive movement in currents, and seasonal changes in river discharge and surface flow in Hood Canal may contribute to different migration patterns among populations (Bax 1982). The rate of movement, especially early in the season, appears to be correlated with surface outflow in Hood Canal (Bax 1982, 1983a). Movement of chum salmon juveniles apparently is also influenced by the abundance of pink and chum salmon juveniles of the same size class in Hood Canal (Salo 1991).

Hood Canal fall-run chum salmon_Establishing riverine or estuarine residence times of hatchery fall-run chum salmon is particularly important because of possible overlap with summer-run chum salmon juveniles in Hood Canal. Chum salmon juveniles released from the Hood Canal and Quilcene Hatcheries in Hood Canal showed little delay in their migration out of Hood Canal, traveling in distinct groups past the Bangor Annex sampling site in the northern part of Hood Canal (Whitmus 1985). However, some portion of large and small hatchery chum salmon fry released at the same time from hatcheries in the southern part of Hood Canal resided in the large Skokomish River delta region for up to 4 weeks (Whitmus 1985). Although the hatchery fish released into southern Hood Canal were derived from the Hood Canal and Quilcene hatcheries, they not only had longer residence times near their release site but failed to pass the Bangor Annex as a distinct group (Whitmus 1985).

Hood Canal summer-run chum salmon—No experimental mark-and-release studies have been conducted on natural or fall chum in Hood Canal, including summer-run chum salmon. However, the outmigration of chum was monitored before the release of hatchery fish into Hood Canal, and small peaks of outmigrants have been observed in February and March at sites on both the east and west sides of Hood Canal (Bax et al. 1979, Bax et al. 1980, Bax 1982, 1983a). Juveniles from early-spawning adults at Big Beef Creek were observed passing Bangor in Hood Canal (Fig. 1) one week after peak outmigration from Big Beef Creek, but juveniles from late-run fish, which had emerged in April, took two weeks to cover the same distance (Bax 1982). These differences were interpreted to result from differences in surface outflow in Hood Canal rather than from any intrinsic behavior in the chum salmon juveniles (Bax 1982).

While these results indicate that summer-run chum salmon quickly migrate up the Canal and into the main body of Puget Sound, preliminary data from ongoing snorkel and beach-seine surveys by the U.S. Fish and Wildlife Service (USFWS) have revealed the presence of natural chum salmon juveniles in Quilcene Bay, Hood Canal, from mid-January to mid-April (Tabor-Cook et al.). These observations would suggest that either these fish emerge from streams over an extended period or that juveniles remain in Quilcene Bay for several weeks. Washington fisheries co-managers are currently conducting studies to clarify residence times and the timing of juvenile migration for summer-run juveniles in Hood Canal (Tynan[23]).

Based on the time when summer-run chum salmon spawn, emergence of fry would be expected at least a month prior to fall-run chum salmon emergence, but Koski (1975) found that summer-run chum salmon in Big Beef Creek delayed embryonic development by an average of 12 days compared to the length of time it took fall-run chum salmon to emerge from the gravel. However, in so doing, the fry apparently sacrificed their robustness (mass) and lipid reserves. Therefore, if size at ocean entry is similar for all chum salmon (Peterman 1978), summer-run chum salmon would be expected to spend more time in a nearshore estuarine environment, either Hood Canal or the main body of Puget Sound, until they reached this optimal size (Salo 1991).

Japan—In Japan, prey availability may also influence the estuarine migration patterns of juvenile chum salmon. The warm summer Oyashio Current off northern Japan moves inshore in May and June, forcing cold-water oceanic plankton populations to move far offshore: Many fish are then forced to move offshore also. Kaeriyama (1986, 1989) divided juvenile chum salmon from this region into three groups: 1) "river" type, which remain in the river until they are large enough to migrate offshore as the warm current approaches; 2) "foraging" type, which move into offshore feeding areas in February and March before the warm currents arrive; and 3) "escape

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[22] C. Tabor-Cook, T. Kane, and D. Zajac, USFWS Western Washington Fisheries Resource Office, 2625 Parkmont Lane, Bld. A, Olympia, Washington 98502. Pers. commun., November 1995 and January 1996.

[23] T. Tynan, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., June 1996.

foragers," which migrate to low-salinity inshore and estuarine waters, where they feed until the Oyashio Current retreats in June and July.

Growth and feeding in estuaries

Growth greatly influences the survival and migration timing of juvenile chum salmon. Chum salmon grow rapidly in estuaries, and even though growth rates vary substantially between areas, there are some consistent patterns. Salo et al. (1980) and Bax and Whitmus (1981) measured growth of chum salmon fry in Hood Canal and found a daily gain of 5.7-8.6% body mass, but found gains as high as 10.1% body mass in the first 4 days of estuarine residence. Chum salmon in the Skagit River salt marsh grew 6% of their body mass per day (Congleton 1979, Congleton et al. 1982). Marked chum captured in the Nanaimo River estuary on Vancouver Island also grew at about 5.7% of their body mass per day (Healey 1979), whereas unmarked chum salmon in the Nitinat Lake (British Columbia) estuary grew only about 2.7% body mass per day. However, Healey (1982) suggested this latter growth rate may have been underestimated because larger fish migrated seaward from the lake. He suggested that the true growth rate was closer to 3.5% body mass per day, but was still significantly less than the growth rates in the Nanaimo estuary.

In some areas, such as the Fraser River estuary, chum salmon fry captured high in the estuarine marshes were smaller than those captured in other estuaries (Levy and Northcote 1981), but the fry were larger farther seaward in the Fraser River (Goodman 1975). Fry also increased in size more slowly in the Squamish (British Columbia) and Yaquina (Oregon) River estuaries than in the Nanaimo estuary (Levy and Levings 1978, Myers 1980). However, in all of the above studies, chum salmon juveniles captured in estuaries were heavier than those captured in rivers, and the difference increased with time. Also, while some fry remained for considerable time in the inner estuary, all fry moved seaward by mid-May, with heavier fish migrating first.

Juvenile salmon, particularly chum and chinook, depend heavily on benthic organisms for food in estuaries, but in outer areas they depend more on planktonic organisms. Detritus-based food webs and juvenile chum salmon production in estuaries are closely linked (Sibert et al. 1978). In the 1970s and 1980s, chum salmon feeding and food-chain relationships were examined in the above studies along with migrational timings of juveniles in fresh and estuarine waters.

Simenstad et al. (1982) summarized the diets of juvenile salmonids in 16 estuaries and concluded that small (#50-60 mm FL) juveniles of chum salmon fed primarily on such epibenthic crustaceans as harpacticoid copepods, gammarid amphipods, and isopods, whereas larger juveniles (>50-60 mm FL) in neritic habitats fed on drift insects and on such plankton as calanoid copepods, larvaceans, and hyperiid amphipods. This diet is broader than that of similarly sized pink salmon juveniles, which feed only on neritic zooplankton similar to those consumed by large chum salmon juveniles, even in shallow sublittoral habitats (Healey 1982, Simenstad et al. 1982). However, the early diet of juvenile chum salmon at some localities also consists exclusively of neritic zooplankton.

Juvenile chum salmon in the Nanaimo River, British Columbia (Healey 1980) and in Auke Bay, Alaska (Landingham 1982) fed only on harpacticoid copepods; but at other localities, such as at some localities in the Skagit River (Congleton 1979) and in some estuaries of Vancouver Island (Mason 1974), fry fed only on dipterans, primarily chironomids. Comparisons between juvenile chum and chinook salmon in marsh habitats in the Fraser River estuary indicated that the diet of chum salmon varied less from place to place than did the diets of chinook salmon (Levy and Northcote 1981). Feeding preferences among juvenile salmon appear to correlate with the degree to which a species depends on estuarine habitats (Healey 1982). Chum salmon fry may exploit a greater variety of prey, because they can withstand greater changes in salinity than other salmonids. For example, chum salmon fry in the Skagit River fed on freshwater, estuarine, and marine organisms during a single tidal cycle (Congleton 1979).

Migration of chum salmon juveniles out of estuaries appears to be closely correlated with prey availability. Chum salmon juveniles move offshore as they reach a size that allows them to feed on the larger neritic plankton, and this movement normally occurs as inshore prey resources decline (Salo 1991). This transition has taken place at 45-60 mm FL in Puget Sound and Hood Canal, Washington (reviewed in Simenstad and Salo 1982, Salo 1991), but at 60 mm FL in Prince William Sound, Alaska (Cooney et al. 1978).

Habitat utilization

Do different groups of chum salmon, or chum salmon compared to other salmon species, use estuarine habitats differently? In the few studies published on this subject, juvenile chum and pink salmon apparently occupy shallow sublittoral habitats before moving into neritic habitats. They appear to remain in the shallow areas until they reach 45-60 mm FL, after which they move into neritic habitats. Chum salmon apparently prefer exposed cobble or gravel beaches in nearshore areas (Miller et al. 1977, 1980), especially within embayments. Chum salmon also school in shallow habitats during daylight, but disperse into smaller groups at night (Salo et al. 1980). Juveniles from most runs of chum salmon migrate in schools through northern Puget Sound and into the Strait of Juan de Fuca (Fresh 1979). In contrast, juvenile coho salmon move directly into neritic waters after entering an estuary and school much less than do pink and chum salmon.

Interspecific interactions

Chum salmon interact with other salmonids in several ways (reviewed in Gallagher 1979, Salo 1991). Most notable is the observation that returns from odd-year broods of chum salmon in the Pacific Northwest and from even-year broods in Alaska tend to be lower when pink salmon juveniles coexist with chum salmon juveniles in estuaries (Rounsefell and Kelez 1938, Smirnov 1947, Lovetskaya 1948, Noble 1955). Ivankov and Andreyev (1971) modeled chum salmon populations in southeastern Russia and found that when pink salmon juveniles were abundant, predicted feeding and growth rates of juvenile chum salmon were lower. Ames (1983) also hypothesized that competition for food and predation between pink and chum salmon juveniles in estuary and nearshore marine habitats may cause distinct odd- and even-year cycles in natural chum salmon populations in Puget Sound. The diets of pink and chum salmon in Hood Canal overlapped up to 84% (Simenstad et al. 1980). Chum salmon diet also shifted in years when pink salmon were abundant (Gallagher 1979), but this may have been due in part to a more diverse diet in chum salmon juveniles than in pink salmon juveniles. Invertebrates not eaten by pink salmon juveniles may be more available to chum salmon in years when pink salmon are also abundant.

Culture techniques may also influence interactions between chum salmon juveniles and other salmonids. Estuarine predation on natural and hatchery pink and chum salmon by larger, piscivorous salmon—such as coho and chinook salmon smolts—may have caused declines in some Puget Sound pink and chum salmon populations (Johnson 1973, Simenstad et al. 1982).

Freshwater and estuarine survival

Estimates of mortality of chum salmon in freshwater after emergence from the gravel have been made by several authors, including Neave (1953) and Hunter (1959) in British Columbia, Semko (1954) in the Russian Federation, and Beall (1972) and Fresh and Schroder (1987) in Big Beef Creek, Washington. Although estimates of mortality in a study can vary greatly (e.g., mortality varied from 5 to 60% in the study by Fresh and Schroder (1987)), the average for all of the above studies was about 45%. Mortalities in natural habitats can be influenced by such short-term physical factors as extreme cold, water diversions, and flooding. Mortality is also affected by long-term factors such as the cumulative effects of habitat degradation, climatic changes, and urbanization, and by biotic factors such as disease, interspecific competition, bird and other predation, and the introduction of exotic predators and competitors. Fish in most experimental studies are usually monitored in relatively stable environments over a short period of time. Most of the above natural sources of mortality are absent, and the only natural cause of mortality reported is usually predation. Nonetheless, estimates of mortality under such experimental conditions can still be helpful for identifying vulnerable life-history stages. Predation by juvenile coho salmon was the primary cause of mortality to chum salmon in all the freshwater studies reviewed here. In Big Beef Creek on Hood Canal, size selection of chum salmon juveniles by coho salmon was identified by Beall (1972), but in a later study (Fresh and Schroder 1987) size selection by coho salmon and rainbow trout was not observed.

Mortality of chum salmon juveniles, especially those from natural populations, is difficult to estimate in estuaries. In studies on fluorescently marked juvenile chum salmon released from the Enetai Hatchery in Hood Canal, Bax (1983a, b) estimated average daily mortalities between 31 and 46% over a 2- and 4-day period. In a study on releases of equal numbers of fish of two different sizes, Whitmus (1985) estimated that small fish suffered higher mortalities than did large fish. About 58% of the small fish died over 2 days, and of the fish remaining after 10 days only 26% were small fish. This mortality was apparently due to predation by cutthroat trout and marine birds. However, predator selectivity on fish size may have been due to the distribution of the differently sized fish rather than to selective behavior: Large fish avoided predation in the study area by emigrating out of the area sooner than small fish.

Juvenile offshore movement and residualism

It is unclear how long chum salmon juveniles remain in estuarine areas, but chum salmon in the Washington and southern British Columbia generally entered the ocean earlier than did more northern and western populations (Hartt 1980, Hartt and Dell 1986). In studies of juvenile chum salmon (300-400 mm FL) captured and tagged in June in central Puget Sound, Jensen (1956) found that juveniles moved northward to the Strait of Georgia and the west coast of Vancouver Island shortly after release. They appeared to migrate northward along the coast in a narrow band about 32 km in width. Hartt (1980) and Hartt and Dell (1986) summarized available data on the distribution, migration, and growth of chum salmon in their first year at sea and found that chum, pink and sockeye salmon juveniles tended to group together and remained nearer shore (within 36 km) than juvenile coho and chinook salmon and steelhead. Later in the season, pink salmon were extensively caught offshore by Canadian longline gear in November and December, but no juvenile sockeye or chum salmon were caught in these offshore waters. As groups of chum salmon reached Alaska, they moved offshore in a generally southwestern direction, although movement was variable and appeared to be strongly influenced by currents (Hartt 1980, Hartt and Dell 1986). A difficulty in these studies is that few numbers of tagged fish were recovered. In the tag recoveries summaries by Hartt and Dell, over 110,000 juvenile salmon and steelhead were caught and 35,259 tagged, of which 4,412 were chum salmon, although only 6 chum salmon, or 0.1%, were recovered.

A second factor that obscures patterns of oceanic distribution and migration is the extent of delayed ocean migrations and residualism by chum salmon. In the tagging studies by Jensen (1956) juvenile chum salmon remained in nearshore waters beyond the usual time of ocean migration, although the extent of this residualism was unclear (Jensen 1956, Hartt 1980, Fresh et al. 1980, Hartt and Dell 1986). Not all of the chum salmon juveniles tagged in Hood Canal and Puget Sound moved northward toward British Columbia; some remained in Puget Sound throughout the summer, perhaps not leaving until the next spring (Jensen 1956). In November, Hartt and Dell (1986) found juvenile chum salmon in central Puget Sound and in Hecate Strait that averaged 230 mm in length, an indication of good growth. It has been hypothesized that these fish may not make an extended northwest migration along the British Columbia/Alaska coast, but may instead proceed directly offshore into the north Pacific Ocean (Hartt and Dell 1986).

Marine Life History

Marine migration patterns

Oceanic distributions of salmonids have been used to differentiate salmonid populations for ESA considerations (Waples et al. 1991, Weitkamp et al. 1995). The International North

Pacific Fisheries Commission (INPFC) has collected a large amount of information since 1952 on the distributions and origins of high-seas chum salmon. Studies by the INPFC have focused on tagging experiments and scale pattern analysis (see Davis et al. 1990), and more recently on mixed-stock identification (MSI) (see Winans et al. 1994). There have also been several regional studies on the identification of high-seas chum salmon. These studies have used a variety of techniques including gonad development, scale characteristics, age, morphology, allozyme patterns, mtDNA variation, and DNA fingerprinting (e.g., Altukhov et al. 1980, Okazaki 1986, Nikolaeva 1987, Ishida et al. 1989, Park et al. 1993, Taylor et al. 1994). However, until recently, these studies focused on estimating the continent of origin for chum salmon, and little information has been developed on the distributions of specific regional populations.

Tagging and scale studies by the INPFC showed that although chum salmon from both Asia and North America are distributed throughout the North Pacific Ocean and Bering Sea, Asian chum salmon apparently migrate farther across the Pacific Ocean than do North American fish. Neave et al. (1976) reported that North American chum salmon were rarely found west of the mid-Pacific Ocean (beyond long. 175°E), whereas Asian chum salmon were routinely encountered far east of this line. Asian chum salmon have extended their distribution in recent years into the central and eastern North Pacific Ocean, perhaps because of the large increase in releases of hatchery fish in Japan (Kaeriyama 1989, Salo 1991), and because of the change from high-sea to inshore fisheries by Japan’s fishing industry (Kaeriyama 1989, Ogura and Ito 1994). Bigler and Helle (1994) and Helle and Hoffman (1995) suggested that the overlap of continental groups may be detrimental to North American chum salmon because maturing chum salmon in the North Pacific Ocean may be at or above carrying capacity.

Limited information exists on stock- or population-specific migrational patterns, and distributions of chum salmon during their oceanic phase are limited. Maturing chum salmon in the North Pacific begin to move coastward in May and June and enter coastal waters from June to November (Neave et al. 1976, Fredin et al. 1977, Hartt 1980). No region-specific information on chum salmon migrations to Washington and Oregon has been reported. Whether the large populations of chum salmon that once inhabited the Columbia River (Rich 1942) and Tillamook basins (Henry 1953, 1954) had oceanic distributions similar to Puget Sound chum salmon is unknown. As landings in coastal Oregon historically excluded landings on the Oregon side of the Columbia River (Henry 1953), one speculation is that these fish had a more southern distribution, like the present distribution of Columbia River coho salmon (Sandercock 1991), and may have returned northward along the Oregon coast as do some Columbia River coho salmon.

Age and growth

Age and growth in adult chum salmon have been extensively studied (reviewed in Bakkala 1970 and Salo 1991). Although clear trends are difficult to detect because most studies have relied on commercial catches of mixed stocks (Helle 1984), regional differences in growth rate, age at maturity, and size at maturity are evident.

Growth rate—Asian chum salmon grow faster in the marine environment (higher instantaneous growth rate) than do North American chum salmon. North American fish, however, are usually larger at each stage of marine life. Salo (1991) suggested that the faster growth rate in Asian chum salmon may be a genetic (bioenergetic) adaptation to poor habitat conditions in the western Pacific Ocean. LaLanne (1971) and Ricker (1964) suggested that the growing season may be longer for North American fish because scale analysis showed that growth began earlier and ended later in the Gulf of Alaska than it did in Asian waters.

In general, average size for chum salmon of all ages increases from north to south, and age at maturity decreases from north to south (reviewed in Salo 1991). This is attributed to the longer growing season and earlier maturation of southern populations. However, Helle (1984) demonstrated that in individual populations from the Noatak River in northern Alaska to Whiskey Creek in central Oregon, 4-year males during the same year were largest in southern southeast Alaskan mainland (Fish Creek at the head of Portland Canal) and decreased in size both to the north and to the south. The average mass of chum salmon in Alaska was less than in British Columbia, but the average sizes of chum salmon in northern British Columbia did not differ significantly from average sizes in southern British Columbia (Ricker 1980). The greater number of 3-year-old fish in southern catches and greater variability in fish age in northern British Columbia may explain these results (Ricker 1980). Four-year-old chum salmon were longer in northern Puget Sound (average 78.3 cm FL in 1964, and 75.7 cm FL in 1970) than in the southern Puget Sound (from Discovery Bay to Tacoma) (average 74.3 cm FL in 1963-1966 and 72.4 cm FL in 1970) (Pratt 1974).

Age at maturity—Age at maturity also appears to follow a latitudinal trend in which a greater number of older fish occur in the northern portion of the species' range. Age at maturity has been investigated in many studies, and in both Asia and North America, it appears that most chum salmon (95%) mature between 3 and 5 years of age, with 60-90% of the fish maturing at 4 years of age. However, there is a higher proportion of 5-year-old fish in the north, and a higher proportion of 3-year-old fish in the south (southern British Columbia, Washington, Oregon) (Gilbert 1922, Marr 1943, Pritchard 1943, Kobayashi 1961, Oakley 1966, Sano 1966). Helle (1979) has shown that the average age at maturity in Alaska is negatively correlated with growth during the second year of marine life, but not with growth in the first year, and that age at maturity is negatively correlated with year-class strength. A few populations of chum salmon also show an alternation of dominance between 3- to 4-year-old fish, usually in the presence of dominant year classes of pink salmon (Gallagher 1979).

Differences in age at maturity might be expected between summer and fall chum salmon in such rivers as the Yukon and Amur, where distinct differences in the life history of the runs occur. However, Buklis and Barton (1984) found little difference in the age at return for Yukon River summer-run and fall-run chum salmon in commercial catches between 1973 and 1983. Four-year-old fish made up 72.7% of the fall-run fish and 70.5% of the summer-run fish; age-5 fish were next most abundant, followed by age-3 and age-6 fish. An important consideration in all studies of age composition is the large year-to-year variation common to all large data sets on chum salmon.

Several authors have shown that the fluctuations observed in age composition are explained by differences in abundances between brood years (Helle 1979, Buklis and Barton 1984). For example, in Olsen Creek, Prince William Sound, Alaska, 62% of the male chum salmon from the 1956 brood came back as 3-year olds in 1959 (Helle 1979). The 1971 brood produced the next largest percentage (32%) of 3-year-old males during the 20-year study. The percentage of production of 3-year-old males ranged from 0 to 62%. Production of 4-year-old males from the 1956-1972 brood years ranged from 33 to 94%. Production of 5-year-old males from 1956-72 brood years ranged from 1 to 64% (Helle 1979). On the Amur River in the Russian Federation, Lovetskaya (1948) reported data collected in the late 1920s and early 1930s on age at maturity for summer-run and fall-run fish, and found that 4-year-old fish made up 73.0% of the summer-run and 68.6% of the fall-run chum salmon. However, age structure varied widely between years. Only 26.6% of the summer-run fish in 1929 were 4-year-old fish, but 98.1% in 1930 were 4-year-old fish. No data are available for fall-run fish in 1930, although 73.7% in 1929 were 4-year-old fish.

Adult chum salmon have been decreasing in size since the early 1980s (Fig. 12). Helle and Hoffman (1995) found that the average mass of 4-year-old fall chum salmon returning to the Quilcene National Fish Hatchery on the Quilcene River in Hood Canal, Washington and to Fish Creek at the head of Portland Canal in Southeast Alaska declined about 46% between the early 1970s and early 1990s (Helle footnote 14). The average age at maturity for fish at both localities has also increased as size has decreased. Helle and Hoffman (In press) added four more years (1993-96) of data on size changes in chum salmon to their previously published data set from Fish Creek (1972-92) in southern southeast Alaska and Quilcene National Fish Hatchery (1973-92) on the Quilcene River in Hood Canal in Washington (Helle and Hoffman 1995) (Fig. 12). These new data on size changes in chum salmon show an abrupt significant increase in mean length in 1995 and 1996 at Fish Creek and a significant increase in mean length for chum salmon at Quilcene National Fish Hatchery in 1994, 1995 and 1996. Because population abundance of chum salmon in both Asia and North America increased during these years, the authors suggest that the climate regime of the North Pacific Ocean may be undergoing another change (Helle and Hoffman In press).

Earlier, Bigler et al. (1996) examined mean length and mass of chum salmon captured in commercial fisheries throughout North America from 1970 to the early 1990s, and most of the catches showed declines in size. In addition, Japanese and Russian chum salmon have declined in average size and have increased in average age at maturity during the past 15 years (Ishida et al. 1993). The similarity of changes in size and age of chum salmon in North America, as well as in Asia, suggests that these changes are the result of one or more factors in the ocean experience of chum salmon.

A major change in ocean climate in the North Pacific Ocean occurred during 1976-77 (McLain 1984, Miller et al. 1994). Sea surface temperatures cooled in the central North Pacific Ocean and warmed along the coast of North America. These conditions continued through the mid-1990s. Although these oceanic changes enhanced survival and increased abundance, particularly in Alaska and Asia, the relationship of these changes to the decline in size is uncertain. The declining size and older age at maturity may be the result of density-dependent

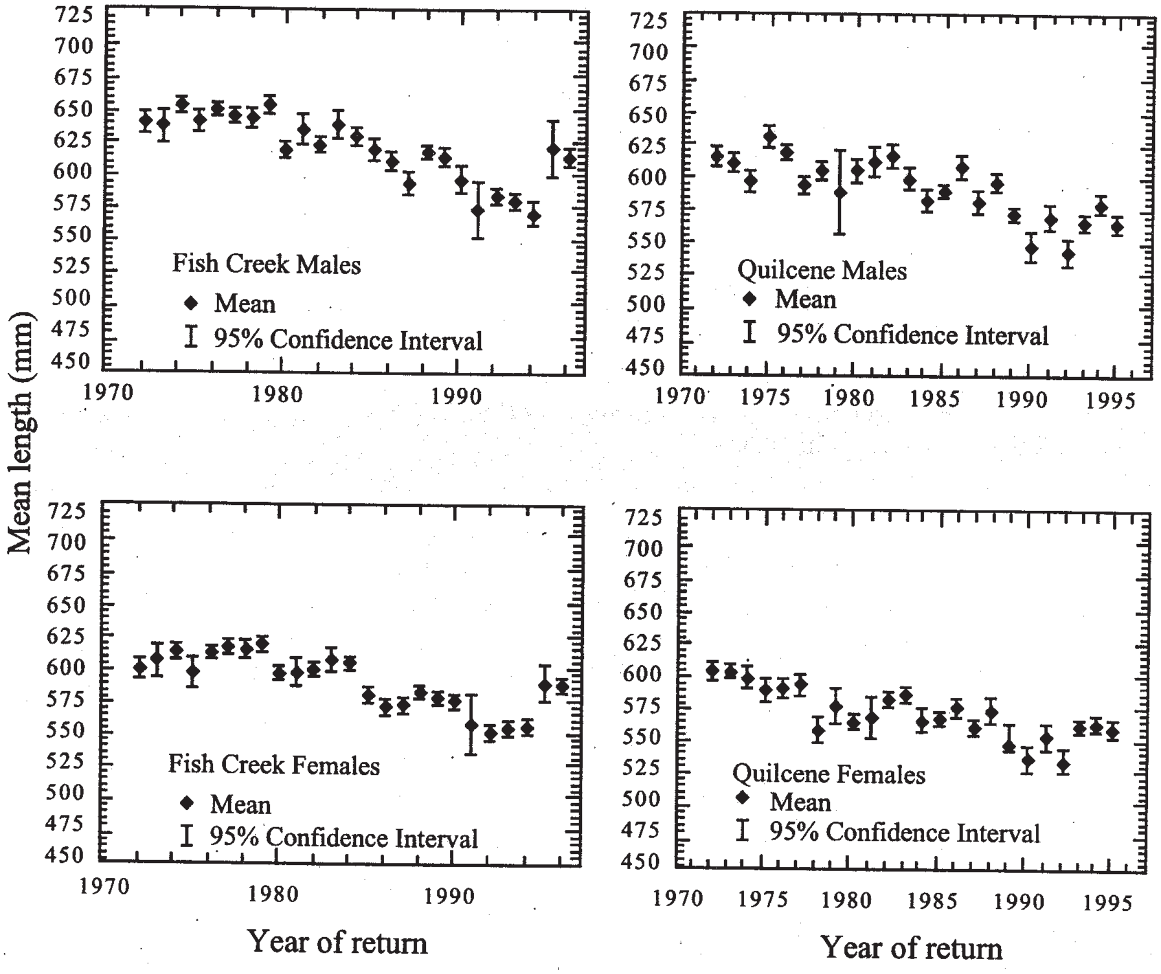

Figure 12. Mean length and 95% confidence interval of age-4 male and female chum salmon spawners at Fish Creek, southeast Alaska, 1972-1996, and at the Quilcene National Fish Hatchery, Hood Canal, Washington, 1973-1996. Data from Helle and Hoffman (In press).

factors (see Kaeriyama 1989, Ishida et al. 1993, Helle and Hoffman 1995, Bigler et al. 1996). Density-dependent growth of salmonids in the ocean is complex and poorly understood (see Peterman 1978, Rogers 1980, Peterman and Wong 1984).

Significance of Life-History Information for ESU Determinations

Life-history characteristics are complex attributes of biological organisms, derived from the interaction of genetic and environmental influences. They may reveal population-specific differences among local populations, useful in the identification of ESUs, although life-history differences are often obscured by regional trends, environmental perturbations, and selective sampling. In the BRT’s review of chum salmon life-history traits, only run timing appeared to be important in defining ESUs, especially for populations of summer-run and winter-run chum salmon, which show unusual run timings.

Chum salmon show several distinct run-timing patterns: 1) In both Asia and North America, there is a bimodal distribution in return timing, with an early or summer peak and a late or fall peak; 2) these seasonal peaks of returning fish appear to follow a north-to-south cline, from earlier to later spawning times; 3) populations with early run times are common in Alaska and in northern British Columbia, but are rare farther south; and 4) south of southeast Alaska there is a distinct break between natural summer-run and fall-run chum salmon.

Genetics of Chum Salmon

In this section we consider the genetic evidence for 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. Populations of chum salmon have been examined for genetic variability throughout most of their geographical range around the North Pacific Rim. Most of these studies were made with protein electrophoresis, but recent studies have also used the analysis of mitochondrial DNA (mtDNA) and VNTR (variable number of tandom repeats) microsatellite DNA.

One approach to detecting reproductive isolation is to compare frequencies of protein variants (allozymes) among samples with a contingency-table analysis and the chi-square statistic or the G-statistic (log likelihood ratio statistic). The finding of significant frequency differences between groups can be taken as evidence of reproductive isolation. Another approach to identifying reproductively isolated groups is to analyze genetic distances between samples with such clustering methods as the unweighted pair groups method with averages (UPGMA) (Sneath and Sokal 1973) or multidimensional scaling (MDS) (Kruskal 1964). The UPGMA method is appropriate for analyzing populations of species such as salmon that largely have hierarchical genetic population structure, with large geographical groups divided into subgroups. However, when genetic variability varies continuously, as in a cline, or when geographically intermediate populations are also genetically intermediate between groups, MDS more accurately depicts relationships among samples than does agglomerative clustering such as the UPGMA (Lessa 1990). MDS is a nonmetric ordination of samples in two or three dimensions that represents dissimilarity among samples. Principle component analysis (PCA) of allelic frequencies can also be used to examine genetic relationships among populations. The results of PCA analysis are usually similar to the results of MDS analysis for a set of data.

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 chum salmon, as well as other salmonids. It is unclear, however, which measure is best. An attractive feature of Rogers' and Cavalli-Sforza and Edwards' distances is that they are metrics and satisfy the triangle inequality: Given three populations (A, B, C), the sum of the distances between A and B and between B and C is greater than or equal to the distance between A and C. Nei's (1972, 1978) distances sometimes distort genetic distance so that the triangle inequality is not met. On the other hand, Cavalli-Sforza and Edwards' and Rogers' genetic distances do not use a correction for sample size; thus distances are biased upward, especially for small sample sizes (Nei 1978). In contrast, Nei's (1978) distance is unbiased.

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. Sample sizes much less than 50 individuals may inflate estimates of genetic distance between populations, because of the increased error in estimating allele frequencies. An unbiased statistic is therefore more desirable. However, when genetic distances between populations are also small, as they often are between populations of salmon, low but significant levels of genetic differentiation may not be detected by an unbiased distance measure because sample-size corrections may reduce estimates of genetic distance to zero.

Another consideration is that Nei's (1972, 1978) and Rogers' (1972a) distance measures can be influenced by different levels of heterozygosity between populations, whereas Cavalli-Sforza and Edwards' (1967) measure cannot. Discussions of these and other features of genetic distances appear in Nei (1978), Hillis et al. (1996), and Rogers (1991). Most of this discussion 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 genetic differentiation among populations of species like salmon, which typically show 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 (1978), Rogers' (1972a), and Cavalli-Sforza and Edwards' (1967) genetic distances to identify results that may not be robust to the distance measure used. In most cases, the different genetic distance measures yielded results that were highly correlated. 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).

A gene diversity analysis (Nei 1973, Chakvaborty 1980) was used to apportion allele-frequency variability into its geographic or behavioral components for a regional data set. Most genetic variability in salmonids occurs as genotypic difference among individuals within a population. A smaller proportion is generally due to genetic differentiation between spawning populations in rivers and streams that have been defined by geography or run timing. These statistics facilitate comparisons among regions and may detect regional differences in gene flow or the effects of hatchery strays on genetic population structure.

Several life-history characteristics in chum salmon may influence the population genetic structure. Fish return to natal streams at 3-5 years of age and spawn as early as June in northern areas and as late as March in southern areas. Overlapping generations of fish at spawning localities tend to increase the effective size of a population in a river, decreasing the effects of random-drift genetic variability within and between populations. Since chum salmon generally do not migrate far into a river to spawn, less genetic differentiation might be expected relative to other species of salmon which have more geographically isolated populations scattered throughout a river system.

Regional Differentiation

A major east-west genetic subdivision of Pacific Rim chum salmon populations has been detected in several studies. In an ocean-wide study, Okazaki (1983) found a major genetic discontinuity between Asian and North American chum salmon; however, because his study included only a few samples, he was not able to resolve the geographic boundaries of these groups. Seeb et al. (1995) combined data for 200 populations around the Pacific Rim from studies of Kondzela et al. (1994), Phelps et al. (1994), Seeb et al. (1995), Wilmot et al. (1994), and Winans et al. (1994). In this data set, genetically homogeneous populations were pooled into regional groups, and some alleles occurring at low frequencies were pooled with alleles with similar electrophoretic mobilities. Analyses of Cavalli-Sforza and Edwards' (1967) genetic chord distances between samples resolved a large geographic subdivision among Pacific Rim chum salmon populations, with the break occurring to the east (Wilmot et al. 1994, Seeb et al. 1995) of the break suggested by Okazaki (1983). The results of Seeb et al. (1995) indicated that northwestern Alaskan populations were genetically more similar to Asian populations than they were to populations on the Alaska Peninsula and those in central and southeastern Alaska.

The analysis of mini-satellite nuclear DNA genes, however, showed a different geographical pattern of genetic subdivision. Taylor et al. (1994) examined variability for two putative VNTR loci in 1,211 fish from 39 localities extending from Honshu Island, Japan to southern British Columbia, including localities in the Russian Federation, the Yukon River, and southeastern Alaska. A UPGMA cluster analysis of a generalized genetic distance based on band frequencies pooled into 44 size classes showed three hierarchical groups in which the greatest subdivision was between Japanese samples and the remaining samples, and the next lower subdivision was between Russia/Yukon River samples and southeastern Alaska/British Columbia samples. The differences in population structure suggested by allozymes and by nuclear mini-satellite DNA may be due to the analysis of only two linked mini-satellite loci.

The analyses of nucleotide sequence variability in mitochondrial DNA by Park et al. (1993) showed a pattern of regional differentiation similar to that indicated by the analysis of mini-satellite DNA by Taylor et al. (1994). Park et al. (1993) found a lack of sequence variability in the control region (D-loop) of mtDNA in 798 fish collected from 42 localities extending across the Pacific Rim from Japan to Washington. However, they found restriction fragment variability in polymerase chain reaction (PCR) amplified mtDNA fragments of the NADH dehydrogenase gene that showed strong frequency differences across the Pacific Rim. The largest frequency differences were between Japan and all other regions including the Russian Federation, Alaska/Yukon, and British Columbia/Washington. The mean frequency of this variant in Japan was 0.80, whereas its frequency in the other regions was 0.13 or less.

Asian Populations

On the Asian side of the North Pacific, Japanese and Russian populations constitute genetically discrete geographic units. Winans et al. (1994) compared 17 Japanese populations on Honshu and Hokkaido Islands with 12 Russian populations extending from the Okhotsk Sea in the south to the Anadyr River in the north. Cluster analysis of Nei's unbiased genetic distances (Nei 1978) between samples and a principal component analysis (Winans et al. 1994) showed that the Japanese and Russian chum were genetically distinct from one another, with an average genetic distance of 0.006 for a sample of 62 isozyme loci. This genetic distance is near the low end of the range typically found for conspecific populations (Thorpe 1982).

Ninety percent of chum salmon produced in Japan are raised in about 300 hatcheries (Kaeriyama 1989) located on most of the rivers that historically had runs of chum salmon. In a study of 43 populations on Hokkaido and Honshu Islands, Okazaki (1982a,b) reported genetic subdivision between populations on the two islands and, to a lesser degree, between areas on each island. We reexamined the published allelic frequencies with genetic distances and cluster analyses and found no evidence of regional or local genetic groupings among Japanese populations of chum salmon. Our gene-diversity analysis of these data indicated a small amount of genetic differentiation among populations. Of the total genetic variability, 96% was contained on average within populations, 3.1% was due to differences among populations within four regions, 0.4% was due to differences between islands, and 0.5% was due to the average difference between east and west coast populations on each island.

Winans et al. (1994) examined an overlapping set of 17 populations on Hokkaido and the northern part of Honshu Island for geographic variability at 26 polymorphic loci. Their UPGMA clustering of Nei's genetic distance between populations for these data indicated that the greatest amount of geographic differentiation was between east and west coast populations and not between Hokkaido and Honshu Islands, as suggested by Okazaki (1982a,b).

Kijima and Fujio (1982) examined genetic relationships among populations of chum salmon in Japan based on allele-frequency variability at six loci. They searched for correlations between genetic distances and geographical distances between samples with four different analyses of population groups delimited by different potential pathways of migration around Hokkaido and Honshu. In the genetic-distance/geographical-distance comparisons, the magnitude of genetic distances between pairs of populations increased for a separation of up to 600 km between the pairs of samples. Pairs of samples separated by more than 600 km showed no correlation between genetic distance and geographic distance. This was interpreted to indicate that gene exchange between populations was largely limited to distances less than 600 km and that populations separated by more than 600 km were genetically independent of one another.

In contrast to Japanese chum salmon populations, Russian populations appear to be subdivided into two genetically distinct groups with a few genetic outliers. In a genetic study of chum salmon collected at river mouths, Viktorovskii et al. (1986) found two large groups, one located on the eastern Kamchatka Peninsula and the other on the western side of the Peninsula and around the Sea of Okhotsk. The southernmost populations on Sakhalin Island and around the Bay of Amur were genetic outliers. The results of Winans et al. (1994) generally confirmed the existence of two large Russian populations. In that study, samples of chum salmon were collected from 17 localities in the Russian Federation, extending from the Ola River on the Okhotsk Sea in the south around the Kamchatka Peninsula to the Anadyr River in the north, and were examined for variability at 35 loci. A UPGMA analysis of Nei’s unbiased genetic distance produced four clusters that were geographically poorly resolved. Nonetheless, populations around the Okhotsk Sea (mainland and western Kamchatka Peninsula) tended to be genetically distinct from those of the eastern Kamchatka Peninsula.

North American Populations

Northwestern Alaska/Yukon—Chum salmon of northwestern Alaska and the Yukon River exhibit diverse life-history patterns and run times. Some chum salmon, for example, migrate 2,000 miles up the Yukon River to spawn, whereas others spawn in the lower sections of the Yukon River basin. In a study of Alaskan and Canadian chum salmon spawning in the Yukon River and its tributaries, Beacham et al. (1988) examined 7 polymorphic loci in 10 populations, including those spawning several hundred miles from the mouth of the Yukon River. They found that fall-run fish of the upper Yukon River were genetically distinct from summer-run fish in the lower Yukon River in northwestern Alaska. Other genetic studies (Seeb et al. 1995, Wilmot et al. 1994) also confirmed major genetic differences between upper Yukon fall-run chum salmon and summer-run chum salmon in the lower river. The large genetic differences between these two groups of populations appear to reflect large differences in run times and large geographic distances between spawning areas.

Wilmot et al. (1994) examined 24 polymorphic loci (plus 30 invariant loci) in 30 river populations around Bristol Bay, in the Yukon River, and on the Alaska Peninsula. Three samples from the Russian Federation were also included in this study. In a UPGMA and neighbor-joining cluster analysis of chord genetic distances, they found three major clusters of samples: 1) Russia-Alaska Peninsula samples, 2) Bristol Bay samples, and 3) upper and lower Yukon River samples. A hierarchical gene-diversity analysis of allele-frequency variability indicated that 95.4% of gene diversity was contained, on average, within populations, 1.4% was due to allele-frequency differences among populations within regions, 0.5% to differences between fall- and summer-spawning populations in the Yukon River, and 2.7% to differences among areas within years.

Southeastern Alaska/British Columbia—Kondzela et al. (1994) examined 42 variable loci (plus 4 monomorphic loci) in 61 samples of chum salmon from populations in southeastern Alaska and northern British Columbia. A neighbor-joining cluster analysis of chord distances (based on 40 loci) showed four more or less distinct clusters of populations: 1) central southeastern Alaska, 2) southern southeastern Alaska and north and central British Columbia, 3) Prince of Wales Islands, and 4) Queen Charlotte Islands. A gene-diversity analysis of these data indicated that 97% of the genetic diversity occurred as differences between individuals within populations, 1.3% as allele-frequency differences among populations within regions, and 1.4% as frequency differences among regions.

British Columbia—Beacham et al. (1987) studied allozyme variability for 9 polymorphic loci in 83 chum salmon populations in central and southern British Columbia. A UPGMA tree of Nei's unbiased genetic distance indicated five more or less distinct clusters of samples: 1) Queen Charlotte Island samples, 2) north and central coast British Columbia samples, 3) east coast of Vancouver Island and south coast of British Columbia samples, 4) west coast of Vancouver Island samples, and 5) Fraser River samples. This study did not include samples outside British Columbia, thus the relationships of these groups to chum salmon populations to the north in Alaska or to the south in Washington are unclear. An analysis of geographic variability with the fixation index (F_{ST}) indicated that on average 97.7% of the total gene diversity was contained within populations, and 2.3% was due to allele-frequency variability differences among populations.

Washington/British Columbia—Phelps et al. (1994) examined genetic variability at 39 polymorphic loci in 153 samples from 105 locations in southern British Columbia, Washington, and Oregon (Table 11). Five of 30 spawning localities examined for interannual variability showed significant ($P < 0.05$) allele-frequency differences between or among years. Genetic marking or hatchery transplantations could explain the temporal variability in three of these populations, and temporal variability at two localities with small population sizes was probably due to random genetic drift. Allelic frequencies were pooled over years for those populations sampled in more than 1 year, except for the Samish Hatchery which had a recent history of transfers that apparently have produced significant allele-frequency shifts among years.

A UPGMA tree of chord genetic distances consisted of clusters with samples from the same geographical region or run-time. The most important result of this analysis was that summer-run chum salmon in Hood Canal and the Strait of Juan de Fuca were distinct from fall-run chum salmon in the same areas and from other fall- and summer-run populations. This genetic distinction also appeared in the multidimensional scaling analysis of the chord distances. Unlike Hood Canal and Strait of Juan de Fuca summer-run chum salmon, the summer-run chum salmon of southern Puget Sound clustered with fall-run chum salmon of the same geographical region.

Another important result was that among fall-run chum salmon, geographically close populations were generally more similar genetically to one another than to widely separated

Table 11. Locations of samples of chum salmon examined by Phelps et al. (1994) and Phelps (unpubl., Wash. Dep. Fish Wildl., Olympia).

British Columbia (fall-run)
  Western Vancouver Island
    1. Nahmint R.
    2. Sarita R.
    3. Nitinat R.
  East-central Vancouver Island
    4. Puntledge (hatchery)
    5. Big Qualicum (hatchery)
    6. Little Qualicum R.
  Southern Vancouver Island
    7. Nanaimo R.
    8. Chemainus R.
    9. Cowichan R.
    10. Goldstram R.
    11. Sooke R.
  Southern Coast
    12. Sliammon R. (hatchery)
    13. Tzoonie R.
    14. Cheakamus R.
    15. Mamquam R.
    16. Indian Arm
    17. Alouette R.
    18. Stave R.
    19. Inch Cr. (hatchery)
    20. Squakum Cr.
    21. Chehalis R. (hatchery)
    22. Chehalis at Harrison Hatchery
    23. Weaver Cr.
    24. Harrison R.
    25. Wahleach Cr.
    26. Chilliwack/Vedder R. (hatchery)

Washington
  Northern Puget Sound (fall-run)
    27. Nooksack R.
    28. Kendall (hatchery)
    29. Maple Cr.
    30. Bellingham Maritime (hatchery)
    31. Chuckanut Cr.
    32. Samish R. (hatchery)
    33. Bob Smith Cr.
    34. Thomas Cr.
    35. Finney Cr.
    36. Skagit R.
    37. Illabot Cr.
    38. Dan Cr.
    39. N. Fork Stillaguamish R.
    40. Fortson Cr.
    41. Squire Cr.
    42. Jim Cr.
    43. Wallace R.
    44. Skykomish R.
    45. Schoolhouse Slough
    46. Bear Cr.
  Southern Puget Sound (fall-run)
    47. Keta Cr. (hatchery)
    48. Green R.
    49. Fennel Cr.
    50. Carbon R.
    51. Swift Cr.
    52. Perry Cr.
    53. Kennedy Cr.
    54. Elson Cr. (hatchery)
    55. Lower Skookum R.-Little Cr.
    56. Little Cr.
    57. Reitdorf Cr.
    58. Upper Skookum R.
    59. Mill Cr.
    60. Goldsborough Cr.
    61. Sherwood-Rock-Coulter Crs.
  Kitsap Peninsula (fall-run)
    62. Lackey Cr.
    63. Olalla Cr.
    64. Donkey Cr.
    65. Minter Cr. (hatchery)
    66. Chico Cr.
    67. Gorst Cr.
    68. Cowling Cr. (hatchery)
  Southern Puget Sound (summer-run)
    69. Johns Cr.
    70. Sherwood Cr.
    71. Coulter Cr.
    72. Blackjack Cr.
  Southern Puget Sound (winter-run)
    73. Chambers Cr. (hatchery)

Table 11 (Continued).

- 74. Nisqually R.
- Hood Canal (fall-run)
  - 75. Big Beef Cr.
  - 76. Dewatto R.
  - 77. Tahuya R.
  - 78. Big Misson Cr.
  - 79. Little Mission Cr.
  - 80. McKernan (hatchery)
  - 81. Vance Cr.
  - 82. N. Fork Skokomish R.
  - 83. Enetai Cr. (hatchery)
  - 84. Hood Canal (hatchery)
  - 85. Lilliwaup Cr.
  - 86. Hamma Hamma R.
  - 87. Dosewallips R.
  - 88. Walcott (hatchery)
  - 89. Big Quilcene Cr. (hatchery)
- Straits of Juan de Fuca
  - 90. Lower Elwha R. (hatchery)
  - 91. Elwha R. No. 1
  - 92. Elwha R. No. 2
  - 93. Lyre R.
  - 94. Deep R.
  - 95. Pysht R.

Outer coast of Washington
- Chehalis River
  - 96. Stevens Cr.
  - 97. Wynoochee R.
  - 98. Satsop R.
- Willapa Bay
  - 99. Cloquallum Cr.
  - 100. Bitter Cr.
  - 101. Ellsworth Cr.
  - 102. Bear R.
  - 103. Nemah R.
  - 104. Canon R.
  - 105. Grays Cr.
  - 106. Hamilton Cr.

Oregon
- 107. Coal Cr.

Washington (Summer-run)
- Straits of Juan de Fuca
  - 108. Salmon Cr.
  - 109. Snow Cr.
  - 110. Jimmycomelately Cr.
- Hood Canal
  - 111. Union R.
  - 112. Duckabush R.
  - 113. Dosewallips R.
  - 114. Hamma Hamma R.
  - 115. Quilcene Bay
  - 116. Lilliwaup Cr.

populations. One exception was fall-run chum salmon in the Strait of Juan de Fuca and coastal Washington and Oregon, which were more similar to Georgia Strait and west-coast Vancouver Island populations than to populations in Puget Sound. Samples from two southern Puget Sound winter-run populations were included in the study, and these two samples were genetic outliers that were most closely related to samples of fall-run Hood Canal and northern Puget Sound populations (Fig. 12).

Phelps[24] (and Phelps 1995) added allele-frequency data for an additional 16 chum salmon populations to the data of Phelps et al. (1994) and resolved three reasonably distinct clusters of samples: 1) summer-run chum salmon of Hood Canal and Strait of Juan de Fuca, 2) Puget Sound fall-run and southern Puget Sound winter- and summer-run chum salmon, and 3) Strait of Juan de Fuca, coastal Washington, and Oregon fall-run chum salmon. Samples from British Columbia were not included in this second analysis, but the previous results of Phelps et al. (1994) indicated that group 3 was most closely related to Fraser River and Georgia Strait chum salmon populations in British Columbia.

A gene-diversity analysis of the 105 populations sampled by Phelps et al. (1994) was typical of that for other regions around the North Pacific and indicated that 97.17% of the total diversity was contained within populations and that 2.83% was due to differences between population differences and run-timing differences. Within run timings, 0.80% was due to differences among populations, and 0.27% was due to regional differences. The calculation of diversity within and between run timings was not straightforward, because southern Puget Sound summer-run fish are genetically closer to Puget Sound fall-run fish than to summer-run fish in Hood Canal and the Strait of Juan de Fuca. Summer-run fish in southern Puget Sound were therefore excluded from the calculation of diversity among populations within a run timing, which was 0.91%. The addition of southern Puget Sound fish represented 0.05% of the diversity, and the diversity due to differences among run timings was 0.80%.

To develop a better perspective of regional genetic variability, we combined the allele-frequency data of Phelps et al. (1994) with those of Phelps (footnote 26). The combined data set included allelic frequencies for 34 loci in samples from 116 localities. Multidimensional scaling in three dimensions of Cavalli-Sforza and Edwards (1967) chord distances (Fig. 13) showed four groups of chum salmon: 1) summer-run populations in the Strait of Juan de Fuca (nos. 108-110) and Hood Canal (111-116); 2) fall-, summer-, and winter- run chum salmon in British Columbia (1-26) and Puget Sound (27-74) and fall-run fish in Hood Canal and the Strait of Juan de Fuca (75-95); 3) all samples of chum salmon from outer coastal populations of Washington and Oregon (96-104, 107); and 4) all samples of chum salmon from the Columbia River (105-106).

To depict the genetic relationships among Washington and British Columbia populations, we used multidimensional scaling in two dimensions of chord distances based on 34 loci (Fig.

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[24] S. Phelps, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., July 1995.

13). These populations consist largely of fall-run chum salmon, but also of genetically similar winter- and summer-run chum salmon in Puget Sound. Several geographically meaningful clusters appeared in the graph. Samples of fall-run chum salmon from southern Puget Sound (nos. 47-74) and from Hood Canal, or fish of Hood Canal origin (75-89), formed a large cluster. Three samples from Puget Sound summer-run chum salmon (69-72) and from two winter-run populations (73-74) were included in the large Puget Sound cluster of samples. Two overlapping clusters of samples from northern Puget Sound (27-46) and the Fraser River (17-26) were placed next to the large southern Puget Sound-Hood Canal cluster. Clusters of samples from southern British Columbia (12-16), eastern and southern Vancouver Island (4-11), and the Strait of Juan de Fuca (92-95) populations overlapped with each other.

No clear genetic boundaries appeared between adjoining clusters, but more widely separated populations generally showed larger genetic distance than did nearby populations. West Vancouver Island populations (nos. 1-3) were placed in a distinct cluster separate from other British Columbia populations. Samples from Washington and Oregon outer coastal populations (96-104, 107) and Columbia River populations (105-106) formed two distinct clusters, in which the nearest genetic neighbors of the Columbia River populations were among the outer coast populations.

We further analyzed allelic frequencies of the fall-run chum salmon samples reported by Phelps et al. (1994) with spatial autocorrelation to test for isolation by distance among populations. The autocorrelation coefficient, Moran’s I (Cliff and Ord 1981), was calculated between samples in 13 50-km distance classes for 19 independent alleles and presented as a correlogram (Fig. 14, Table 12). Significant deviations of Moran’s I from zero were detected by standard normal testing procedures following the methods described by Sokal and Oden (1978) and Jumars et al. (1977). This statistic detects positive and negative correlations between sample allelic frequencies within a distance class relative to the average allelic frequencies over all samples.

The results for five alleles—sIDHP-2*86, sIDHP-2*36, sMDHA-1*100, sMDHB-1*100, and mMEP-2*100—were typical of those for 14 other alleles and are shown in Figure 15. High positive autocorrelation appeared between allelic frequencies in samples separated by less than about 250 km. Populations separated by distances greater than 250 km do not, on average, influence one another significantly through migration. The neighborhood size for chum salmon populations in the Pacific Northwest is considerably less than the estimated 600 km reported for Japanese chum salmon by Kijima and Fujio (1982), who estimated this parameter by regressing genetic distances between populations on geographic distances. Larger neighborhood size for Japanese populations could be due to the greater number of egg and fry transfers between hatcheries. Among Pacific Northwest samples, significant negative autocorrelation appeared for pairs of samples separated between 250 and 600+ km, except for significant positive autocorrelation for 5 of the 19 alleles between pairs of samples from populations separated by about 300-450 km. These unexpected positive autocorrelations between widely separated populations may be due to genetic similarity from recolonization by the same ancestral populations after deglaciation (McPhail and Lindsey 1986). Alternatively, they may result from

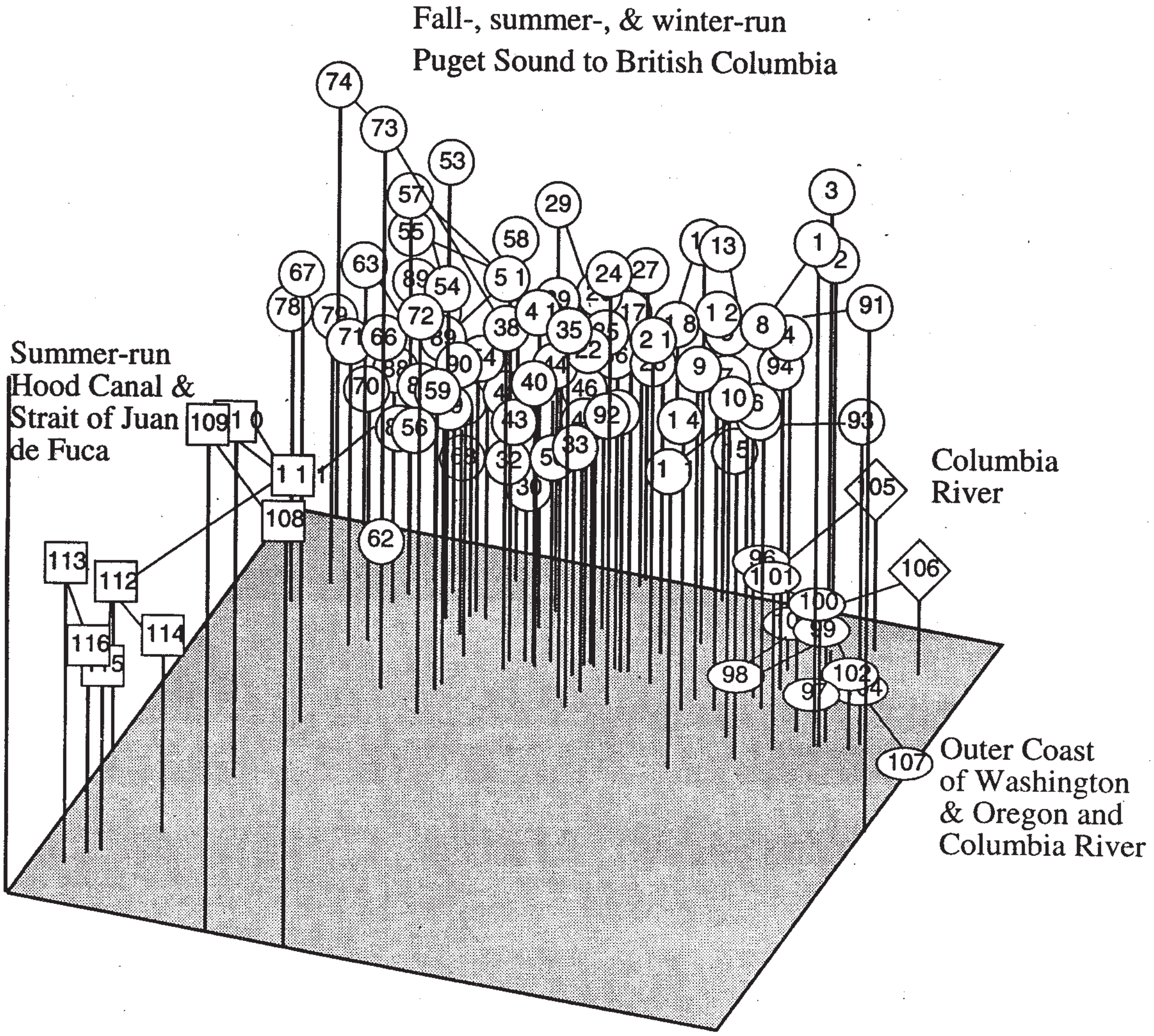

Figure 13. Multidimensional scaling in three dimensions of chord genetic distances between samples of chum salmon from 116 localities in Washington and British Columbia. Genetic distances were based on 34 loci. Locality numbers as in Table 11.

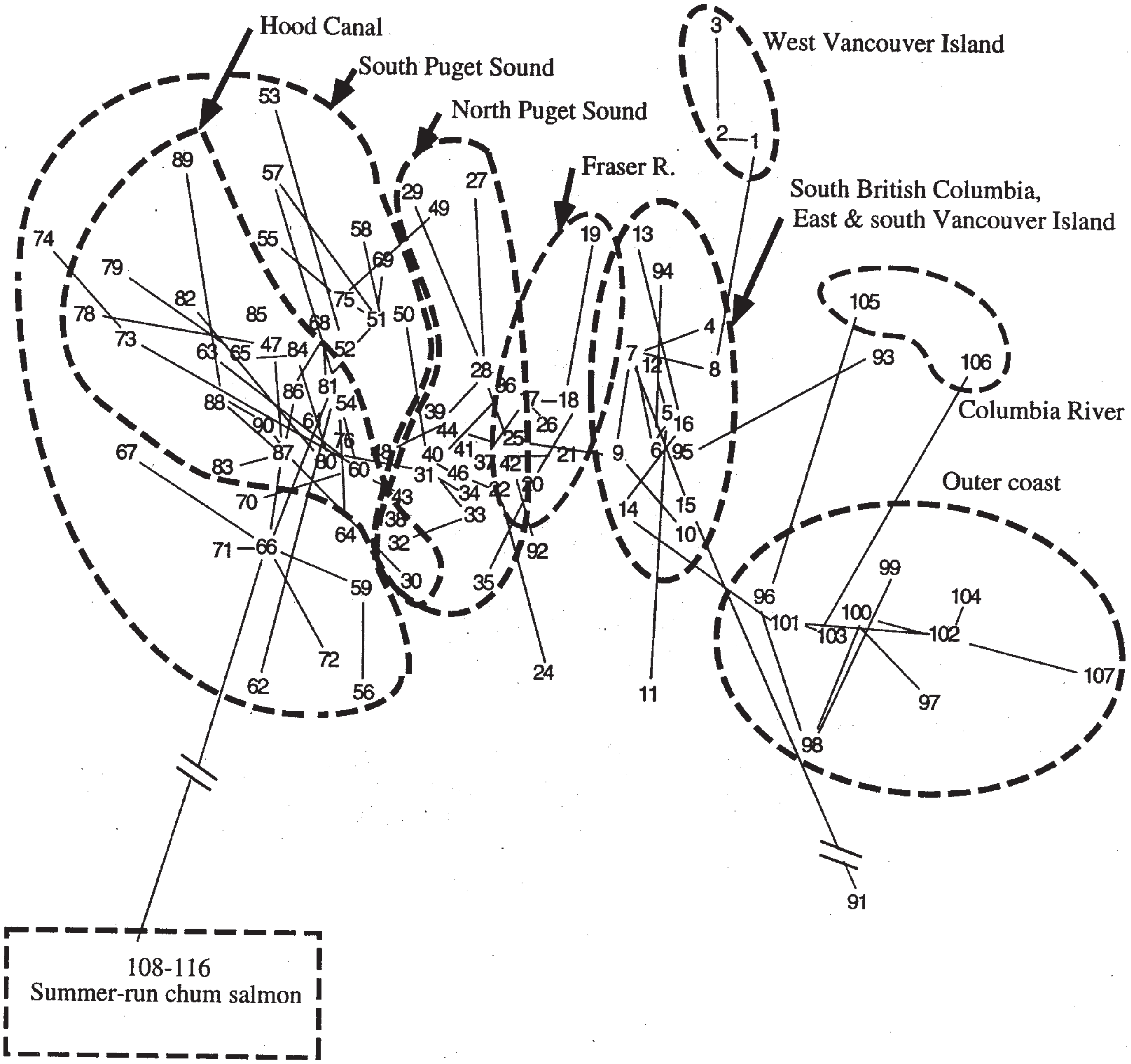

Figure 14. Multidimensional scaling in two dimensions of chord genetic distances between samples of chum salmon in Washington and British Columbia. Summer-run chum salmon populations in Hood Canal and the Strait of Juan de Fuca (Nos. 108-116) lie off the scale of this enlargement. Locality numbers as in Table 11.

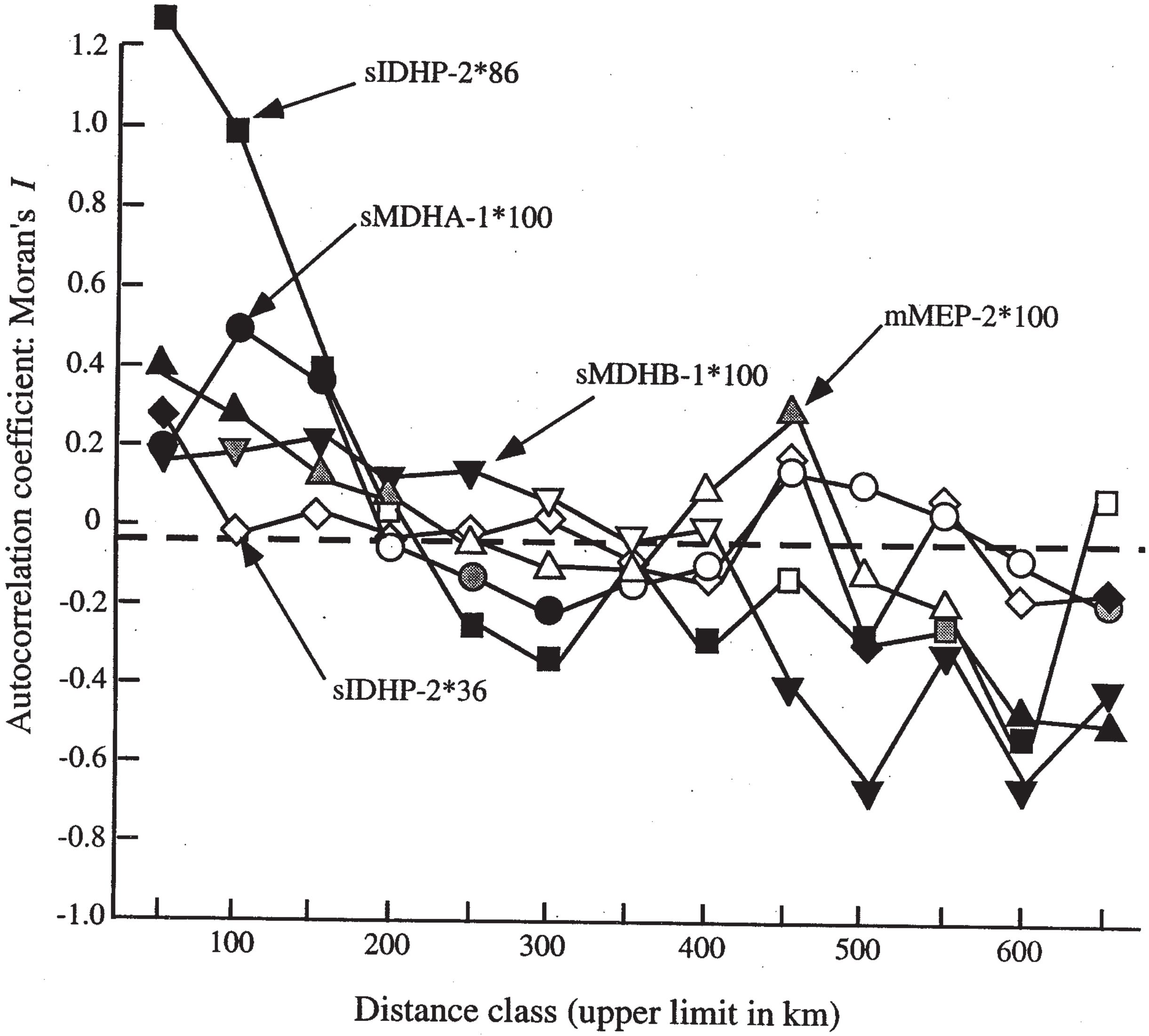

Figure 15. Autocorrelation coefficients (Moran's I) for 5 alleles over thirteen 50-km distance classes. Solid symbols represent highly significant correlations ($p < 0.01$), and shaded symbols represent significant correlations ($0.05 > p > 0.01$).

Table 12. Autocorrelation coefficients (Moran's I) averaged over 19 variable alleles of 5 groups of natural chum salmon populations classified by region, and 4 groups hatchery or hatchery-related populations. Statistical significance was determined with a jackknife variance.

	Population Group[a]							
	1	2	3	4	5	6	7	8
1	-							
2	-0.038	-						
3	-0.144	-0.057	-					
4	-0.162	-0.051	-0.080	-				
5	-0.054	-0.054	-0.279*	0.421*	-			
6	-0.131*	-0.053	0.114	0.124	0.053	-		
7	-0.106	-0.100	0.068	-0.318*	0.010	0.469*	-	
8	-0.051	-0.046	0.029	-0.253*	-0.022	0.273*	0.405*	-

* $p<0.05$

[a] Population groupings (nos. identified in Table 11): 1=British Columbia (1-18); 2=North Puget Sound (19-34); 3=South Puget Sound (35-48); 4=Hood Canal, wild (49-052); 5=Outer coast (56-63; 6=Outplanted populations (64-70); 7=Hood Canal hatcheries (71-75); 8=Hatcheries outside Hood Canal (76-79).

long-distance straying induced by alternate migration around Vancouver Island (Beacham et al. 1987) or translocations of chum salmon eggs and fry (Phelps et al. 1994).

Within-Population Genetic Diversity

The amount of genetic variability in a population reflects the effects of past population events, such as random genetic drift, the introduction of variability through immigration or mutation, and natural selection. If the effects of mutation and natural selection on electrophoretic variability are assumed to be minimal, reduction in genetic variability within a population may be taken as an indication of past reductions in population size. Larger populations are less subject to the loss of genetic variability through random genetic drift. For example, Kijima and Fujio (1984) found a significant correlation ($R = 0.40$, $P < 0.05$) between average, direct-count heterozygosity and population size in 37 river populations of chum salmon in Japan.

In a study of Asian chum salmon populations by Winans et al. (1994), gene diversities (expected heterozygosities) in over 62 loci (including monomorphic loci) ranged from 0.066 to 0.087 among samples, averaging 0.079. However, no regional trends were apparent in the geographical distributions of these values. Overall, this level of genetic variability represents a large amount of genetic diversity relative to that found in other vertebrates (Ward et al. 1992). For northwestern Alaska and Russian populations, Wilmot et al. (1994) estimated expected heterozygosities from 54 loci and found values ranging from 0.056 to 0.072. Heterozygosities averaged by Wilmot et al. (1994) over populations within regions were 0.064 among lower Yukon River summer-run populations, 0.062 among upper Yukon River fall-run populations, 0.065 among Bristol Bay populations, 0.064 among Alaska Peninsula populations, and 0.063 among Russian populations. In 83 chum salmon populations in British Columbia, Beacham et al. (1987) used 9 loci to estimate expected heterozygosities in 5 areas and found that populations in the Fraser River and on the south coast of British Columbia tended to have smaller values. However, population abundances, and presumably effective population sizes, are smaller in northern areas, especially on Queen Charlotte Island, than in southern areas of British Columbia (Beacham 1984). Since Beacham et al. (1987) used only 9 polymorphic loci, their heterozygosity values cannot be compared directly to other studies that used 50 or more loci in their estimates of heterozygosity.

Phelps et al. (1994) estimated population heterozygosity from direct counts of heterozygotes in a set of data that included 38 polymorphic loci and that overlapped with the sets of loci used by Beacham et al. (1987) and Winans et al. (1994). Since monomorphic loci were not included in the estimates of Phelps et al. (1994), heterozygosities between the studies are not directly comparable. Average heterozygosities varied among populations from 0.082 to 0.116 and did not deviate more than 0.005 from heterozygosities expected with random mating. The highest heterozygosities occurred in Hood Canal fall-run chum salmon (0.108 on average) and southern Puget Sound fall- and summer-run populations (0.102 on average). The lowest values were found in the Strait of Juan de Fuca (0.090), Georgia Strait (0.090), and the west coast of Vancouver Island (0.089) fall-run populations. Heterozygosities in hatchery populations were nearly the same as heterozygosities in nearby wild populations. These results suggest that chum salmon hatchery populations in Washington have not experienced recent or historical bottlenecks in population size.

Summary of Genetic Information

Allelic frequencies for a large number of protein-coding loci indicate that chum salmon populations along the rim of the North Pacific are divided into several regional groups. Russian and northwestern Alaska chum salmon appear to be more closely related to each other than either is to Japanese chum salmon. Frequencies of a mitochondrial DNA variant and mini-satellite DNA variants also show a major difference between Japanese chum salmon populations and all other populations. In northwest Alaska, allozyme frequencies indicate that fall-run chum salmon in the upper Yukon River are distinct from summer-run chum salmon in the lower Yukon River. In the eastern North Pacific, populations of chum salmon from central Alaska to Washington appear to be genetically isolated by distance, so that geographically proximate populations are more closely related to one another than populations separated by large distances.

Two major genetic groups are present in central and southern British Columbia, Washington, and Oregon. One consists of summer-run chum salmon in Hood Canal and the Strait of Juan de Fuca, and a second large group consists of fall-, winter-, and summer-run chum salmon in other areas. The second large group is weakly divided into two groups: 1) coastal populations along the outer coast of Washington and Oregon, including those in the Columbia River, and 2) the remaining populations in British Columbia and Washington (including the Strait of Juan de Fuca populations). Levels of genetic variability within and between populations in several geographic areas are similar, and populations in Washington show levels of genetic subdivision which are typical of those seen between summer- and fall-run populations in other areas and which are typical for populations within run types.

Discussion and Conclusion of ESU Determinations

Based on a review of the biology and ecology of chum salmon, the BRT identified four ESUs for the species in the Pacific Northwest (Fig. 16). Genetic data (from protein electrophoresis and DNA markers) were the primary evidence considered for reproductive isolation criterion. This evidence was supplemented by inferences about barriers to migration created by natural geographic features. Data considered important in evaluations of ecological/genetic diversity included distributions, migrational and spawning timing, life history, ichthyogeography, hydrology, and other environmental features of the habitat. In the following summaries, we describe those factors that were valuable in making individual ESU determinations.

Each of the ESUs include multiple spawning populations of chum salmon, and most ESUs also extend over a considerable geographic area. This result is consistent with NMFS species definition policy (Waples 1991:20), 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." However, considerable diversity in genetic or life-history traits or habitat features may exist within a single complex ESU, and the descriptions below briefly summarize some of the notable types of diversity within each ESU. This diversity is considered in the next section in evaluating risk to the ESU as a whole.

Puget Sound/Strait of Georgia ESU

The Puget Sound/Strait of Georgia ESU (Figure 16) includes most U.S. populations of chum salmon and the vast majority of adult spawners that return to U.S. waters outside Alaska. This ESU includes all chum salmon populations from Puget Sound and the Strait of Juan de Fuca as far west as the Elwha River, with the exception of summer-run populations in Hood Canal and along the eastern Strait of Juan de Fuca. The BRT concluded that this ESU also includes Canadian populations from streams draining into the Strait of Georgia. A northern boundary for this ESU was tentatively identified as Johnstone Strait, but this determination was hampered by a paucity of information from populations in central and northern British Columbia. Chum salmon from the west coast of Vancouver Island are not considered part of this ESU, in part because available genetic information suggests these fish are distinct from Puget Sound or Strait of Georgia fish.

Genetic, ecological, and life-history information were the primary factors used to identify this ESU. Environmental characteristics that may be important to chum salmon (e.g., water temperature, and amount and timing of precipitation) generally show a strong north-south trend, but no important differences were identified between Washington and British Columbia populations. An east-west gradient separating Olympic Peninsula populations from those to the east was considered to be more important for evaluating chum salmon populations.

Chum salmon populations within this ESU exhibit considerable diversity in life-history features. For example, although the majority of populations in this ESU are considered to be fall-run stocks (spawning from October to January), four summer-run (spawning from September to November) and two winter-run (spawning from January to March) stocks are recognized by state and tribal biologists in southern Puget Sound. Summer chum salmon in southern Puget Sound are genetically much more similar to Puget Sound fall chum salmon than they are to other summer-run populations in Hood Canal and the Strait of Juan de Fuca. These data suggest relatively weak isolation between summer- and fall-run chum salmon in southern Puget Sound and/or a relatively recent divergence of the two forms. Reproductive isolation of the Nisqually River and Chambers Creek winter-run populations, which are the only populations in the ESU whose spawning continues past January, may be somewhat stronger.

The Nisqually and Puyallup Rivers are also unique in southern Puget Sound because their headwaters are fed by glaciers on Mount Rainier, giving the rivers different characteristics than other regional river systems. The Nisqually population is also one of the more genetically distinctive chum salmon populations in Puget Sound. However, the genetic differences are not large in an absolute sense, and the majority of the BRT felt that the distinctiveness of the winter-

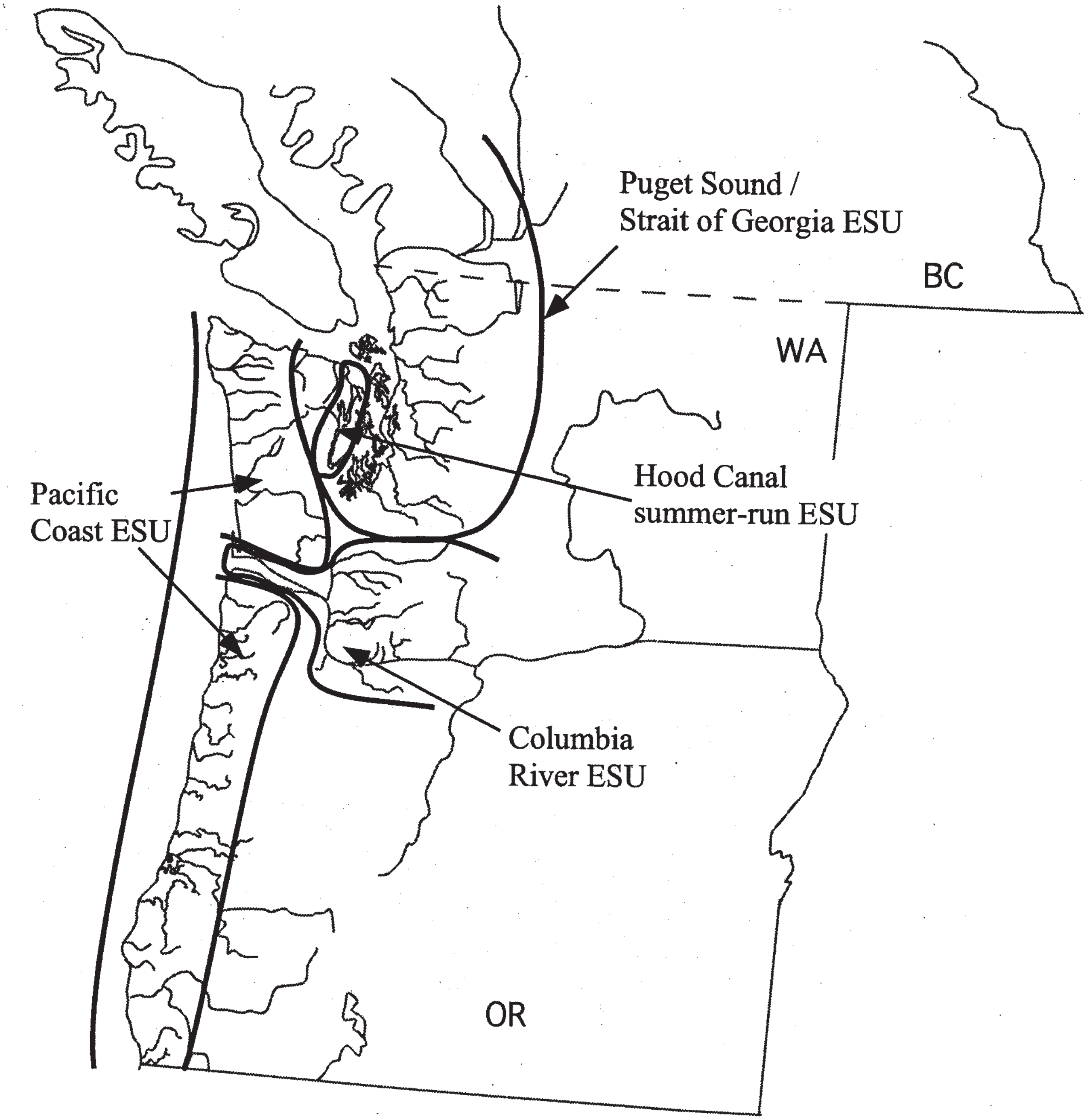

Figure 16. Locations of chum salmon Evolutionarily Significant Units (ESUs) identified by the Biological Review Team (BRT) for the U.S. Pacific Northwest. The Hood Canal summer-run ESU includes populations in Sequim and Discovery Bays in the Strait of Juan de Fuca.

run populations was not sufficient to designate these populations a separate ESU. Rather, the team concluded that these populations, along with the summer-run populations in southern Puget Sound, reflect patterns of diversity within a relatively large and complex ESU.

Hood Canal Summer-Run ESU

This ESU includes summer-run chum salmon populations in Hood Canal in Puget Sound and in Discovery and Sequim Bays on the Strait of Juan de Fuca. It may also include summer-run fish in the Dungeness River, but the existence of that run is uncertain. Distinctive life-history and genetic traits were the most important factors in identifying this ESU.

Hood Canal summer-run chum salmon are defined in SASSI (WDF et al. 1993) as fish that spawn from mid-September to mid-October. Fall-run chum salmon are defined as fish that spawn from November through December or January. Run-timing data from as early as 1913 indicated temporal separation between summer and fall chum salmon in Hood Canal. Even though for many years there have been hatchery releases of fall chum salmon in Hood Canal of about 35 million fish annually, and many[25] of these fish return to hatcheries in Hood Canal and were historically spawned before the end of October, recent spawning surveys show that temporal separation still exists between summer and fall chum salmon. Genetic data indicate strong and long-standing reproductive isolation between chum salmon in this ESU and other chum salmon populations in the United States and British Columbia. Hood Canal is also geographically separated from other areas of Puget Sound, the Strait of Georgia, and the Pacific Coast.

In general, summer-run chum salmon are most abundant in the northern part of the species' range, where they spawn in the main stems of rivers. Farther south, water temperatures are so high and stream flows are often so low during late summer and early fall that conditions become unfavorable for salmonids. River flows typically do not increase and water temperatures do not decrease until the arrival of fall rains in late October/November. Presumably for these reasons, few summer chum populations are recognized south of northern British Columbia. Ecologically, summer-run chum salmon populations from Washington must return to freshwater and spawn during peak periods of high water temperature, suggesting an adaptation to specialized environmental conditions that allow this life-history strategy to persist in an otherwise inhospitable environment. The BRT concluded, therefore, that these populations contribute substantially to the ecological/genetic diversity of the species as a whole.

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[25] As described in Table 14, WDFW data from the 1960s to 1980 (NRC 1995) identify a total of about 1.5 million fall chum salmon spawned at Hood Canal hatcheries before November. From 1980 to 1987, about 600,000 fish were spawned prior to November. In 1988 from 30 October to 5 November, about 2 million Finch Creek stock fall chum salmon were spwned. In recent years no fall chum salmon have been spawned prior to October 30th at state, tribal or federal hatcheries in Hood Canal.

Some chum salmon populations in the Puget Sound/Strait of Georgia ESU, which has four recognized summer-run populations and two recognized winter-run populations, also exhibit unusual run timing. However, allozyme data indicate that these populations are genetically closely linked to nearby fall-run populations. Therefore, variation in run timing has presumably evolved more than once in the southern part of the species' range. Genetic data indicate that summer-run populations from Hood Canal and the Strait of Juan de Fuca are part of a much more ancient lineage than summer-run chum salmon in southern Puget Sound.

Pacific Coast ESU

This ESU includes all natural chum salmon populations from the Pacific coasts of Washington and Oregon, as well as populations in the Strait of Juan de Fuca west of the Elwha River. This ESU is loosely defined at present, and is defined primarily on the basis of life-history and genetic information. Allozyme data show that coastal populations form a coherent group that show consistent differences between other fall-run populations in Washington and British Columbia. Geographically, populations in this ESU are also isolated from most populations in the Puget Sound/Strait of Georgia and Columbia River ESUs.

Ecologically, the western Olympic Peninsula and coastal areas inhabited by chum salmon from this ESU experience a more severe drought in late summer and are far wetter during the winter than areas in the Puget Sound/Strait of Georgia region. All chum salmon populations in this ESU are considered to include fall-run fish. Some Oregon populations are the only known locations to which 2-year-old adult chum salmon return with any appreciable frequency.

Chum salmon from this ESU cover a large and diverse geographic area—from the Strait of Juan de Fuca (lat. 48°20´N) to at least southern Oregon—and the historic ESU may have extended to the recorded extreme limit of the species' distribution near Monterey, California (lat. 36°50´N). Many BRT members concluded that multiple ESUs of chum salmon may exist in this area, but a more detailed evaluation was hampered by a scarcity of biological information of all types. It is possible that many (perhaps most) reports of chum salmon in California and southern Oregon do not represent permanent spawning populations, but rather episodic colonization from northern populations. Even if this is the case, however, the southern limit to permanent natural populations is unclear.

The boundary between this ESU and the Puget Sound/Strait of Georgia ESU is uncertain, particularly with respect to fall chum salmon in the Dungeness and Elwha Rivers. Genetic data for these two populations are ambiguous (Elwha—because of hatchery stocking) or nonexistent (Dungeness), and run timing is also largely uninformative regarding the affinities of these two populations. Although coastal populations generally return and spawn slightly earlier than those in Puget Sound, there is little difference in run timing between Puget Sound and Strait of Juan de Fuca populations. The Washington Department of Fish and Wildlife (Phelps et al. 1995) considers the Dungeness and Elwha River populations to be affiliated with Strait of Juan de Fuca populations to the west, primarily because of their geographic separation from inner Puget Sound fall-run populations. However, the transition to the wetter, coastal climate occurs west of the

Elwha and Dungeness Rivers on the Olympic Peninsula. After considerable discussion, the BRT concluded, based on available information, that fall chum salmon from the Dungeness and Elwha Rivers should be considered part of the Puget Sound/Strait of Georgia ESU.

Columbia River ESU

The BRT concluded that, historically, there was at least one ESU of chum salmon in the Columbia River. Ecologically, Columbia River tributaries differ in several respects from most coastal drainages. Genetic data are available only for two small Columbia River populations, which differ substantially from each other as well as from all other samples examined to date.

Historically, chum salmon were abundant in the lower reaches of the Columbia River and may have spawned as far upstream as the Walla Walla River (over 500 km inland). Today only remnant chum salmon populations exist, all in the lower Columbia River. They are few in number, low in abundance, and of uncertain stocking history.

The question of the extent of the Columbia River ESU along the Washington and Oregon coasts prompted considerable debate within the BRT. The BRT concluded, based upon the genetic and ecological data available, that chum salmon in the Columbia River were different enough from other populations in nearby coastal river systems (e.g., Willapa Bay, Grays Harbor, Nehalem River, and Tillamook River) that the Columbia River ESU should extend only to the mouth of the river.

Relationship to State Conservation Management Units

Busack and Shaklee (1995) identified Major Ancestral Lineages (MALs) and Genetic Diversity Units (GDUs are subdivisions of MALs) for several salmon species in Washington. This effort, which sought 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 (e.g., Leider et al. 1995). According to Busack and Shaklee (1995), GDU designations were based on a combination of genetic, life-history/ecological, and physiographic/ecoregion data. The authors also stated that they expected that individual ESUs would often include multiple GDUs but would be unlikely to include multiple MALs.

The geographic boundaries of the proposed ESUs for chum salmon are largely consistent with the GDUs and MALs identified by Phelps et al. (1995). With respect to populations in Washington, three of the ESUs for chum salmon proposed here (Puget Sound/Strait of Georgia, Hood Canal Summer-Run, and Coastal) are similar to MALs identified by WDFW. Each of the three MALs identified by WDFW included multiple GDUs. As noted above, one difference between the NMFS and WDFW frameworks is that Phelps et al. (1995) consider all fall chum salmon from the Strait of Juan de Fuca to be in the Coastal MAL, whereas the BRT includes the

Dungeness and Elwha River fall-run populations in the Puget Sound/Strait of Georgia ESU. Another difference is that the BRT recognize a Columbia River ESU, whereas Columbia River populations were considered by Phelps et al. (1995) to be part of two GDUs within a larger MAL that included coastal and Strait of Juan de Fuca populations.

Relationship to ESU Boundaries for Other Anadromous Pacific Salmonids

As part of an effort to complete comprehensive status reviews for all anadromous Pacific salmonids, NMFS has made ESU determinations for coho and pink salmon and steelhead from the same geographic areas covered by this status review for chum salmon. Although there are similarities in the geographic coverage of ESUs for these species, each species has distinctive attributes that merit special consideration.

The Puget Sound/Strait of Georgia ESU for chum salmon proposed here is similar in geographic coverage to ESUs for coho and odd-year pink salmon. As was the case for chum salmon, genetic and life-history data for both these species showed substantial genetic similarities between U.S. and Canadian populations. Although no recent genetic data are available for comparing U.S. and British Columbia steelhead populations, life-history data showed an abrupt change in smolt age at approximately the U.S.-Canada border, and this was a significant factor in the determination that the Puget Sound ESU for steelhead does not include populations from British Columbia. The western boundary for the Puget Sound/Strait of Georgia chum salmon ESU is similar to the boundaries proposed for coho, pink, and steelhead salmon ESUs.

The Hood Canal Summer-Run and Pacific Coast ESUs for chum salmon have no clear analogues in the other species for which comprehensive status reviews have been completed. However, the even-year pink salmon ESU (which contains a single U.S. population) shares with the Hood Canal Summer-Run ESU the features of restricted geographic range and a small number of component populations. The geographic coverage of the Pacific Coast ESU for chum salmon includes areas that are inhabited by steelhead and coho salmon from multiple ESUs. It is possible that additional information will indicate that multiple ESUs of chum salmon also occur in this area. The geographic extent of the Columbia River ESU for chum salmon is similar, but not exactly congruent with ESUs for coho salmon and steelhead in the same area.

ARTIFICIAL PROPAGATION

NMFS Artificial Propagation Policy

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, defined as the progeny of naturally spawning fish (Waples 1991). 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 substitutes 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, transfers of fish from one area to another might change the genetic or life-history characteristics of 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). Second, artificial propagation poses a number of risks to natural populations that may affect their risk of extinction or endangerment (see “Assessment of Extinction Risk,” p. 144). Finally, if any natural populations are listed under the ESA, 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 chum salmon.

Overview of Worldwide Artificial Propagation of Chum Salmon

More artificially propagated chum salmon are released annually into the Pacific Ocean than are any other salmonid species. The majority of these fish, from both Asia and North America, are released directly from hatcheries as 1- or 2-month-old fed fry, although unfed fry are occasionally released (as well as eyed eggs planted) (Mahnken et al. 1983, Salo 1991, NRC 1995). Traditionally, most chum salmon hatcheries released juveniles directly into freshwater streams located near seawater. More recently, releases of chum salmon juveniles from seawater acclimation facilities have become common, especially in Japan, northern Puget Sound (Lummi ponds), Hood Canal (the Hoodsport Hatchery in Hood Canal has acclimated chum salmon in seawater since the early 1950s), and on the Oregon coast.

Asia

Chum salmon are the primary focus of salmonid artificial production in Asia, and the vast majority of this production is from Japan (Fig. 17). Of 2.8 billion artificially propagated chum salmon released annually from Asia and North America, approximately 2 billion are from Japanese hatcheries (Mahnken et al. In press). Adult returns to Japanese coastal fisheries from these releases were more than 78 million fish in 1995 (Mahnken et al. In press). Japan has pioneered the production of hatchery chum salmon, and worldwide most programs follow guidelines developed in Japan. More than 300 chum salmon hatcheries are located on the islands of Honshu and Hokkaido, and at least 262 rivers are managed almost entirely for artificial propagation (Salo 1991).

Japanese hatchery programs started in 1888 with the construction of the Chitose River Central Hatchery in Hokkaido (Kaeriyama 1989). By 1900, 45 chum salmon hatcheries had been built in Japan; but until the 1960s, hatchery technology and fish culture practices (primarily unfed fry were released) were not well developed. In the 1960s, the Japanese began to feed fry in the hatcheries and to use cold well water to delay the time of release. This led to an increase in the size of juveniles at release in May, when coastal temperatures generally exceeded 10°C and oceanic conditions were most favorable to fry survival (Kobayashi 1980, Kaeriyama 1989). As the percentage of fed fry increased, return rates to both Honshu and Hokkaido hatcheries increased substantially, reaching 2.3% in Hokkaido after 1966 (Mahnken et al. 1983, Nasaka 1988, Isaksson 1988). By 1974, the Japanese catch of chum salmon had reached 10 million fish, the highest catch since the 1880s before artificial enhancement began (Mahnken et al. 1983). Since 1979, more than 1.5 billion juvenile chum salmon have been released annually, leading to recent annual harvests of over 40 million adults (Nasaka 1988, Isaksson 1988, Kaeriyama 1989). In 1995, more than 78 million chum salmon returned to Japanese rivers (Urawa[26]).

This success of Japanese hatchery programs has been attributed in part to efficient hatchery practices (e.g., seawater acclimation and to the timing of fry releases to coincide with coastal conditions favorable to survival [Kaeriyama 1989]), predator swamping (Peterman and Gatto 1978), decreased effort for chum salmon in offshore gill-net fisheries (Mathews 1990), and changing ocean conditions that favor survival (Pearcy 1992).

In Korea and China, small remnant populations of chum salmon are believed to exist, but no definitive information was found on their distribution and abundance. Folsom et al. (1992) reported that little artificial propagation of chum salmon has occurred in Korea, although the Japanese established a few hatcheries during their occupation of the Korean Peninsula in the early 1940s. Presently, in Korea, three hatcheries produce chum salmon: Yang Yang Inland Research Institute (NFRDA), Sam Ceog Inland Development Business in Gang Oweon Do, and the Inland Laboratory in Gyeong Bug. In 1996, the total number of hatchery-reared fry released

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[26] S. Urawa, Genetics Section, Research Division, Hokkaido Salmon Hatchery, 2 -2 Nakonoshima, Toyohira-ku, Sapporo 062, Japan. Pers. commun., June 1996.

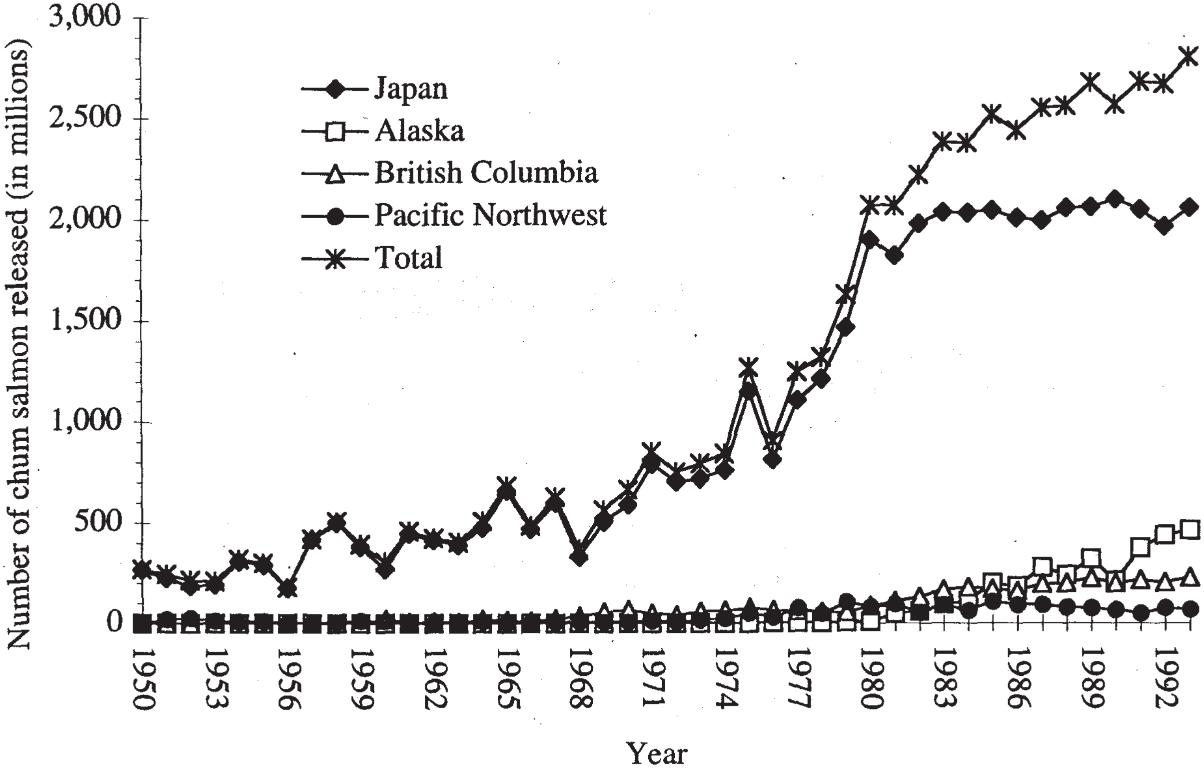

Figure 17. Releases of chum salmon into the North Pacific Ocean from artificial propagation facilities in Japan, Alaska, British Columbia, and the United States (1960 to 1993). Data from NRC (1995a).

from Korean hatcheries was about 15,850,000 fish, and the NFRDA facility produced about 75% of these fish. Most Korean chum salmon are released when they reach 7.0 cm in length (Baik[27]).

In the Russian Federation, about 1 billion chum fry are released from hatcheries each year, most of these on Sakhalin Island and the Kuril Islands (Zolotukhin and Augerot[28]). The first chum salmon hatchery in the Russian Far East was constructed in 1927-1928 at Teplovka Lake, a tributary of the Amur River. This hatchery produced an average of 23.2 million eggs and 20.4 million fry annually from 1938 to 1952. By the 1980s at least 17 hatcheries operated on Sakhalin Island, 3 on Iturup Island in the Kurile Archipelago, 4 on the Amur River, and 1 on the Kamchatka River (Atkinson 1983). Construction of new hatcheries has continued in the 1990s, primarily by joint Russian and Japanese cooperatives (Zolotukhin and Augerot footnote 29). Rukhlov (1982, cited in Atkinson 1983) reported that 391 million chum salmon and 468 million pink salmon were released from Russian hatcheries in 1978. During the 1970s, hatcheries on Sakhalin Island released approximately 150-200 million chum salmon fry annually (Kanid'yev et al. 1970). However, production has often been less than anticipated. In Primorye Territory, two chum salmon hatcheries built in 1986 have each produced only 10,000-30,000 chum fry per year, whereas plans called for production of 80 million (Zolotukhin and Augerot, footnote 29).

Unlike Japanese programs, Russian hatchery programs were never designed to manage rivers exclusively for hatchery fish. Russian hatcheries have generally used local chum salmon for broodstock, and no attempt has been made to block natural production. However, natural production and habitat protection were not first priorities: Chum salmon eggs were transferred among hatcheries, and surplus hatchery fish were allowed to spawn with natural fish (Atkinson 1964, 1983; Zolotukin and Augerot, footnote 29). In the late 1970s, on the advice of Russian geneticists, hatchery managers reduced the number of egg transfers to reduce the effects of interactions between natural and hatchery fish (Helle 1979).

Alaska

Until recently, chum salmon were not highly regarded by Alaskan fish culturists and were seldom propagated (Roppel 1982). However, in response to low salmon abundance in the early 1970s, chum salmon were identified in the Southeast Regional Plan as the preferred species for large-scale hatchery production (Bachen and Linley 1995), and legislation permitting the operation of private, nonprofit hatcheries was enacted in 1974 (McNair 1996). In the 1990s, over 450 million juvenile chum salmon have been released annually (Fig. 17), with a total of about 34 billion released since 1974 (McNair 1996). In 1995, there were 5 Alaska Department of Fish and

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[27] Kook-Ki Baik, Yang Yang Inland Research Institute, Gang Oweon Do National Fisheries Research and Development Agency, Yang Yang, RSK. Pers. commun., June 1996.

[28] S. Zolotukhin, Pacific Institute of Fisheries and Oceanographic Research (TINRO), Vladivostok, Russia, and Xan Augerot, Center for the Analysis of Environmental Change, Nash Hall, Oregon State University, Corvallis, OR. Pers. commun., August 1996.

Game (ADF&G) facilities and 31 private, nonprofit hatcheries propagating chum salmon in Alaska, with most of the effort concentrated in Prince William Sound and southeast Alaska (McNair 1996).

Hatchery releases in Alaska are very large compared to other North American chum salmon artificial propagation programs: In 1995, Hidden Falls Fish Hatchery on Baranof Island in southeast Alaska released more than 70 million juvenile chum salmon, Neets Bay Hatchery Complex in Prince William Sound released 66 million, and the Ester Lake Hatchery Complex released 96 million. By contrast, since 1974, total releases of chum salmon from several hatcheries in Hood Canal have averaged about 37.3 million fish per year. In 1995, hatcheries contributed more than 40% (16 million fish) of all chum salmon harvested in Alaska (McNair 1996).

An example of a large artificial propagation program in Alaska is the Hidden Falls Fish Hatchery, which has been especially successful in producing fish for harvest. Between 1978 and 1995, more than 13 million chum salmon returned to the facility, with 3.5 million adults returning in 1995. Hidden Falls Hatchery is the largest chum salmon producer in North America (McNair 1996), and the largest single producer of chum salmon outside Japan (Bachen 1994). The Hidden Falls Hatchery alone contributed about 22% of the chum salmon harvest in southeast Alaska in 1993 (Bachen and Linley 1995). To minimize any effect the hatchery program may have on local natural populations, the facility is located about 21 km from the nearest stream with a native run of chum salmon. Terminal harvests restricted to the vicinity of the hatchery apparently have minimized the interception and overharvest of natural chum salmon populations in other streams in the district. However, even small but persistent rates of straying from large hatchery programs can have a significant influence on nearby natural populations (see “Straying,” p. 61 and “Genetics of Chum Salmon,” p. 86).

British Columbia

More than 3.3 billion chum salmon have been released from hatcheries in British Columbia since 1960, with most of this production occurring since 1980 (Fig. 17). Currently, 90 facilities in British Columbia rear chum salmon to various early life stages before release, and 29 of these are spawning channels (Table 13) (NRC 1995). In the 1950s, the Canadian Department of Fisheries and Oceans began to use spawning channels to enhance the natural production of chum salmon, with an early facility located on Jones Creek on the Fraser River (Hourston and MacKinnon 1956). These channels allowed natural spawning and did not require the handling of fish. Recently, efforts by the provincial government to promote private participation in enhancement efforts have resulted in a large increase in the numbers of chum salmon hatcheries and spawning channels.

Table 13. Artifical spawning channels in British Columbia with the number of fish released and years of release (NRC 1995).

Channel name	Years in operation	Years fish released	Number of fish released
Airport	1981-93	12	20,182,198
Andesite	1987-90	4	445,235
Alouette	1989-91	3	484,552
B. C. Rail	1986-93	8	4,925,000
Brandt	1989-93	5	5,000,000
Brennen Park	1989-93	5	3,750,000
Englishman	1989-90	2	4,430,000
Glendale	1989-92	3	7,522,813
Hixon	1989-93	5	400,000
Hopedale	1988-93	6	6,191,073
Jitcoe	1988	1	169,500
Kawkawa	1989-93	5	750,000
Lang	1988-93	6	1,700,000
Mamquam	1984-93	10	15,686,000
Mashiter	1988-93	6	3,645,000
McNab	1987-92	6	2,985,736
Moodie's	1987-93	7	4,390,000
Paradise	1980-93	13	16,960,188
Pretty's	1988-93	6	400,000
Ruskin	1992, 93	2	1,250,000
Seabird	1985-91	7	657,700
Smokehouse	1987-93	7	6,411,790
Stave	1991-93	3	3,540,000
Tiampo	1988-93	5	2,500,000
Tower	1989-93	5	2,500,000
Usher	1992, 93	2	1,750,000
Weaver Creek	1966-93	28	152,739,338
Weldwood	1988-93	6	3,055,000
Westholme	1979-93	15	15,535,734
Total Releases:			**289,956,857**

Washington and Oregon

In the U.S. Pacific Northwest, approximately 85 million juvenile chum salmon have been released annually between 1983 and 1993 (Figs. 17 and 18), and most of this production has come from hatcheries in Washington (Figs. 19 and 20, Tables 14 and 15, and Appendix) (NRC 1995). Hatcheries in Oregon (Fig. 19 and Table 14) have released only small numbers of chum salmon, chiefly into rivers on the north coast of Oregon and into the lower Columbia River Basin (Table 15) (NRC 1995), but these releases were stopped by 1990 (Kostow 1995).

In most areas, the number of hatchery chum salmon produced in Washington is small compared to the number naturally produced, and very small compared to the number of hatchery fish produced annually in other areas such as Japan (2 billion) or Alaska (over 450 millon) (Fig 17) (Salo 1991, McNair 1996). Chum salmon are not the primary focus of salmon artificial propagation in either Washington (except Hood Canal) or Oregon, as they are in Asia. For example, in recent years, hatcheries in Washington have released almost as many juvenile coho salmon annually (75 million) (Weitkamp et al. 1995) as chum salmon, and the vast majority of these coho salmon are smolts, requiring a year of hatchery rearing, instead of the 0-2 months required by chum salmon. Also, while about 25 hatcheries rear chum salmon in Washington, there are more than 50 hatcheries in the state rearing coho salmon and more than 100 hatcheries rearing chinook salmon.

Many chum salmon hatchery programs in Washington have been highly successful, with the ratio of juvenile releases to adult returns similar to those of Japan. Many of these hatcheries have produced substantial numbers of fish relative to natural production, especially in areas where hatcheries have been used to supplement or create fall chum salmon fisheries. These areas include Hood Canal, Bellingham Bay, and Tulalip Bay in northern Puget Sound, the Nisqually River, and southern Puget Sound (WDF et al. 1993).

Egg-box programs and remote-site incubation facilities (RSI) were used extensively from the late 1970s to early 1990s in the Pacific Northwest (Figs. 21 and 22). These programs incubate salmon eggs in streamside facilities, producing emergent unmarked, unfed fry (defined as all fish released at less than 0.4 g in the NRC [1995] database) and are particularly attractive for chum salmon because of the species' early immigration into seawater (Fuss and Seidel 1987). The potential contribution of releases of unfed fry from egg-box, RSI, and hatchery facilities may have been substantial. Estimates from the NRC database (1995) indicate that approximately 12% of all chum salmon released in Washington from 1970 to 1990 were unfed fry. Further, the number of releases from egg boxes and RSIs has been concentrated in some locations (e.g., Hood Canal, Fig. 22) (WDF et al. 1993, Fuss and Fuller 1994).

Although the effect of unfed fry releases may be substantial, it is extremely difficult to estimate how many unfed fry enter rivers of their own volition from the wide variety of eggbox, RSI, and other programs producing fry throughout the Northwest. Consequently, unfed fry have been excluded from the tabulation of artificially propagated chum salmon in Table 16 and the evaluation of these programs within this Section. Possible ecological effects of unfed fry releases

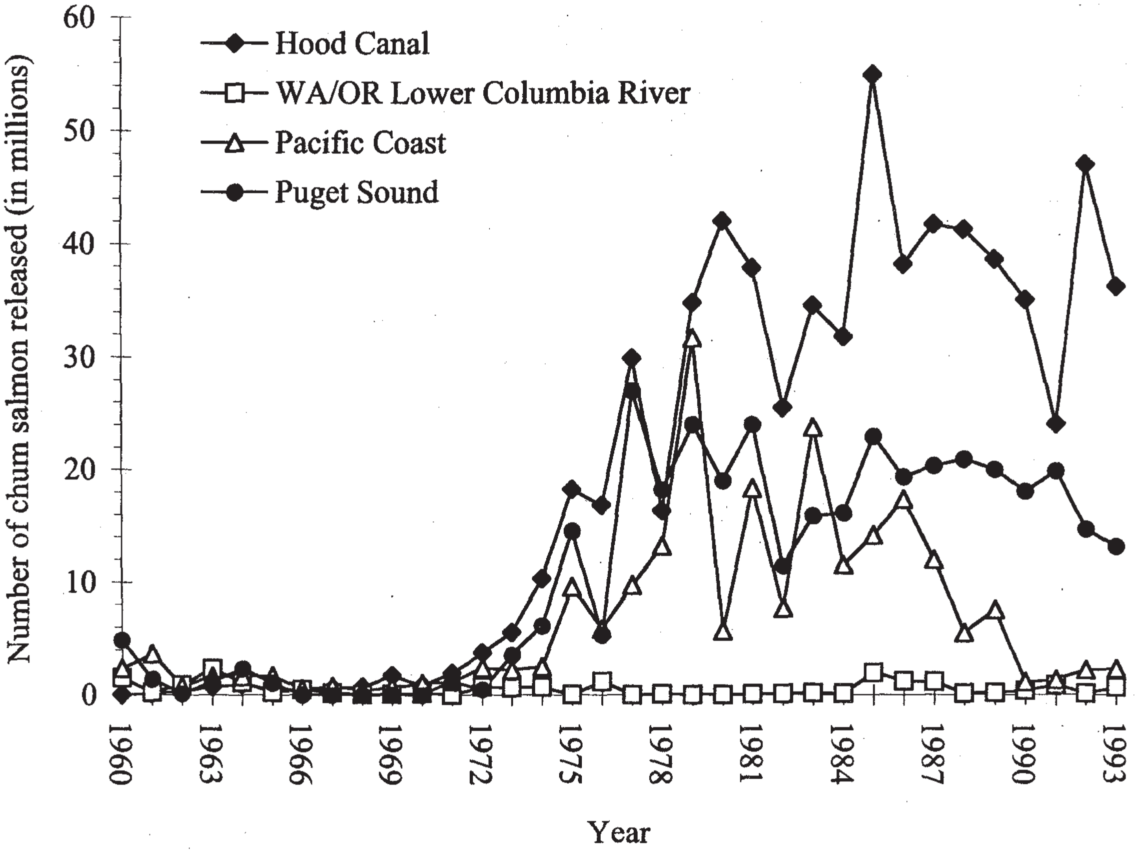

Figure 18. Releases of chum salmon from artificial propagation facilities into Washington waters by geographic region (1960 to 1993). Data from NRC (1995).

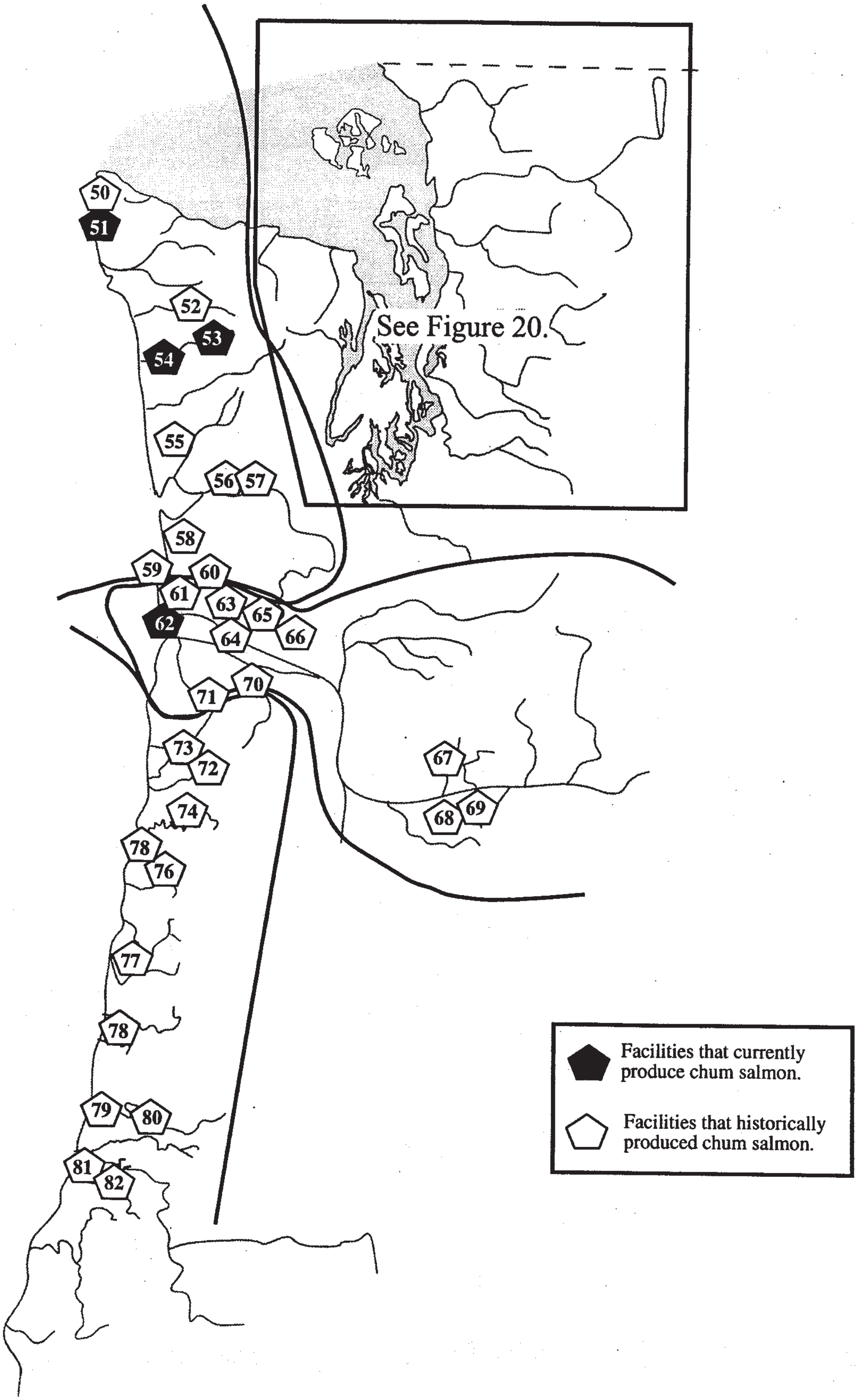

Figure 19. Hatcheries that produce chum salmon in the Pacific Coast and Columbia River ESUs. Numbers refer to locations described in Table 14.

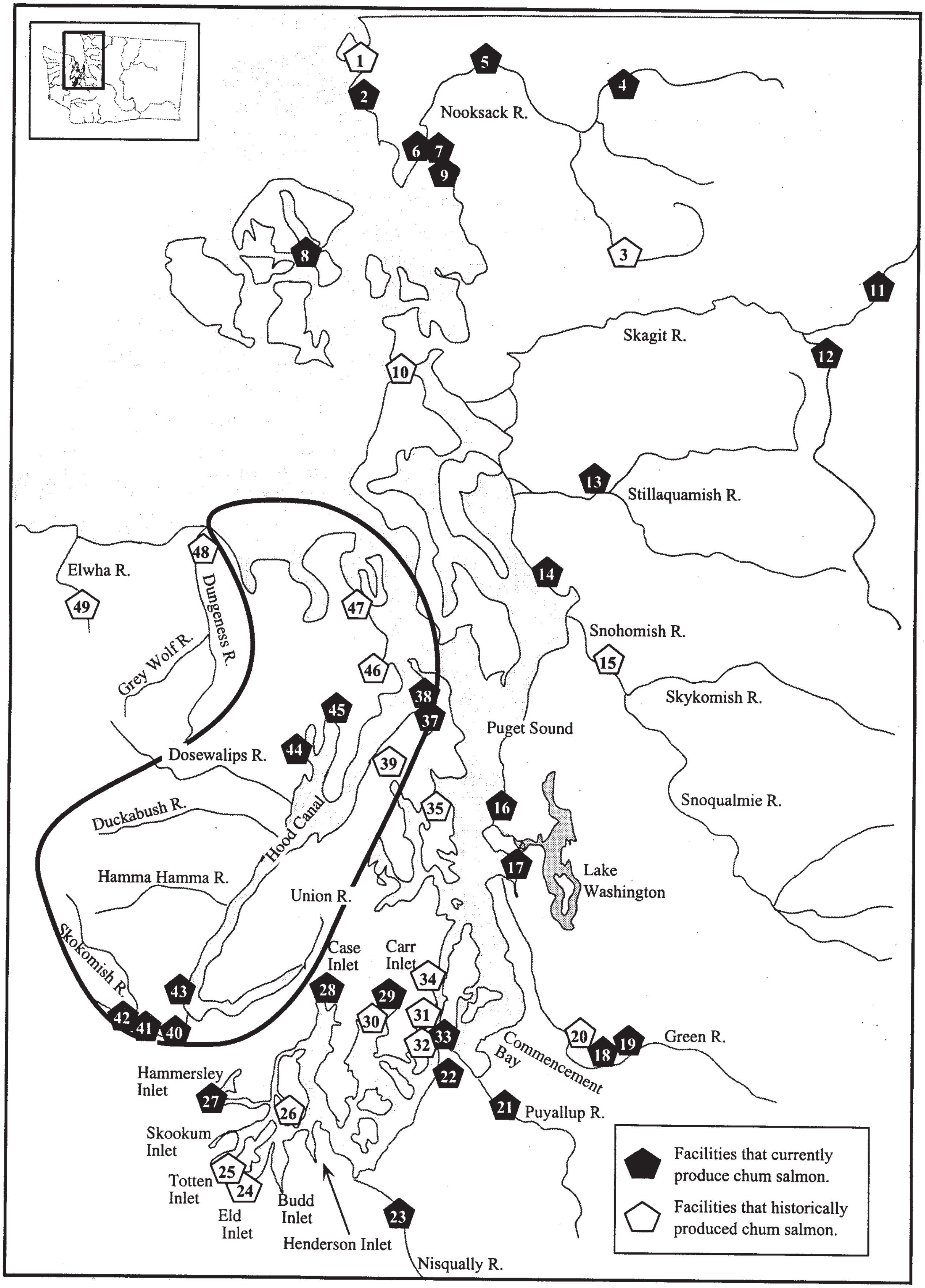

Figure 20. Hatcheries that produce chum salmon in the United States' portion of the Puget Sound/Strait of Georgia ESU and in the Hood Canal Summer-run Chum Salmon ESU (circled). Numbers refer to locations described in Table 14.

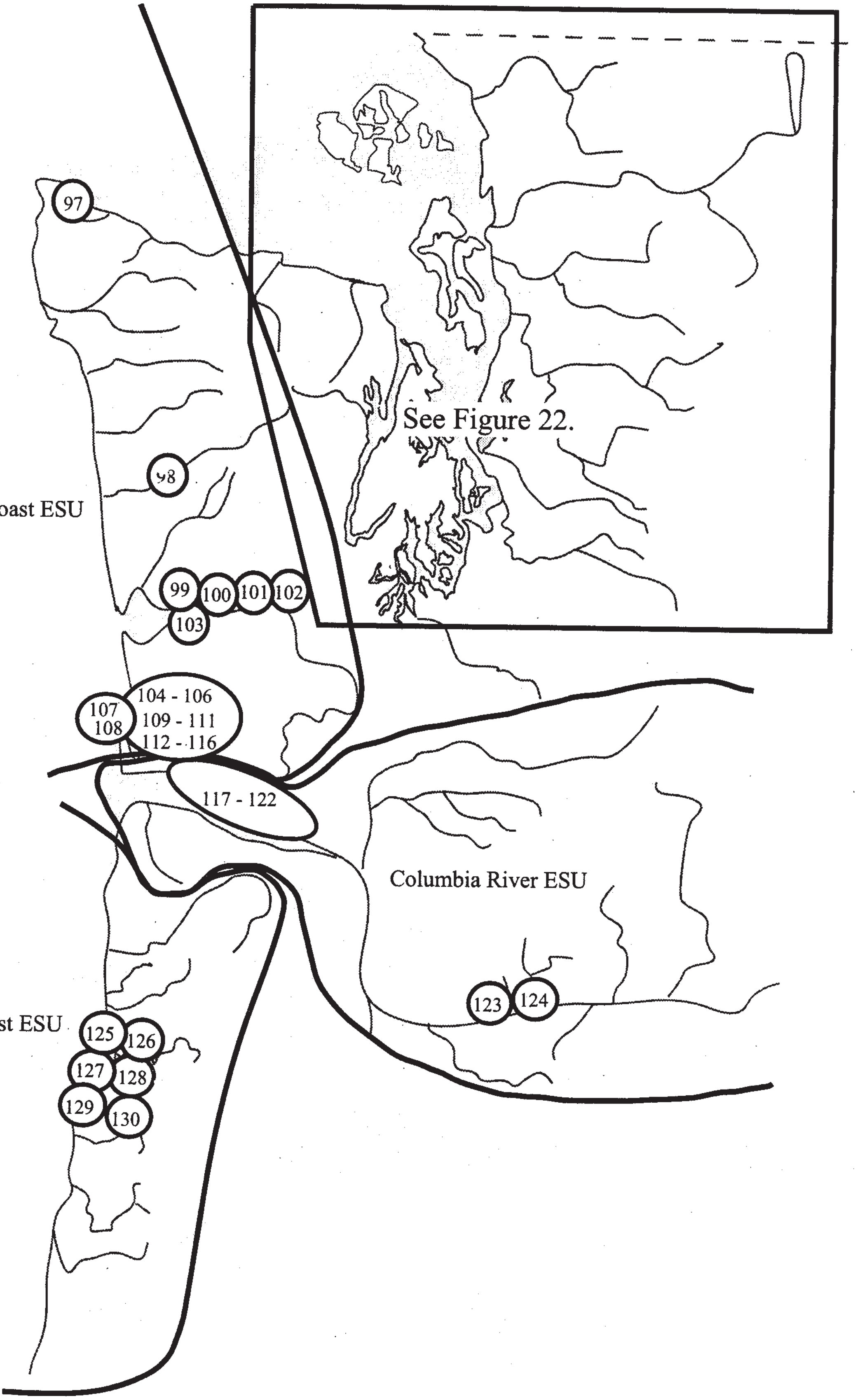

Figure 21. Locations of chum salmon egg box or remote incubator sites in the Pacific Coast and Columbia River ESUs. Numbers refer to locations and years of operation described in Table 16.

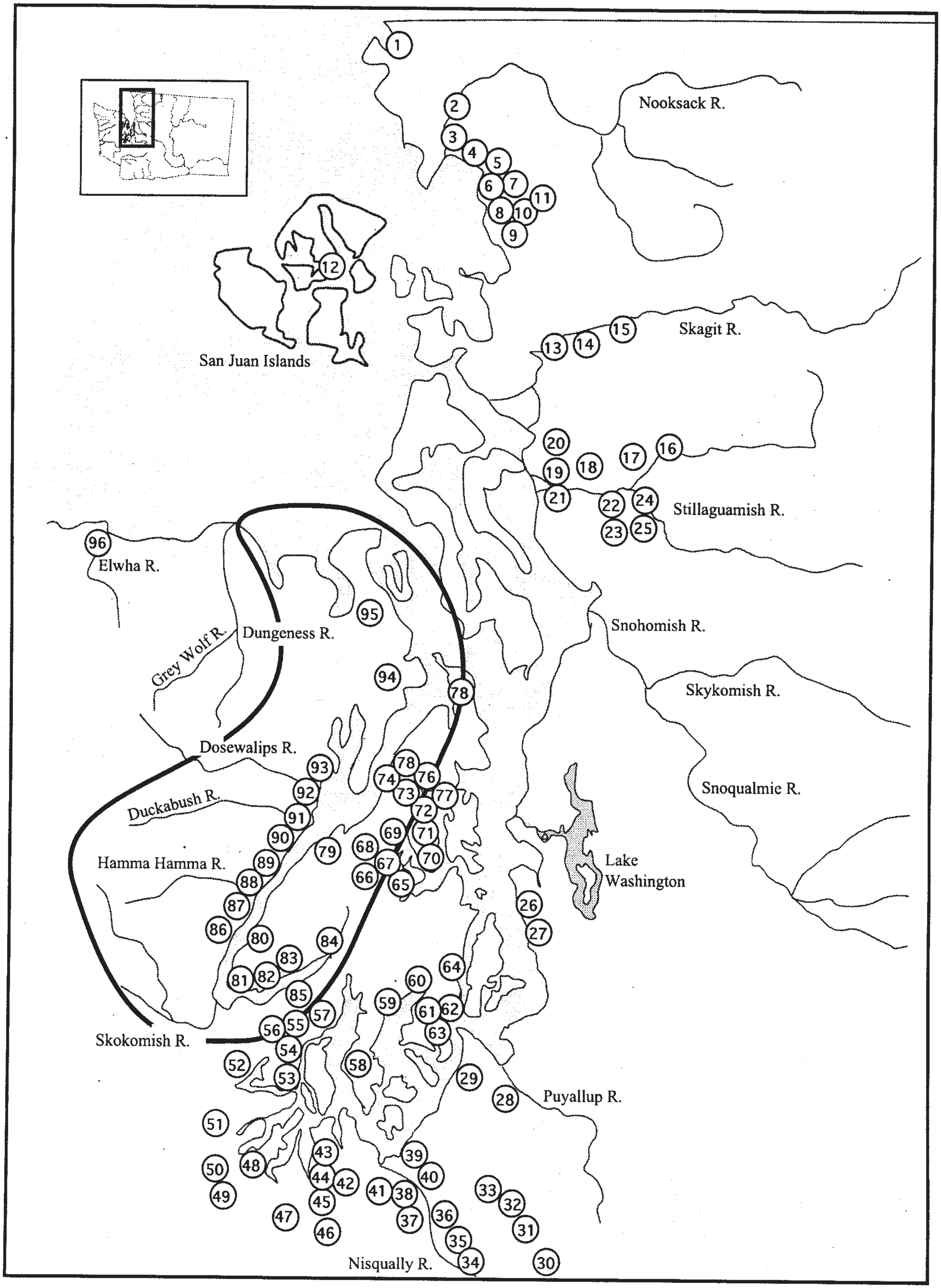

Figure 22. Locations of chum salmon egg box or remote incubator sites that have occurred in the United States' portion of the Puget Sound/Strait of Georgia ESU and in the Hood Canal Summer-run Chum Salmon ESU (circled). Numbers refer to locations described in Table 16.

Table 14. Hatcheries in the U.S. Pacific Northwest (by evolutionarily significant unit [ESU]) that have recently produced chum salmon.

State	Facility	Agency	Years	Location	Code
	ESU 1 - Puget Sound				
WA	Drayton Harbor	COOP	1980-81	Dakota Cr.	1
WA	Lummi Sea Ponds	Tribe	1975-Pres.	Lummi Bay	2
WA	Lummi	Tribe	1983-84	Skookum Cr. (Nooksack R.)	3
WA	Nooksack Hatchery	WDFW	1954-Pres.	Kendall Cr. (Nooksack R.)	4
WA	Nooksack	Tribe	1979-Pres.	Nooksack River	5
WA	Whatcom/Bellingham	COOP	1979-Pres.	Whatcom Cr.	6
WA	Bellingham/Samish Bay	COOP	1978-Pres.	Oyster Cr.	7
WA	Friday Harbor	COOP	1977-Pres.	San Juan Island	8
WA	Samish	WDFW	1950-Pres.	Friday Cr.	9
WA	Bowman's Bay	WDFW	1950-65	Deception Pass	10
WA	Skagit	WDFW	1950-Pres.	Clark Cr. (Skagit R.)	11
WA	Skagit	Tribe	1977-Pres.	Red Cr. (Sauk R.)	12
WA	Stillaguamish	Tribe	1979-Pres.	Strong Cr. (Stillaguamish R.)	13
WA	Tulalip	Tribe	1976-Pres.	Tulalip Cr.	14
WA	Skykomish	WDFW	1975-87	May Cr. (Skykomish R.)	15
WA	Carkeek	COOP	1991-Pres.	Carkeek Cr.	16
WA	Seattle Aquarium	COOP	1977-Pres.	Elliott Bay	17
WA	Muckleshoot	Tribe	1976-Pres.	Keta Cr. (Green R.)	18
WA	Muckleshoot	Tribe	1989-Pres.	Crisp Cr. (Green R.)	19
WA	Green	WDFW	1951-62	Big Soos Cr.	20
WA	Puyallup	Tribe	1977-Pres.	Diru Cr. (Puyallup R.)	21
WA	Garrison Springs	WDFW	1972-Pres.	Chambers Cr.	22
WA	Nisqually	Tribe	1977-Pres.	Kalama Cr. (Nisqually R.)	23
WA	Allison Springs	WDFW	1977-84	Mclane Cr. (So. Puget Sound)	24
WA	Squaxin	Tribe	1979-83	Elson Cr. (So. Puget Sound)	25
WA	Squaxin Island Pens	COOP	1984-89	Peale Passage	26
WA	Shelton	WDFW	1979-Pres.	Oakland Bay	27
WA	Coulter Cr.	WDFW	1979-Pres.	Case Inlet	28
WA	Minter Cr.	WDFW	1950-Pres.	Carr Inlet	29
WA	Hupp Springs	WDFW	1980-87	Carr Inlet	30
WA	Penninsula	COOP	1979-86	Gig Harbor	31
WA	Gig Harbor Civic Club	COOP	1976-91	Gig Harbor	32
WA	Save Our Salmon	COOP	1989-Pres.	Gig Harbor	33
WA	Ollala Elementary	COOP	1989-92	Colvos Passage	34
WA	Agate Pass Sea Pens	COOP	1986-91	Agate Pass	35

Table 14 (Continued).

State	Facility	Agency	Years	Location	Code
WA	Suquamish	Tribe	1977-93	Cowling Cr.	36
WA	Port Gamble	Tribe	1977-Pres.	Little Boston Cr.	37
WA	Port Gamble Pens	Tribe	1977-Pres.	Port Gamble	38
WA	Big Beef Cr.	UW	1977-85	Big Beef Cr.	39
WA	McKernan	WDFW	1979-Pres.	Skokomish River	40
WA	George Adams	WDFW	1963-Pres.	Skokomish River	41
WA	Skoomish	Tribe	1977-Pres.	Skokomish River	42
WA	Hood Canal	WDFW	1955-Pres.	Finch Cr.	43
	ESU 2 - Hood Canal Summer Run				
WA	Hood Canal	WDFW	1962-66	Finch Cr.	43
WA	Quicene NFH	USFWS	1993-Pres.	Quilcene River	44
WA	Quilcene	USFWS	1951-Pres.	Big Quilcene River	45
WA	Wild Olympic Salmon	COOP	1989-Pres.	Dabob Bay	46
WA	Robert Sanders	COOP	1987-90	Ludlow Cr.	47
WA	Chilicum High School	COOP	1985-90	Chimicum Cr.	48
WA	Dungeness	WDFW	1950-88	Dungeness River	49
WA	Elwhat	Tribe	1977-86	Elwha River	50
	ESU 3 - Pacific Coast				
WA	Makah	Tribe	1978-88	Waatch Cr.	51
WA	Makah NFH	USFWS	1982-Pres.	Sooes River	52
WA	Hoh	Tribe	1978-81	Chalaat Cr.	53
WA	Quinault Net Pen	Tribe	1973-Pres.	Lake Quinault	54
WA	Quinault NFH	USFWS	1970-Pres.	Cook Cr.	55
WA	Simpson	WDFW	1958-88	Bingham Cr. (Satsop R.)	56
WA	Satsop Springs	WDFW	1978-86	Satsop River	57
WA	Humptulips	WDFW	1977-86	Humptulips River	58
WA	Willapa	WDFW	1958-69	Fork Cr. (Willapa R.)	59
WA	Willapa Bay Gillnetters	COOP	1977-91	Willapa River	60
WA	Nemah	WDFW	1958-91	Nemah River	61
WA	Naselle	WDFW	1980-89	Naselle River	62
OR	Nehalem	ODFW	1939-60	Foley Cr. (Nehalem R.)	73
OR	Nehalem CSCO	Private	1981-93	Vosberg Cr.	74
OR	Trask	ODFW	1937-61	Gold Cr. (Trask R.)	75
OR	Netarts Bay	Private	1970-90	Whiskey Cr.	76
OR	Keta	Private	1972-87	Jewell Cr. (Sand Lk.)	77
OR	Oregon Aquafoods 1	Private	1975-87	Yaquina Bay	78

Table 14 (Continued).

State	Facility	Agency	Years	Location	Code
OR	Harris & Hugie	Private	1973-75	Dick Cr. (North Coast)	79
OR	Suislaw Fisheries	Private	1973-81	Sweet Cr. (Suislaw R.)	80
OR	Domsea Farms	Private	1981-83	North Spit (Suislaw Bay)	81
OR	Oregon Aquafoods 2	Private	1979	Coos Spit	82
OR	Heckard	Private	1983-87	Catching Slough (Coos Bay)	83
	ESU 4 - Columbia River				
WA	Sea Resources	COOP	1972-Pres.	Chinook River	63
WA	Grays	WDFW	1963-76	Grays River	64
WA	LCR Gillnetters	COOP	1978-83	Lower Columbia River	65
WA	Elokomin	WDFW	1958-69	Elokomin River	66
WA	Abernathy NFH	USFWS	1960-91	Abernathy Cr.	67
WA	Little White Salmon NFH	USFWS	1951-64	Little White Salmon River	68
OR	Bonneville	ODFW	1930-45	Tanner Cr.	69
OR	Oxbow	ODFW	1939-58	Herman Cr.	70
OR	Big Cr.	ODFW	1940-84	Big Cr.	71
OR	Klaskanine	ODFW	1929-85	Klaskanine River	72

Table 15. Hatchery releases of chum salmon in the U.S. Pacific Northwest by evolutionarily significant unit (ESU) and watershed.

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
ESU 1. Puget Sound/Strait of Georgia summer and fall runs					
Summer run					
South Puget Sound	1977-92	16	Johns Creek	27,723,595	27,723,595
Fall run					
North Puget Sound	1960, 61	2	Samish River	1,493,510	1,493,510
Nooksack River	1975-79	5	Big Quilcene River	5,655,009	
	1981	1	Chambers Creek	29,400	
	1980-83	3	Finch Creek	7,409,135	
	1980-84	4	Lummi Bay	3,911,000	
	1981	1	May Creek	81,100	
	1979-93	13	Nooksack River	10,519,402	
	1984	1	Oyster Creek	598,500	
	1953-85	9	Samish River	2,438,894	
	1974-80	4	Unknown	1,265,100	
	1976, 77	2	Walcott Slough	268,107	
	1984-93	10	Whatcom Creek	10,597,092	42,772,739
Samish River	1974	1	Big Quilcene River	1,486,400	
	1975	1	Finch Creek	1,492,000	
	1953-2	21	Samish River	8,583,157	
	1960-66	4	Unknown	2,002,909	
	1987, 91	2	Whatcom Creek	1,218,000	14,782,466
Skagit River	1977	1	Big Quilcene River	2,797,893	
	1955-92	11	Clark Creek	4,403,677	
	1972-75	4	Finch Creek	7,170,284	
	1953, 57	2	Samish River	274,800	
	1974-93	11	Skagit River	2,706,595	
	1976	1	Undetermined Mixed	27,946	
	1975	1	Walcott Slough	4,330,260	21,711,455
Stillaguamish River	1979-93	14	Stillaguamish River	9,347,440	9,347,440
Tulalip/Mission Creeks	1974-83	7	Big Quilcene River	3,427,200	
	1977	1	Finch Creek	974,600	
	1977	1	May Creek	992,650	

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
	1988	1	Tulalip Bay	7,618,000	
	1986-92	7	Tulalip Creek	34,576,000	
	1978	1	Unknown	1,840,174	
	1973-82	6	Walcott Slough	4,500,408	53,929,032
Skykomish River	1975-78	3	Finch Creek	5,482,789	
	1978	1	May Creek	45,510	
	1975	1	Walcott Slough	1,791,905	
	1987	1	Wallace River	260,300	7,580,504
Snohomish River	1985	1	May Creek	598,000	
	1993	1	Minter Creek	50,000	
	1957-59	2	Walcott Slough	244,835	
	1983, 84	2	Wallace River	952,717	1,845,552
Lake Washington	1989-92	4	Elson Creek	80,000	
	1984-93	7	Minter Creek	225,800	
	1980, 90	2	Portage Bay	6,000	311,800
Green River	1976	1	Big Quilcene River	10,000	
	1982-85	3	Big Soos Creek	524,600	
	1961	1	Columbia River	246,500	
	1991-93	3	Cowling Creek	1,455,123	
	1981-89	5	Creekisp Creek	3,556,381	
	1990, 91	2	Elson Creek	116,500	
	1977-80	4	Finch Creek	2,751,015	
	1985-87	3	Keta Creek	1,372,488	
	1953;84-93	6	Minter Creek	609,260	
	1977-79	3	Unknown	90,000	10,731,867
Puyallup River	1984-93	7	Chambers Creek	2,570,069	
	1989, 90	2	Clarks Creek	401,451	
	1978-80	3	Finch Creek	1,179,229	
	1977, 81	2	George Adams	800,561	
	1987	1	Hylebos Creek	52,744	
	1983	1	Voight Creek	20,700	5,024,754
Chambers Creek	1977-92	7	Chambers Creek	4,365,030	
	1960, 61	2	Columbia River	524,669	
	1975-80	3	Finch Creek	3,428,090	8,317,789
Nisqually River	1961	1	Columbia River	49,880	
	1991	1	Kalama Creek	31,440	

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
	1992	1	Kalama Falls	550	
	1984	1	Kennedy Creek	230,541	
	1977-90	9	Nisqually River	4,828,316	
	1961, 62	2	Unknown	212,640	5,353,367
South Puget Sound	1984	1	Allison Springs	70,000	
	1975, 77	2	Big Quilcene River	3,694,255	
	1977-92	9	Chambers Creek	4,373,377	
	1978-86	6	Chico Creek	4,146,476	
	1960, 61	2	Columbia River	740,450	
	1980-92	13	Coulter Creek	14,412,710	
	1984-93	8	Cowling Creek	127,692,191	
	1978	1	Deschutes River/Hatchery	327,000	
	1976-82	3	Donkey Creek	634,526	
	1979-93	14	Elson Creek	39,966,655	
	1971-93	12	Hokkaido	28,969,761	
	1976	1	George Adams	3,976,608	
	1987	1	Gorst Creek	45,000	
	1985	1	Grovers Creek	164,909	
	93	1	Johns Creek	390,381	
	1977-92	16	Kennedy Creek	14,204,891	
	1977-83	5	May Creek	10,296,190	
	1981	1	Mcallister Creek	45,970	
	1981	1	Minter Creek	50,483	
	1952-64	10	Minter Creek	18,797,023	
	1975-93	15	Minter Creek and Hatchery	34,477,106	
	1979	1	Samish River	4,222,501	
	1964	1	Sherwood Creek	898,200	
	1977-87	8	Unknown	4,450,008	
	1957-79	5		1,953,641	319,000,312
West Puget Sound	1959, 60	2	Big Quilcene River	2,059,704	
	1980	1	Chico Creek	45,000	
	1983-93	11	Cowling Creek	4,943,859	
	1974, 93	2	Finch Creek	106,190	
	1985-88	4	Gorst Creek	507,492	
	1977	1	Lacky Creek	302,500	
	1993	1	Minter Creek	26,000	
	1958, 65	2	Samish River	200,100	
	1959-63	3	Unknown	1,953,641	10,144,486

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
North Hood Canal	1980-84	5	Big Beef Creek	538,312	
	1977-79	2	Big Quilcene River	5,183,023	
	1983	1	Chambers Creek	73,000	
	1971-93	14	Finch Creek	21,123,327	
	1985, 93	2	George Adams	3,251,768	
	1988	1	Gorst Creek	54,317	
	1984-93	7	Little Boston Creek	3,165,900	
	1987	1	Mckernan	108,000	
	1977-79	3	Unknown	1,461,738	
	1975-79	3	Walcott Slough	200,000	35,159,385
South Hood Canal	1983	1	Allison Springs	906,000	
	1974-81	6	Big Quilcene River	7,972,245	
	1983	1	Chambers Creek	37,000	
	1982-93	12	Enetai Creek	25,430,571	
	1955-93	33	Finch Creek	446,971,195	
	1984-94	8	George Adams	137,750,050	
	1982-93	10	Mckernan	8,573,200	
	1982-93	10	Mckernan and Hatchery	60,287,720	
	1992	1	Minter Creek	10,000	
	1958	1	Samish River	50,000	
	1984	1	Walcott Slough	566,852	688,554,833
West Hood Canal	1983	1	Allison Sprs	504,500	
	1952, 74-93	11	Big Quilcene River	7,972,245	
	1982, 91-93	4	Enetai Creek	4,466,593	
	1970-93	14	Finch Creek	21,123,327	
	1983-93	7	George Adams	3,251,768	
	1990	1	Hood Canal Mixed	2,353,069	
	1977	1	Johns Creek	1,433,820	
	1985, 86	2	Mckernan	3,930,700	
	1983	1	Minter Creek	810,000	
	1987	1	Quilcene+Walcott	2,503,091	
	1972, 79	2	Unknown	1,799,270	
	1951-89	37	Walcott Slough	167,853,509	218,001,892
Chimicum/Ludlow	1952	1	Big Quilcene River	129,500	
	1986	1	Finch Creek	15,000	
	1985-89	3	George Adams	23,000	

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
	1987	1	Mckernan	15,000	182,500
Snow Creek	1970	1	Finch Creek	188,748	188,748
Dungeness River	1952	1	Big Quilcene River	1,099,855	
	1964	1	Dungeness River	66,848	
	1970, 79	2	Finch Creek	1,350,000	2,516,703
Elwha River	1977-80	4	Big Quilcene River	8,111,856	
	1980-86	7	Elwha River	2,511,140	
	1981, 82	2	Enetai Creek	1,051,842	
	1979	1	Unknown	9,445	
	1980	1	Walcott Slough	165,000	11,849,283
ESU 2. Hood Canal summer run					
South Hood Canal	1962-66	3	Finch Creek	250,000	250,000
West Hood Canal	1993, 94	2	Quilcene River	241,225	241,225
ESU 3. Pacific Coast/Strait of Juan De Fuca fall run					
Lyre River	1970	1	Finch Creek	188,748	188,748
Sail River	1978, 79	2	Unknown	174,000	174,000
Waatch River	1980	1	Big Quilcene River	1,097,744	
	1982	1	Chambers Creek	806,000	
	1959	1	Dungeness	40,000	
	1979, 83	2	Unknown	955,700	
	1985-88	3	Walcott Slough	1,084,775	3,984,219
Sooes River	1983	1	Cook Creek	551,978	
	1982-93	9	Sooes River	2,062,435	
	1986	1	Sooes River+Walcott	2,351,900	
	1975-79	5	Unknown	8,647,222	
	1984-88	4	Walcott Slough	6,549,478	20,163,013
Quillayute River	1980	1	Finch Creek	6,000	
	1985, 86	2	Walcott Slough	316,500	
	1964	1	Minter Creek	50,433	372,933

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
Hoh River	1980	1	Finch Creek	1,000	
	1973	1	Nemah River	31,050	
	1978, 79	2	Unknown	493,000	
	1981, 85	2	Walcott Slough	402,000	927,050
Queets River	1975, 78	2	Walcott Slough	1,009,800	1,009,800
Raft River	1978	1	Walcott Slough	676,000	676,000
Quinault River	1977	1	Big Quilcene River	490,000	
	1975-93	8	Cook Creek	4,317,023	
	1985, 86	2	Elson Creek	2,031,490	
	1970-93	19	Quinault River	10,720,004	
	1979	1	Quinault+Quilcene	2,200,000	
	1975, 76	2	Quinault+Walcott	204,415	
	1972-84	13	Unknown	23,344,966	
	1971-78	5	Walcott Slough	4,375,259	47,683,157
Humptulips River	1979	1	Finch Creek	2,697,512	
	1977-86	9	Humptulips River	7,706,547	
	1978-83	3	Nemah River	1,467,154	11,871,213
Chehalis River	1977, 79	2	Finch Creek	1,896,079	
	1981	1	Humptulips River	13,000	
	1979, 83	2	Nemah River	2,527,262	
	1958-87	21	Satsop Springs	9,839,128	
	1978, 82	2	Satsop River and Hatchery	1,042,644	
	1974, 79	2	Unknown	324,696	
	1981, 93	2	Wishkah River	203,000	15,845,809
North River	1991-93	3	Nemah River	992,000	992,000
Willapa River	1958, 69, 91	3	Nemah River	1,051,319	
	1959-62	3	Unknown	250,330	1,301,649
Palix River	1991	1	Nemah River	130,000	130,000
Nemah River	1982, 86	2	Ellsworth Creek	453,000	
	1958-89	31	Nemah River	39,078,369	
	1961, 62, 88	3	Unknown	5,286,160	44,817,529

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
Naselle River	1982-86	3	Ellsworth Creek	1,855,202	
	1977	1	Finch Creek	475,000	
	1984-89	5	Nasell River	9,495,800	
	1973-87	9	Nemah River	1,960,000	
	1978, 79	2	Unknown	762,586	
	1979-87	6	Fork Creek	670,000	
	1980-87	7	Williams Creek	14,377,383	29,595,971
Bear River	1977-79	2	Unknown	938,300	938,300
Nehalem	1943	1	Nehalem River/Big Creek	1,735,700	
	1960-89	9	Nehalem River	4,049,549	
	1984-93	10	Netarts Bay	3,337,500	9,122,749
Miami River	1959, 60	2	Salmon River	275,719	275,719
Netarts Bay	1987-89	3	Coos Bay	860,000	
	1970-90	17	Netarts Bay	11,157,268	12,017,268
Nestucca River	1978, 79	2	Nehalem River	773,300	
	1972-87	10	Nestucca River	2,155,500	2,928,800
Neskowin River	1982	1	Neskowin River	99,985	99,985
Yaquina Bay	1974-84	6	Netarts Bay	3,295,525	
	1975, 79	2	Hood Canal	1,038,175	
	1982-84	3	Nehalem River	1,203,589	
	1981	1	Nisqually River	342,999	
	1981	1	Minter Creek	457,556	
	1982-87	4	Oregon Aqua Foods	1,826,780	
	1978	1	S. Puget Sound	2,174	
	1981-85	3	Unknown	4,022,339	12,189,137
Alsea River	1973-75	3	Netarts Bay	26,600	26,600
Siuslaw River	1974, 79	2	Hood Canal	1,603,800	
	1977-81	5	Siuslaw River	341,300	
	1973, 75	2	Netarts Bay	809,500	2,754,600
Coos Bay	1985, 87	2	Coos River	26,000	
	1983, 79	2	Netarts Bay	702,000	
	1979	1	Unknown	8,212,354	

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
	1981	1	Johns Creek	176,000	
	1982	1	Siuslaw River	58,000	9,174,354
ESU 4. Columbia River					
Chinook River	1973	1	Bear River	74,910	
	1973-94	15	Chinook River	2,655,571	
	1986	2	Naselle River	405,149	
	1970, 87	2	Nemah River	295,265	
	1972-79	4	Unknown	178,482	3,609,377
Grays River	1973, 74	2	Big Quilcene River	1,175,916	
	1963-74	14	Grays River	1,233,652	
	1978, 79	2	Unknown	102,000	2,511,568
Skamokawa Creek	1983	1	Ellsworth Creek	60,000	
	1983	1	Finch Creek	100,000	
	1982	1	Hood Canal	80,000	
	1978, 79	2	Unknown	112,000	352,000
Elokomin River	1979	1	Hood Canal	376,000	
	1973, 74	2	Big Quilcene River	1,175,916	
	1983	1	Ellsworth Creek	125,000	
	1958-69	7	Elochoman River	1,927,853	
	1972	1	Finch Creek	638,493	
	1976	1	Hokkaido	1,126,752	
	1963-74	9	Grays River	1,233,652	
	1982	1	Hood Canal+Ellsworth R.	140,000	
	1978, 79	2	Unknown	102,000	6,845,666
Abernathy Creek	1963	1	Mixed	791,700	
	1964-67	3	Abernathy Creek	198,913	
	1961	1	Chehalis River	228,900	
	1986	1	George Adams+Abernathy	742,871	
	1991	1	Grays River	157,798	
	1982	1	Hood Canal+Ellsworth R.	625,000	
	1987	1	Nemah River	923,400	
	1960, 64	2	Quilcene River	911,160	
	1962	1	Quilcene River/Big Creek	484,800	
	1958	1	Unknown	559,880	

Table 15 (Continued).

Watershed	Years planted	No. of years planted	Stock planted	Stock Total	Watershed totals
	1959	1	Walcott Slough	250,000	5,874,422
Germany Creek	1983	1	Ellsworth Creek	65,000	
	1982	1	Hood Canl	60,000	125,000
Little White Salmon River	1951-64	9	Unknown	2,501,053	2,501,053
Youngs River	1984	1	Big Creek	10,010	10,010
Big Creek	1940-84	18	Big Creek	1,501,366	1,501,366
Klaskanine River	1930-44, 84	7	Klaskanine River	1,924,218	
	1942, 43	2	Klaskanine R./Big Creek	3,193,500	
	1929, 30		Unknown	792,700	5,910,418
Tanner Creek	1943	1	Big Creek	390,810	
	1940, 45	2	Bonneville	114,024	
	1930, 32		Bureau Of Fisheries	291,588	796,422
Herman Creek	1939, 55-58	4	Oxbow	54,737	54,737

Table 16. Chum salmon egg box or remote-site incubation (RSI) facilities in the U.S. Pacific Northwest by evolutionarily significant unit (ESU).

State	Facility	Agency	Years	Location	Number indicates location on map
	ESU 1 - Puget Sound/Strait of Georgia and ESU 2 - Hood Canal summer run				
WA	O061	WDFW	1983	N. Puget Sound	1
WA	Smith Creek	COOP/Tribe	1986-91	N. Puget Sound	2
WA	Squalicum Creek	COOP/Tribe	1989-91	N. Puget Sound	3
WA	Padden Creek	COOP	1989-92	N. Puget Sound	4
WA	Chuckanut Creek	COOP	1978-92	N. Puget Sound	5
WA	Oyster Creek	COOP	1978-81	N. Puget Sound	6
WA	Whitehall Creek	COOP	1980-92	N. Puget Sound	7
WA	Colony Creek	COOP	1991, 92	N. Puget Sound	8
WA	Friday Creek	WDFW	1987	Samish River	9
WA	Bob Smith Creek	COOP	1993	Samish River	10
WA	Samish River	COOP	1992	Samish River	11
WA	Beaverton Valley Creek	COOP	1977-92	San Juan Islands	12
WA	Park Creek	WDFW	1986	Skagit River	13
WA	Clark Creek	WDFW	1983, 92	Skagit River	14
WA	Bacon Creek	WDFW	1980	Skagit River	15
WA	Fortson Creek	WDFW	1983-86	Stillaguamish River	16
WA	NF Stillaguamish River	Tribe	1983	Stillaguamish River	17
WA	Camp Creek	Tribe	1988	Stillaguamish River	18
WA	Church Creek	Tribe	1988	Stillaguamish River	19
WA	Harvey Creek	Tribe	1987	Stillaguamish River	20
WA	Armstrong Creek	Tribe	1982	Stillaguamish River	21
WA	Navy Base Creek	Tribe/WDFW	1986	Stillaguamish River	22
WA	Jim Creek	Tribe	1983	Stillaguamish River	23
WA	O339	Tribe	1988, 89	Stillaguamish River	24
WA	Siberia Creek	COOP	1991-93	Duwamish River	25
WA	Miller Creek	COOP	1992, 93	Central Puget Sound	26
WA	Des Moines Creek	COOP	1992, 93	Central Puget Sound	27
WA	Clarks Creek	Tribe	1989	Puyallup River	28
WA	Flett Creek	WDFW	1987-93	Chambers Creek	29
WA	Ohop Creek	Tribe	1985-88	Nisqually River	30
WA	Horn Creek	Tribe	1989	Nisqually River	31
WA	Yelm Creek	Tribe	1987-89	Nisqually River	32
WA	Kalama Creek	Tribe	1981-92	Nisqually River	33
WA	Halverson Creek	Tribe	1985, 88	Nisqually River	34
WA	Lacamas Creek	Tribe	1984-89	Nisqually River	35
WA	Johnson Creek	Tribe	1982-87	Nisqually River	36
WA	O019	WDFW	1985	Nisqually River	37

Table 16 (Continued).

State	Facility	Agency	Years	Location	Number indicates location on map
WA	Muck Creek	Tribe	1985-89	Nisqually River	38
WA	Nisqually River	Tribe	1983-92	Nisqually River	39
WA	OO15	WDFW	1984	Nisqually River	40
WA	McAllister Creek	Tribe	1994	Nisqually River	41
WA	Woodland Creek	COOP/Tribe	1988-93	S. Puget Sound	42
WA	Dobbs Creek	Tribe	1989	S. Puget Sound	43
WA	Nelyaley Creek	COOP	1978-87	S. Puget Sound	44
WA	Woodard Creek	COOP	1991, 93	S. Puget Sound	45
WA	Adams Creek	Tribe	1985-87	S. Puget Sound	46
WA	OO26	WDFW	1980, 81	S. Puget Sound	47
WA	Schneider Creek	COOP/Tribe	1985-87	S. Puget Sound	48
WA	Brenner Creek	Tribe	1985-89	S. Puget Sound	49
WA	Holiday Valley Creek	COOP/Tribe	1985-89	S. Puget Sound	50
WA	Shelton Creek	COOP/Tribe	1989	S. Puget Sound	51
WA	Uncle John Creek	COOP	1986-90	S. Puget Sound	52
WA	Malaney Creek	COOP/Tribe	1988, 89	S. Puget Sound	53
WA	Cranberry Creek	Tribe/WDFW	1977-89	S. Puget Sound	54
WA	Leingang Creek	Tribe	1985-87	S. Puget Sound	55
WA	Jones Creek	COOP/Tribe	1984-87	S. Puget Sound	56
WA	Walkers Landing	COOP/Tribe	1984-86	S. Puget Sound	57
WA	Herron Creek	COOP	1990, 91	S. Puget Sound	58
WA	Minter Creek	COOP	1984, 90	W. Puget Sound	59
WA	Burley Creek	COOP	1990	W. Puget Sound	60
WA	Dickson Creek	COOP	1990-93	W. Puget Sound	61
WA	Donkey Creek	COOP	1977-92	W. Puget Sound	62
WA	Gig Harbor Pens	COOP	1991	W. Puget Sound	63
WA	Ollala Creek	COOP	1989-91	W. Puget Sound	64
WA	Kitsap Creek	COOP	1992	W. Puget Sound	65
WA	Dickerson Creek	Tribe	1980-93	W. Puget Sound	66
WA	Chico Creek	Tribe	1987	W. Puget Sound	67
WA	Strawberry Creek	Tribe	1987-88	W. Puget Sound	68
WA	Clear Creek	Tribe	1986-93	W. Puget Sound	69
WA	Barker Creek	Tribe	Jun-09	W. Puget Sound	70
WA	Little Scandia Creek	Tribe	1986-88	W. Puget Sound	71
WA	Big Scandia Creek	Tribe	1986-93	W. Puget Sound	72
WA	Steele Creek	Tribe	1986, 88	W. Puget Sound	73
WA	O284	Tribe	1987-93	W. Puget Sound	74
WA	Johnson Creek	Tribe	1987	W. Puget Sound	75
WA	Dogfish Creek	Tribe	1985-93	W. Puget Sound	76
WA	Agate Pass	COOP	1986-91	W. Puget Sound	77
WA	Harek's Hole	COOP	1992	W. Puget Sound	78
WA	Eagle Creek			Hood Canal	79
WA	O325			Hood Canal	80
WA	Fulton Creek			Hood Canal	81

Table 16 (Continued).

State	Facility	Agency	Years	Location	Number indicates location on map
WA	Stetson Cove			Hood Canal	82
WA	Jorstad Creek			Hood Canal	83
WA	John Creek			Hood Canal	84
WA	Johnson Creek			Hood Canal	85
WA	Little Lilliwaup Creek			Hood Canal	86
WA	Twanoh Creek			Hood Canal	87
WA	Union River			Hood Canal	88
WA	Stimson Creek			Hood Canal	89
WA	Tahuya River			Hood Canal	90
WA	Caldervan Creek			Hood Canal	91
WA	Dewatto River			Hood Canal	92
WA	Anderson Creek			Hood Canal	93
WA	Ludlow Creek	WDFW	1985-90	Upper West Hood Canal / Chimacum and Ludlow Creeks	94
WA	Chimacum Creek	COOP	1990	Upper West Hood Canal / Chimacum and Ludlow Creeks	95
WA	Elwha				96
	ESU 3 - Pacific Coast				
WA	Sail River	Tribe	1979, 80	N. Washington Coast	97
WA	Quinault Lake	Tribe	1985, 86	N. Washington Coast	98
WA	East Fork Hoquium River	COOP	1979, 80	Chehalis River	99
WA	Wishkah River		1979, 80	Chehalis River	100
WA	Mill Creek	COOP	1977, 80	Chehalis River	101
WA	Satsop River	WDFW	1974, 79	Chehalis River	102
WA	Satsop Springs	WDFW	1985	Chehalis River	103
WA	Elk Creek	COOP	1991	Willapa River	104
WA	Rue Creek	WDFW	1984-87	Willapa River	105
WA	South Fork Willapa River	COOP	1987	Willapa River	106
WA	Niawiakum River	COOP	1987	Willapa Bay	107
WA	South Fork Palix River	COOP	1987	Willapa Bay	108
WA	Williams Creek		1980, 91	Nemah River	109
WA	Middle Fork Nemah River	WDFW	1980-87	Nemah River	110
WA	Nemah River	COOP	1991, 93	Nemah River	111
WA	Skidmore Slough	COOP	1987	Naselle River	112
WA	Ellsworth Creek	COOP	1980-87	Naselle River	113
WA	Dell Creek	COOP/WDFW	1978-82	Naselle River	114
WA	Johnson Creek	WDFW	1986	Naselle River	115
WA	Russian Creek	COOP	1986, 87	Naselle River	116

Table 16 (Continued).

State	Facility	Agency	Years	Location	Number indicates location on map
OR	Whiskey Creek - Harris and Hugie	Private	1973-75	Netarts Bay	125
OR	Whiskey Creek - Siuslaw Fisheries	Private	1973-75	Netarts Bay	126
OR	Whiskey Creek - Keta	Private	1973-75	Netarts Bay	127
OR	Whiskey Creek - OR Aqua	Private	1973, 74	Netarts Bay	128
OR	Whiskey Creek - OSU	COOP	1978, 82	Netarts Bay	129
OR	Jewell Creek	Private	1972-77	Sand Lake	130
	ESU 4 - Columbia River				
WA	Hull Creek	COOP	1978-80	Grays River	117
WA	Crippen Creek	COOP	1978-80	Skamokawa Creek	118
WA	Skamokawa Creek	COOP	1981-83	Lower Columbia River	119
WA	Elokomin River	WDFW	1979, 80	Lower Columbia River	120
WA	Abernathy Creek	WDFW	1982, 83	Lower Columbia River	121
WA	Germany Creek	COOP	1982, 83	Lower Columbia River	122
WA	Little Creek	COOP	1981	Near Beacon Rock	123
WA	Hamilton Creek	WDFW	1980	Lower Columbia River	124

are discussed in the Risk Section (p. 144), and these releases are included in the chum salmon production data included in the Appendix (p. 256). This appendix, provided by biologists from WDFW[29], contains numbers of all chum salmon released, both fed and unfed fry, from egg-box programs, remote-site incubators, and hatcheries in Washington, organized by the stock designations in WDF et al. (1993). Egg-box and RSI enhancements are currently being reevaluated by fisheries co-managers in Washington and have been curtailed in many areas (WDFW 1995). There are presently no chum salmon egg-box or RSI programs in Oregon (Kostow 1995).

In Washington, hatchery protocols, transfers of fish between hatcheries, adult returns of chum salmon to hatcheries, and other performance data on hatchery stocks have been published in a variety of sources (e.g., Fuss and Ashbrook 1995; Ashbrook and Fuss 1996; see Crawford 1997 for listing). However, in both Washington and Oregon some historical releases and transfers have not been reported in the published literature. The SASSI report (WDF et al. 1993) is a comprehensive inventory of naturally produced salmon populations in Washington. In SASSI many salmon populations are identified where artificially-produced fish were believed to have hybridized with or otherwise influenced native populations. However, the SASSI report focused on naturally produced fish; in general, hatchery fish were identified only if they were a component of a naturally producing run (WDF et al. 1993, Crawford 1997).

Recent Changes in Hatchery Management in Washington

In 1991, salmon co-managers in Washington instituted statewide policies to reduce the number of out-of-basin, hatchery-to-hatchery transfers of salmonids, including chum salmon (WDF 1991; Fuss and Ashbrook 1995; Ashbrook and Fuss 1996). These policies included genetic guidelines specifying which transfers between areas were acceptable. The policies apply only to transfers between hatcheries and do not explicitly prohibit introductions of non-native salmonids into natural populations (WDF et al. 1993). At present, co-managers in Washington are developing extensive guidelines and rules regarding all aspects of salmonid culture and management (WDFW 1997) including transfers of hatchery chum salmon into natural populations (WDFW 1995, 1997).

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[29] T. Tynan and H. Fuss, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., April 1996.

Artificial Propagation by ESU in the Pacific Northwest

Puget Sound/Strait of Georgia ESU

The majority of chum salmon artificially propagated in the Pacific Northwest are from hatcheries in the Puget Sound-Strait of Georgia ESU, primarily in Hood Canal and southern Puget Sound (Figs. 18 and 20, Tables 13 and 14, Appendix) (WDF et al. 1993). An average of 65 million chum salmon fry per year have been released from U.S. hatcheries in this ESU from 1960 to 1991 (Fig 21). This compares to an average of 1.4 million fry released per year from 1958-1994 in the Pacific coast ESU, and 485,000 fry released per year from 1930 to 1991 in the Columbia River ESU.

Hatchery propagation of chum salmon began in this ESU as early in 1905[30] at the Washington State Skokomish Hatchery (Table 17) (WFC 1907), in 1911 at the USFW Duckabush River (Station) Hatchery, and 1912 at the USFW Quilcene National Fish Hatchery (Cook-Tabor 1994). Both fall and summer chum salmon were reared at the Duckabush River and Quilcene facilities, but the seasonal run reared at the Skokomish Hatchery is not indicated in the WFC reports. By 1913, 4.5 million unfed chum salmon fry were released annually from 7 Puget Sound hatcheries, and by 1919, fry releases had increased to about 13 million from 12 Puget Sound hatcheries (WFC 1916, 1921). However, chum salmon have never been the primary focus of salmonid artificial propagation in this ESU, and it was not until the mid-1970s that relatively large hatchery programs for chum salmon were first established in southern Puget Sound and Hood Canal.

Prior to the mid-1970s, Hood Canal was a salmon preserve, where most commercial salmon fishing was not allowed (although some tribal subsistence fisheries did occur in a few rivers) and harvest of Hood Canal fish occurred in outer Puget Sound or in the ocean (Fuss and Fuller 1994). Releases of chum salmon into Hood Canal from 1951 to 1973 averaged about 5.2 million fish per year, but with the development of large-scale hatchery programs in the Canal, average releases of chum salmon increased to 37.2 million fish per year between 1974 and 1993 (NRC 1995).

Fall-run chum salmon

The majority of chum salmon fry artificially propagated in the Puget Sound/Georgia Strait ESU return as adults to natal areas after mid-October and are designated as fall (formerly

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[30] Although release data are only available beginning in 1905, production of chum salmon may have started earlier at the Skokomish Hatchery as reported by the Fish Commissioner in his 14th & 15th Annual Report (WFC 1905:39): “This hatchery [Skokomish] was built in 1899 and has been operated continuously ever since....It does not produce the best variety of fish, a large per cent of its hatchery being Dog [chum] salmon, some Silversides but no Spring or Steelheads...”

Table 17. Releases of chum salmon from the Skokomish Hatchery from 1905 to 1921 into Hood Canal. Release data available beginning in 1905 and the program was terminated 1921 (WFC 1905, 1907, 1916, 1921).

Year	Number released from hatchery	Number released elsewhere in Hood Canal
1900	-	-
1901	-	-
1902	-	-
1903	-	-
1904	-	-
1905	1,000,000	-
1906	2,000,000	-
1907	579,350	-
1908	1,531,000	-
1909	4,004,000	-
1910	4,389,500	-
1911		
1912	1,987,500	-
1913	3,023,000	-
1914	4,102,875	-
1915	1,984,667	-
1916	1,948,258	-
1917	6,739,075	-
1918	1,791,900	678,650
1919	1,173,925	-
1920	5,993,300	-
1921	1,241,325	-

"normal") chum salmon by Washington fishery co-managers (WDF et al. 1993).

Most hatchery fall chum salmon are released into their native streams in Puget Sound or Hood Canal (Table 15, Appendix) (NRC 1995). Some hatcheries, particularly those in Hood Canal, produced excess numbers of eggs and unfed fry (Fig. 18) (Fuss and Fuller 1994). Historically, this excess production was often distributed to other regions (e.g., Minter Creek and Keta Creek in southern Puget Sound, Tulalip and Bellingham Maritime Heritage Center in northern Puget Sound, and Elwah River in the Strait of Juan de Fuca). In addition, the Samish Hatchery appears to have mixed local fish with hatchery fish originating from Hood Canal (Phelps et al. 1994). These transfers of hatchery fish are described in Table 15 and the Appendix and were so common in the 1970s and early 1980s that at least 50% of hatchery chum salmon released into the Nooksack, Skagit, Puyallup, Deschutes, and Elwha-Dungeness River basins, and into several small southern Puget Sound river basins, were not native to the basin of release (NRC 1995). The most widely distributed stocks were from WDFW Hood Canal, McKernan, and George Adams Hatcheries in Hood Canal (Phelps et al. 1994, 1995). Fish from these hatcheries were even introduced into lower Columbia River tributaries and the Siuslaw River in Oregon (NRC 1995, Table 15).

It is difficult to determine the proportion of non-native hatchery chum salmon released into watersheds, and in this report these numbers may be underestimated (Table 15) for three reasons. First, in the databases used in this status review (primarily NRC 1995), many outplanted fish were designated as "origin unknown." To standardize the data in our tables and figures, we assumed these were native fish, even though in many cases their status may have been reported as "unknown" because they were not native. Second, when juvenile salmon that had been transplanted to an out-of-basin hatchery returned to that hatchery as adults, they were usually designated as stock from that hatchery, and the name of the river or hatchery of origin was dropped. This occurred because it was impossible to distinguish native and non-native fish when they returned as adults. For example, Hood Canal fish introduced into Tulalip and Mission Creeks and released from Tulalip Bay net-pens in Port Susan in northern Puget Sound were designated at the time of their release as juveniles by their stream of origin in Hood Canal as "Big Quilcene River," "Finch Creek," or "Walcott" fall-run chum salmon. However, when these fish returned as adults to the Tulalip Bay area, they could not be distinguished from other Puget Sound fish and thus were designated as "Tulalip Creek" chum salmon, even though they were derived from out-of-basin populations (NRC 1995). Similarly, Hood Canal fall chum salmon were established at the Minter Creek Hatchery in southern Puget Sound and were subsequently introduced into other watersheds as Minter Creek fish (Phelps et al. 1994). A third reason the proportion of non-native hatchery fish released into watersheds may be underestimated is that all egg transfers or releases of unfed fry from egg-boxes, RSI, or hatcheries were excluded in the summary of west coast chum salmon releases (Table 15), as previously noted.

Summer-run chum salmon in southern Puget Sound

Artificial propagation of summer-run chum salmon in southern Puget Sound was only recently initiated and is very small compared to the hatchery production of fall chum salmon.

Two summer-run chum salmon hatchery programs were initiated in the late 1970s on John’s and Coulter Creeks (Table 14), where about 1.8 and 1.1 million native summer-run chum salmon per creek, respectively, were released annually (Table 15) (NRC 1995). Based upon adult returns, it is believed that both hatchery programs contributed considerably to summer-run chum salmon abundance in these streams (WDF et al. 1993). These programs were terminated on John’s Creek in 1991 and Coulter Creek in 1992, and Washington co-managers expect run sizes in these streams to decline because of the lack of augmentation (WDF et al. 1993). However, escapements to these streams in 1996 of 39,600 fish, compared to an average escapement from 1984-1995 of 25,900 fish, suggest otherwise (Crawford 1997).

Winter-run chum salmon

There has been no artificial propagation of Nisqually River winter-run chum salmon, although substantial numbers of hatchery fall-run chum salmon have been planted into the Nisqually River (Table 15, Appendix) to support and enhance commercial fisheries in the area. Based upon timing of adult returns and genetic analysis, these outplants have apparently not affected native winter-run chum salmon in the river (WDF et al. 1993).

Winter-run chum salmon were propagated between 1982 and 1993 in Chambers Creek at the WDFW Garrison Springs Hatchery (Table 14; see no. 22 in Fig. 20) and have been released into Chambers Creek at the site of the hatchery, as well as into Clarks Creek and other tributaries of the Puyallup River (WDF et al. 1993) (Appendix).

Hood Canal summer-run chum salmon ESU

Very few summer-run chum salmon have been artificially propagated in Hood Canal, and the only releases in recent years have been from newly established restoration programs. These recent releases totaled about 241,000 chum salmon fry into Hood Canal in 1993 and 1994 and about 85,000 fry into Discovery Bay on the Strait of Juan de Fuca in 1992. Summer-run chum salmon have been reared in Hood Canal at the Quilcene National Fish Hatchery (QNFH) (Fig. 18) from 1912 to 1937, and at a satellite hatchery, Duckabush River Station, from 1911 to 1942 (Cook-Tabor 1994). Releases of chum salmon were also reported from 1905 to 1921 from the Washington State Skokomish Hatchery (Table 17), but whether these were summer- or fall-run fish is undocumented. Fish from the Skokomish Hatchery were primarily released directly from the hatchery. Chum salmon eggs reared at the other facilities were collected from various rivers in Hood Canal and released primarily into the Little and Big Quilcene Rivers (Fig. 3), although some releases occurred at other locations, such as Walcott Slough[31] (Fig. 3). The program was ended in 1938 when the Lower Quilcene River was “modified” and fish could no longer return to the hatchery (Cook-Tabor 1994). Small numbers of summer chum salmon (mid-September

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[31] Walcott Slough is located just north of the Dosewallips River mouth and was the historical release and recapture site for fall chum salmon produced at the QNFH (Cook-Tabor 1994).

spawning fish) were also released from the WDF Hood Canal Hatchery in 1962-1964, and apparently these were the only chum salmon reared at that hatchery during those years. These fish were apparently native to Finch Creek, the stream that runs past the hatchery (Rasch and Foster 1978).

Hatchery production of summer-run chum salmon in Hood Canal did not occur again until 1992, when the USFWS, WDFW, and Point No Point Treaty Council (PNPTC) began a program to rear the salmon run at the QNFH in response to declines in the population (Cook-Tabor 1994). Since then, about one-half of the annual return of summer-run chum salmon to the Quilcene River has been spawned artificially (Cook-Tabor 1994). In 1993 and 1994, a total of 241,000 summer chum salmon juveniles were released into the Big Quilcene River. In 1995, 203 pairs of summer chum salmon were spawned in the hatchery (Cook-Tabor 1995) and spawning surveys in the Big Quilcene River during this period listed 4,958 live and dead chum salmon (about 1,770 fish per mile) (WDFW 1996).

There has been little artificial propagation of summer chum salmon from the Strait of Juan de Fuca east of the Elwha River. Since 1992 a restoration egg box program has produced about 85,000 fry annually in Salmon Creek, a tributary to Discovery Bay (Appendix). There are no records of summer-run chum salmon fry plants into other streams that enter the Strait of Juan de Fuca, including Jimmycomelately and Snow Creeks, or the Dungeness River (NRC 1995).

Pacific Coast ESU

Artificial propagation of chum salmon in this ESU has averaged about 1.4 million fry released per year from 1958-1994 (Fig. 18). Fry have been released primarily to support commercial and tribal fisheries and, in recent years, most releases have been from a single hatchery near Makah, Washington (Table 15 and Appendix). In Oregon and along the Strait of Juan de Fuca west of the Elwha River, hatchery outplanting has been relatively infrequent compared to the Washington Coast and Hood Canal (Table 15, and Appendix) (NRC 1995, WDF et al. 1993). Chum salmon hatcheries on the Washington coast were first established after the turn of the century, and included a state-run facility on the Chehalis River which incubated 1.2 million eggs in 1913 and increased its output to 39 million eggs by 1919 (WFC 1916, 1921). The USFWS National Fish Hatchery in Neston, Washington (near Makah, Washington) was established in 1968 and released a total of about 33 million chum salmon fry from 1970 to 1993. This hatchery primarily rears a local chum salmon stock from Cook Creek. In Oregon, the first artificially cultured chum salmon were released in 1937 from a state-operated hatchery on the Trask River (NRC 1995). Today, only 4 of the 23 chum salmon hatcheries that once operated on the Washington and Oregon coasts remain, and all are in Washington (Fig. 19; note this figure includes the Columbia River ESU hatcheries) (NRC 1995) .

Along the Strait of Juan de Fuca, fish were released into only two rivers for a total of three years. About 188,000 fry were released in 1970 into the Lyre River, and about 170,000 fry were released in 1978 and 1979 into the Sail River. In contrast, just a few kilometers west on the outer coast, over 20 million chum salmon fry were released into the Sooes River from 1975 to

1993 (Table 15). Equal or larger numbers of fry have been released into rivers along the Washington outer coast (Table 15), but these numbers are relatively small compared to the average of 37.5 million chum salmon released each year into Hood Canal (NRC 1995).

In recent years, chum salmon were artificially propagated on the Washington Coast only in the Sooes and Quinault Rivers on the north coast and in Willapa Bay tributaries on the south coast. Broodstock used in all of these programs are from adults captured in the same river where the juveniles are released. Smaller hatchery programs for chum salmon are also currently operating in the Hoh, Queets, Humptulips, and Chehalis Rivers (NRC 1995).

In Oregon, the magnitude of artificial propagation has been substantially less than in Washington (Table 15). Historically, six state hatcheries produced chum salmon in Oregon's portion of the coastal ESU, but this production has been halted in recent years (Kostow 1995, NRC 1995). Private hatcheries also released chum salmon in Oregon from 1973 to 1994, and many of these fish were of non-native origin, including fish from Hood Canal (Table 15). Some straying was observed from at least one of these private facilities (Kostow 1995). However, returns of non-native chum salmon have generally been poor, and only one private facility still released chum salmon in 1994.

Historically, out-of-basin transplants within the coastal ESU were common (Table 15, Appendix). For example, almost half of about 20 million chum salmon released into the Sooes River from 1975 to 1993 originated from out-of-basin sources, including Hood Canal and Quinault River hatcheries (NRC 1995). In the Quinault River, almost 17% of about 5 million chum salmon fry released annually between 1971 and 1979 originated in Hood Canal (NRC 1995). The effects of these out-of-basin plants are not well studied, and the chum salmon in these rivers have not been genetically characterized. However, WDF et al. (1993) reported that non-native chum salmon have largely replaced native chum salmon in the Sooes River. Non-native chum salmon also appear to have extensively hybridized with native fish in the Quinault River, and chum salmon in the Queets River are also not considered to be a distinct population because of hybridization or replacement of native fish with Quinault River fish.

Chum salmon populations along the southern Washington Coast (e.g., Humptulips, Chehalis, Nemah, and Naselle River systems) show less evidence of introgression from hatchery fish introduced into these rivers (WDF et al. 1993). This relative lack of hybridization between non-native fish and native fish in southern Washington coastal populations may be due to the greater use of local broodstock in hatchery programs from this area (Table 15, Appendix).

Columbia River ESU

Little artificial propagation of chum salmon has occurred in the Columbia River compared to other areas in the Pacific Northwest (Fig. 18, Tables 15 and 16, Appendix), and this has usually been conducted in areas that no longer contain native chum salmon stocks. From 1930 to 1991 an average of only 485,000 chum salmon fry were released annually. Historically, chum salmon were reported to be present in almost every river in the lower Columbia River

Basin, but most of these runs disappeared by the 1950s (Rich 1942, Marr 1943, Fulton 1970). Presently, on the Washington side of the lower Columbia River, only three streams are recognized as containing native chum salmon: Hamilton and Hardy Creeks near Bonneville Dam at RKm 235, and Grays River (RKm 34) (WDF et al. 1993).

Historical plants of non-native hatchery chum salmon into the Columbia River Basin (comprised of fish from the coast, Hood Canal, and a small portion of Japanese origin) are believed by WDFW not to have hybridized with local populations for several reasons. Hatchery fish were planted to supplement fisheries only in areas without native chum salmon and in areas where spawning was poor or nonexistent (WDF et al. 1993). Recent genetic analysis of fish from Hardy and Hamilton Creeks and from the Grays River also indicate that these fish are genetically distinct from other chum salmon populations in Washington (WDF et al. 1993, Phelps et al. 1994). At present, only a single cooperatively owned hatchery on the Chinook River (a tributary to the Columbia) produces hatchery chum salmon for the Columbia River and propagates chum salmon imported from Willapa Bay. Approximately 360,500 chum salmon fry were released annually by this hatchery between 1982 and 1991 (WDF et al. 1993).

About 22 populations of chum salmon have been reported on the Oregon side of the Columbia River (Kostow 1995). Big Creek and the Klaskanine River (the latter a tributary to the Youngs River near Olney, OR) are the only river systems that have received significant numbers of hatchery chum salmon, and in both cases, local fish were used for supplementation (Table 15) (NRC 1995).

ASSESSMENT OF EXTINCTION RISK

Background

The ESA (1973, Sect. 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 distributions, 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 based on the best scientific information available regarding its 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. 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.

Aspects of several of these risk considerations are common to all four chum salmon ESUs. These are discussed in general below; more specific discussion of factors (e.g., harvest) for each of the ESUs under consideration here can be found in the following sections.

Absolute Numbers

The number of individuals in a population is important in assessing two aspects of extinction risk. First, 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) (see Gilpin and Soulé 1986, Thompson 1991). Second, for a declining population, present abundance is an indicator of the expected time until the population reaches critically low numbers; this aspect is related to the idea of "driven extinction" (Caughley 1994).

In addition to total numbers, the spatial and temporal distributions of adults are 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 the size of the potential spawning population if there is no 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, in this review we attempted to distinguish natural fish from hatchery-produced fish. The offspring of all chum salmon artificially spawned for a hatchery, restoration, or egg box (RIS) program are included under "hatchery provided," although we recognize that different types of propagation programs will have different results. 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 composed of two components (Fig. 23): "hatchery produced," which are reared as eggs or juveniles in a hatchery but return as adults to spawn naturally, and "natural" fish, which are progeny of naturally spawning fish.

Historical Abundance, Habitat, and Carrying Capacity

For chum salmon, quantitative estimates of historical abundance are generally lacking. At best, historical abundance can be inferred from fishery landings data. Fishery landings suggest that chum salmon abundance may be near historical levels in the Puget Sound area, but that natural populations south of the Columbia River (and possibly to the north) are at very low levels relative to historic abundance.

Although knowing the relationship of present abundance to present carrying capacity is important for evaluating the health of populations, the fact that a population is near its current capacity does not necessarily signify full health. A population near capacity implies limits of the effectiveness of short-term management to increase chum salmon 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

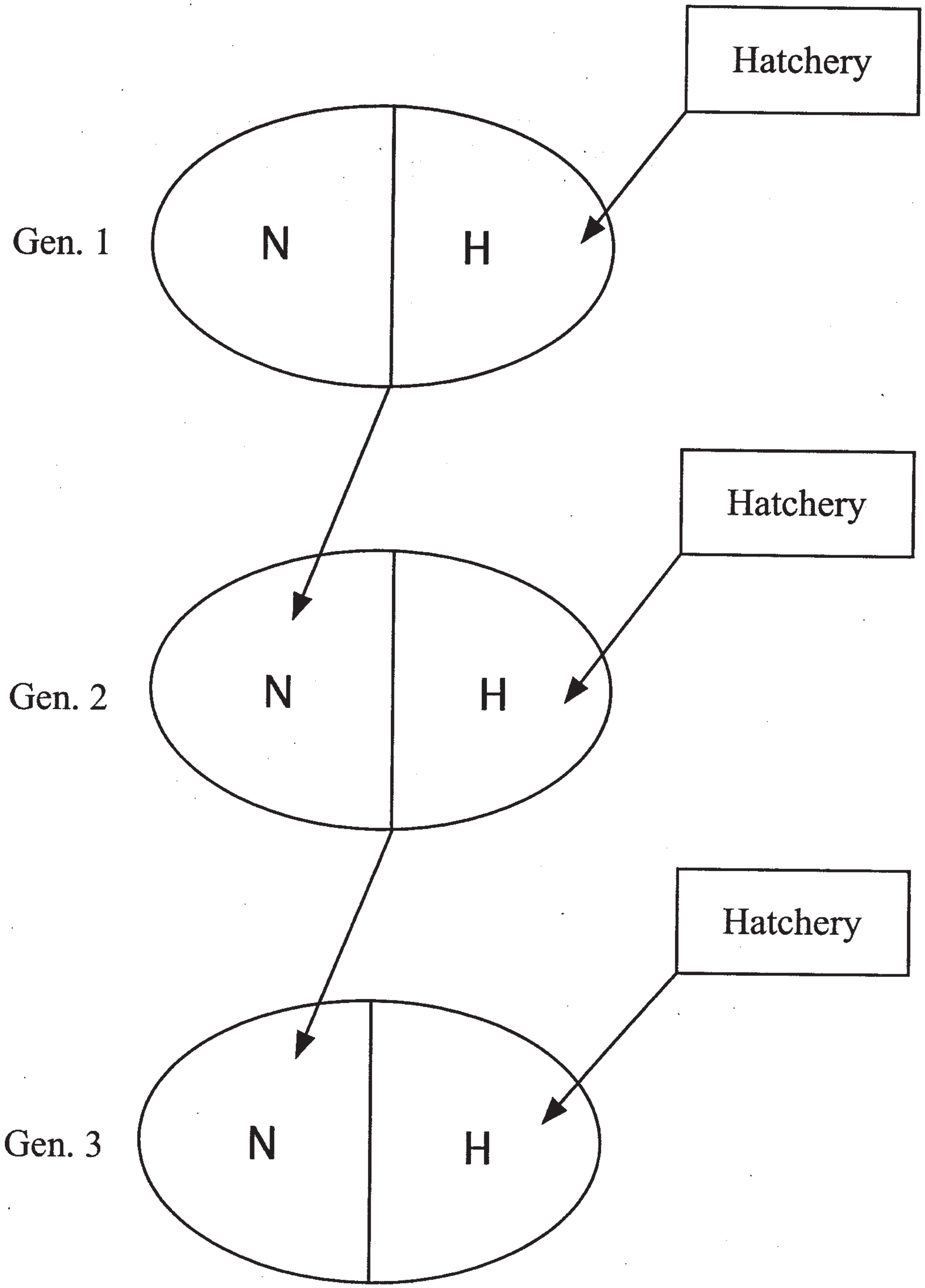

Figure 23. Schematic diagram of mixing of natural and hatchery-produced fish in natural habitat. Ovals represent the total spawning in natural habitat each generation. This total is comprised of natural (N) and hatchery-produced (H) offspring of individuals in the previous generation.

of hatchery fish may further increase population density in a limited habitat.

The relationship between current and historical abundance and habitat capacity is an important consideration in evaluating risk. Knowledge of historical population conditions provides a perspective of 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.

Historical Changes in Estuaries

Chum salmon generally spend only a short time relative to other salmonids in streams and rivers before migrating downstream to estuarine and nearshore marine habitats. Because of this, the survival of early-life-history stages of chum salmon depends more on the health and ecological integrity of estuaries and nearshore environments than for most other Pacific salmon.

Habitat loss in the estuarine or nearshore marine environment is difficult to quantify because there are few historical studies that include baseline information, and these studies encompass a variety of classification methods and several time intervals to measure change (Levings and Thom 1994). One of the first attempts to inventory estuarine areas in the Puget Sound region was a U.S. Department of Agriculture survey by Nesbit (1885). He surveyed 267 km^2 of tidal marshes and swamps in nine counties bordering Puget Sound and reported nearly 320 km of dikes enclosing 4.1 km^2 of marsh. In Skagit and Stilliguamish River areas, Nesbit found that tidelands covered 520 km^2 and extended 20 km inland from the present shoreline. Across the Puget Sound region in the 1880s, Nesbit found that the areas covered by tidal marshes greatly exceeded those covered by tidal flats, and that the extents of non-tidal freshwater marshes were three to four times larger than tidal marshes. In contrast, by the 1980s, Boule et al. (1983) estimated that Puget Sound had only 54.6 km^2 of intertidal marine or vegetated habitat in the entire basin, and that this represented 58% of the state’s total estuarine wetlands.

More recently, Bortelson et al. (1980), Simenstad et al. (1982), Hutchinson (1989), and Levings and Thom (1994) have attempted to quantify changes in some Northwest estuaries. Bortelson et al. estimated historical changes in natural habitats in eleven major estuaries. They found, on average, a decrease in the estimated (km^2) size of subaerial wetland of 64% (SD 35%) with losses in the Puyallup of 100%, in the Duwamish of 99%, and in the Samish of 96%. Only in the Nooksack had wetland area increased, and that was only by 0.2%. Simenstad et al. (1982) used similar methods to calculate losses of wetlands in Grays Harbor and found a decrease of 30.3%. They also reported that the U.S. Army Corps of Engineers, as part of maintenance dredging operations, removed 2.3 million m^3 of sediments annually from estuaries in Washington State, nearly half of this in Grays Harbor. Hutchinson (1989) estimated the change in area of intertidal marshes around the Strait of Georgia and Puget Sound from the time of European settlement to the present. He found overall losses of 18% around the Strait of Georgia and 58% around Puget Sound. Dahl (1990) reported that over 33% of total (freshwater and estuarine) wetland area in Washington and Oregon have been lost and that much of the remaining habitat is degraded.

Levings and Thom (1994) also estimated changes in extent of habitat coverage in Puget Sound for the following habitat types: marshes/riparian, sandflats, mudflats, rock-gravel habitats, unvegetated subtidal, kelp beds, intertidal algae, and eelgrass. They were able to quantify change only in the marshes/riparian and kelp bed habitats. For all other areas, they could estimate change only as a loss or an increase. However, for the marshes and riparian areas in the eleven major river deltas in Puget Sound, they estimated a loss of at least 76% (from 732 km^2 prior to the mid-1800s to 176.1 km^2 in the early 1990s), based upon the reports of Nesbit (1885), Boule et al. (1983), and others.

Levings and Thom (1994) were also able to quantify a change in extent of kelp beds. They found that the locations of kelp beds have been relatively well documented as navigational aids, for marking the location of shallow rocky-bottom areas, and as sources of kelp for potash. Based upon several comprehensive surveys (one dating back to the Wilkes expedition in 1841 [Thom and Hallum 1990]), they estimated that the length of shore with kelp beds in Puget Sound has increased from 1912 to the present by as much as 53% (from 205.5 km^2 to 313.8 km^2). The significance of kelp beds to chum salmon is undocumented, but presumably they would supply a refuge from waves, currents, and perhaps predators.

Most regulatory reviews and environmental analysis of estuarine modification have focused on major estuaries and at river mouths near high-intensity industrial and urban development, but this development affects only 2% of the approximately 3620 km of Puget Sound shoreline (Canning 1997). Perhaps better estimates of overall historical changes in intertidal and nearshore habitats are inventories of shoreline armoring (e.g., construction of rock, concrete, and timber bulkheads or retaining walls) because these habitat modifications occur primarily with residential development in relatively rural areas (Shipman 1997). Armoring has a cumulative environmental impact that eventually results in loss of riparian vegetation, burial of the upper beach areas, altered wave interaction with the shoreline, and obstruction of sediment movement (Shipman 1997). Morrison et al. (1993) inventoried armoring in Thurston County, Washington and compared this to 1977 studies. They found a more than 100% increase in the length of armoring from 1977 to 1993. Kathey (1994) inventoried armoring along Bainbridge Island in Puget Sound and found that between 42 and 67% of the entire shoreline was armored.

In the Columbia River estuary, Sherwood et al. (1990) used a combination of circulation modeling, analysis of river flow records, and computerized cartographic analysis to evaluate historical change in the circulation and morphology of the Columbia River estuary from 1867 to the late 1980s. These authors found a wide variety of significant changes, including large changes in morphology caused by navigational improvements (such as jetties, dredged channels, and pile dikes) and by diking and filling wetland areas. Lesser changes in morphology were attributed to natural shoaling and erosion.

Sherwood et al. (1990) used bathymetric data from 1867 onward to estimate a decrease in the tidal prism of roughly 15%, and a net accumulation of about 68 x 10^6 m^3 of sediment in the estuary. They also report that large volumes of sediment have eroded from the entrance region of the Columbia River and have been deposited both on the continental shelf and in the estuary, contributing to the formation of new land. Ignoring the erosion at entrance to the river, Sherwood et al. (1990) estimated deposition soil in the estuary of roughly five times the rate at which sea level has fallen locally since turn of century. They also report that the river's seasonal flow cycle has been significantly altered by regulation and diversion of water for irrigation, with the greatest change occurring after 1960. They suggest these changes in morphology and river flow have reduced mixing, increased stratification, altered the response to fortnightly (neap-spring) changes in tidal forcing, decreased the salinity intrusion length, and the transport of salt into the estuary.

The effects of these changes (e.g. decrease in freshwater inflow, tidal prism, and mixing; increase in flushing time and fine sediment deposition, and net accumulation of sediment) have been extensive and include concurrent reduction in wetland habitats that have resulted in an estimated 82% reduction in emergent plant production and a 15% reduction in benthic marcoalgae production, a combined production loss of 51,675 metric tons of organic carbon per year (Sherwood et al. 1990). They hyopthesize that there has been a shift from a food web based on macrodetritus derived from emergent vegetation, to one involving microdetritus derived from phytoplankton, consequently causing a shift from shallow-water benthic consumers to water-column pelagic and deep-water epibenthic consumers.

Other changes in the community structure of the Columbia River estuarine ecosystem reported by Sherwood et al. (1990) include increases in some exotic species filling new or undeveloped niches. One example is the American shad (*Alosa sapidissima*), an Atlantic species that migrated northward after plantings in California. The species entered the Columbia River between 1876-1877 and were planted into the river in 1885-1886. Currently, shad constitutes one of the most abundant species in the Columbia River and, as pelagic planktivores, exploits both freshwater copepods and cladocerans as well as other prey concentrated in the estuarine mixing zone. The increase in shad production coincides with a shift toward a microdetritus-based food web.

Historical Changes in Freshwater Habitat

Chum salmon may depend less on freshwater habitats than other Pacific salmonids, but their spawning areas still extend up to 80 Rkm upstream in many rivers, and their requirements for successful spawning and rearing—such as cold, clean water and relatively sediment-free spawning gravel—are similar to other Pacific salmon (See "Life History," p. 34).

Alterations and loss of freshwater habitat for salmonids have been extensively documented in many regions, especially in urban areas or habitat associated with construction of large dams. In the last 25 years, a major issue in "stream restoration" has been the role that large woody debris (LWD) plays in creating and maintaining Pacific salmon spawning and rearing habitat. Descriptions of pre-development conditions of rivers in Washington and Oregon that had abundant salmonid populations suggest that even big rivers had large amounts of instream

LWD, which not only completely blocked most rivers to navigation but also contributed significantly to trapping sediments and nutrients, impounding water, and creating many side channels and sloughs (Sedell and Froggatt 1984, Sedell and Luchessa 1982). Many streams consisted of a network of sloughs, islands, and beaver ponds with no main channel. For example, portions of the Willamette River reportedly flowed in five separate channels, and many coastal Oregon rivers were so filled with log jams and snags that they could not be ascended by early explorers. Most rivers in coastal Washington and Puget Sound were similarly blocked by large woody debris, snags, and instream vegetation. Sedell and Luchessa (1982) compiled a partial list of major rivers that were impassable for navigation in the mid-1800s because of large (100-1500 m-long) log jams; this list included 11 rivers in Oregon and 16 in Washington. However, until recently, up to 90% of the funds for fish-habitat enhancement went for removal of woody debris in streams (Sedell and Luchessa 1982).

Besides clearing rivers for navigation, extensive “stream improvements” were accomplished to facilitate log drives. Simenstad et al. (1982) reported that historically some of the more adverse impacts on the estuarine and freshwater habitats used by chum salmon resulted from “stream improvements” in the 1800s and early 1900s, when logs were transported down streams and stored in main stems of rivers, lakes and estuaries. These activities included blocking off sloughs and swamps to keep logs in the mainstream and clearing boulders, trees, logs, and snags from the main channel. Smaller streams required the building of splash dams to provide sufficient water to carry logs. Scouring, widening, and unloading of main-channel gravel during the log drive may have caused as much damage as the initial stream cleaning. In tributaries to Grays Harbor and Willapa Bay, over 120 logging dams were identified by Wendler and Deschamps (1955). Stream cleaning continued through the mid-1970s in many areas, not only for flood control and navigation, but as a fisheries enhancement tool as well. Debris in streams was viewed as something that would either impede or block fish passage and as a source of channel destruction by scour during storm-induced log jam failures.

The past destruction, modification, and curtailment of freshwater habitat for steelhead was reviewed in the “Factors for Decline” document (NMFS 1996) published as a supplement to the notice of determination for West Coast Steelhead under the ESA. Although chum salmon, in general, spawn lower in river systems than do steelhead and primarily rear in estuarine areas, this document still serves as a catalog of past habitat modification within the range of chum salmon. Among habitat losses documented by NMFS (1996), those with the most impact on chum salmon include water withdrawal, conveyance, storage, and flood control (resulting in insufficient flows, stranding, juvenile entrainment, and instream temperature increases); logging and agriculture (loss of LWD, sedimentation, loss of riparian vegetation, habitat simplification); mining (especially gravel removal, dredging, pollution); and urbanization (stream channelization, increased runoff, pollution, habitat simplification). Hydropower development was considered a major factor in habitat loss for steelhead (NMFS 1996), but is probably less significant for chum salmon (due to chum salmon’s use of lower river areas for spawning) although many spill dams and other small hydropower facilities were constructed in lower river areas. Lichatowich (1989) also identified habitat loss as a significant contributor to the decline of Pacific salmon in Oregon’s coastal streams.

A number of authors have attempted to quantify overall anadromous fish habitat losses in areas within the range of chum salmon. Gregory and Bisson (1997) stated that habitat degradation has been associated with greater than 90% of documented extinctions or declines of Pacific salmon populations. It has been reported that up to 75% and 96% of the original coastal temperate rainforest in Washington and Oregon, respectively, has been logged (Kellogg 1992), and that only 10-17% of old-growth forests in Douglas-fir regions of Washington and Oregon remain (Norse 1990, Speis and Franklin 1988). California has reportedly lost 89% of the state’s riparian woodland to various land-use practices (Kreissman 1991). Within California, Fisk et al. (1966) stated that over 1,600 km of streams had been damaged or destroyed as fish habitat by 1966. Approximately 80-90% of the original riparian habitat in most western states has been eliminated (NMFS 1996). For example, Edwards et al. (1992) reported that 55% of the 43,000 stream kilometers in Oregon were moderately or severely affected by non-point source pollution.

Specific quantitative assessment of habitat degradation or attempts to evaluate the response of fish populations to specific changes in habitat are rare (Reeves et al. 1989). For coho salmon, Beechie et al. (1994) estimated a 24% and 34% loss since European settlement in the capacity for smolt production in summer and winter rearing habitats, respectively, in the Skagit River. Beechie et al. (1994) identified the three major causes of these habitat losses, in order of importance, as hydromodification, blocking culverts, and forest practices. Similarly, McHenry (1996) estimated that since European settlement, Chimacum Creek, Washington (northwest Puget Sound) had lost 12%, 94% and 97% of its spawning, summer-rearing, and winter-rearing habitats for coho salmon, respectively. McHenry (1996) stated that these habitat losses were due to logging, agricultural clearing, channelization, drainage ditching, groundwater withdrawal, and lack of woody debris.

Habitat factors identified in SASSI that may affect chum salmon

Although not all of the chum salmon stocks identified in SASSI had habitat factors listed for them, numerous habitat- or land-use practices were identified as having a detrimental impact on chum salmon (WDF et al. 1993). The northern portion of the Puget Sound/Strait of Georgia ESU was reported to incur its greatest impact from agricultural (diking) and logging practices (sedimentation). Habitat impacts in the southern portion of this ESU (excluding Hood Canal) were listed as loss of freshwater and estuarine wetlands due to diking and armoring (e.g., construction of bulkheads, piers, and docks), urbanization, degradation of water quality, and loss of spawning habitats. Habitat factors in Hood Canal were primarily identified for the Hood Canal Summer Chum Salmon ESU and included gravel aggradation (due to logging in some areas), channel shifting, and diking. No chum salmon habitat factors were identified in the Washington portion of the Coastal ESU, but the greatest impacts to other species were reported to be from forest and agricultural practices. In the Lower Columbia River ESU, habitat “limiters” associated with chum salmon included gravel quality and stability, availability of high-quality nearshore, main stem freshwater and marine habitat, road building, timber harvest, diking, and industrialization (WDF et al. 1993).

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. These data sources and methods are discussed in more detail below, under the "Approach" section (p. 156). Regular sampling has not been conducted for many chum salmon populations outside the Puget Sound region, and data series are quite short for many of those populations that have been sampled. When time series are lacking, general trends may be inferred by comparing historical and recent abundance estimates, or by considering trends in habitat quantity or condition.

The important role of artificial propagation for Pacific salmon and steelhead requires careful consideration in ESA evaluations. Artificial propagation has implications for evaluating both production trends and the genetic/ecological integrity of populations. Waples (1991) and Hard et al. (1992) discussed the role of artificial propagation in ESU determination, emphasizing the need to focus on natural production in the threatened or endangered status determination. Because of the ESA emphasis on ecosystem conservation, this analysis focuses on naturally reproducing fish. Thus, an important question in the threshold determination is whether natural production is 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. Hatchery production of chum salmon in the contiguous United States has been relatively minor compared with natural production, with the exception of a few areas of localized, intensive artificial propagation. In most cases, therefore, there are not large numbers of naturally spawning hatchery fish to complicate the issue of sustainability of natural populations.

Factors Causing Variability in Abundance

A variety of factors, both natural and human-induced, affect the degree of risk facing salmonid populations. Because of time lags in these effects and variability in populations, recent changes in any number of 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. However, forecasting future effects is rarely straightforward and usually involves qualitative evaluations based on informed professional judgment. 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 of the future, how do we evaluate the risk that a population may not persist?

Variations in the freshwater and marine environments are thought to be a primary factor driving fluctuations in salmonid run-size and escapement (Pearcy 1992, Beamish and Bouillon 1993, Lawson 1993). Artificial propagation can also contribute to fluctuations in natural abundance as well as having less obvious genetic and ecological effects. These factors are assessed below and have probably made some populations less resilient to a variety of poor conditions, but these effects are not easily quantified.

Oceanic and Climatic Changes

Climatic conditions are known to have changed recently in the Pacific Northwest (see "Oceanic and Climatic Variability," p. 29). Most Pacific salmonids south of British Columbia have been affected by changes in ocean production that occurred during the 1970s (Pearcy 1992, Lawson 1993). Changes in productivity in the nearshore marine environment have been implicated in declines in chinook and coho salmon abundance and productivity. Chum salmon tend to migrate farther offshore than chinook and coho salmon, and are thought to have been less affected by changes in the nearshore environment. However, the chum salmon populations considered in this review are from the southern end of the range of the species, and their migration patterns are poorly understood. Much of the Pacific coast has also been experiencing drought conditions in recent years, which may depress freshwater production even of species such as chum salmon that spend only a brief time in freshwater. At this time, we do not know whether these climate conditions represent 1) a long-term shift in conditions that will continue to affect salmonids into the future or 2) short-term environmental fluctuations that can be expected to reverse in the near future.

Genetic Integrity

In addition to being a factor in evaluating natural replacement rates, artificial propagation can have a substantial influence on genetic/ecological integrity of natural salmon and steelhead populations. This can occur in several ways. First, stock transfers that result in interbreeding of hatchery and natural fish can lead to the loss of fitness in local populations and the loss of diversity among populations. The latter is important in maintaining long-term viability of an ESU because genetic diversity among salmonid populations helps to buffer overall productivity against periodic or unpredictable changes in the environment (Fagen and Smoker 1989, Riggs 1990). Ricker (1972) and Taylor (1991) summarized some of the evidence for local adaptations in Pacific salmonids that may be at risk from stock transfers.

Second, because a successful salmon or steelhead hatchery dramatically changes the mortality profile of a population, some level of genetic change relative to the wild population is inevitable even in hatcheries that use local broodstock (Waples 1991). These changes are unlikely to be beneficial to naturally reproducing fish.

Third, even if naturally-spawning hatchery fish leave few or no surviving offspring, adult spawners 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. If hatchery fish that are not adapted to local conditions are successful in spawning with natural fish, production may be diverted from more productive natural crosses. The presence of large numbers of hatchery juveniles or adults may also alter the selective regime faced by natural fish.

For populations with low abundance (either natural or hatchery), small-population effects (inbreeding, genetic drift) can also be important concerns for genetic integrity. Inbreeding and outbreeding depression and genetic drift are well understood at the theoretical level, and researchers have found inbreeding depression in various fish species (reviewed by Allendorf and Ryman 1987). Other studies (e.g., Simon et al. 1986, Withler 1988, Waples and Teel 1990) have shown that hatchery practices commonly used in the past with anadromous Pacific salmonids have the potential to affect genetic integrity. However, we are not aware of empirical evidence for inbreeding or outbreeding depression or loss of genetic variability in any natural or hatchery populations of Pacific salmon or steelhead.

Although past hatchery practices may have substantially influenced some isolated chum salmon populations, the relatively small magnitude of most current hatchery programs and the predominant use of local broodstock argue that hatchery practices are unlikely to threaten the genetic integrity of most chum salmon populations considered in this review. Large programs take place in Hood Canal and southern Puget Sound, and genetic concerns in these areas are proportionally greater. Small population effects (such as genetic drift, mutation, and introgression) are likely to influence summer-run chum in Hood Canal and populations spawning from the Columbia River south.

Assessment of genetic influence of hatchery transfers

For almost 100 years, hatcheries in the U.S. Pacific Northwest have produced chum salmon for the purpose of increasing harvest and rebuilding depleted runs. However, as reported by Phelps et al. (1994:64):

> Unfortunately a typological concept [the concept that one individual of a species has the same genetic potential as another] of species existed until recently and considerable movement of eggs and fry from one geographical region to another has occurred. Most of the stock transfers [in Washington] have occurred from chum salmon hatcheries in Hood Canal to streams and hatcheries in south and north Puget Sound, and the Strait of Juan de Fuca. Although these transfers ceased in the early 1980’s, hatchery strains (with the Hood Canal chum salmon gene pools) are still being used at some hatcheries and wild populations may have been mixed with hatchery strains at the hatchery and through straying. Recently, the hatching of chum salmon in small stream-side incubators has become popular with volunteer groups. When eggs are provided from hatchery sources, these projects have the potential to disrupt historic patterns of genetic diversity.

It is difficult to assess directly the influence of these population transfers on natural populations, because information is lacking in most cases. However, the results of two recent genetic analyses provide evidence that introduced hatchery fish have hybridized with hatchery and natural fish. Phelps et al. (1994, 1995), using significance testing of allelic frequencies and cluster analyses, found that chum salmon in five hatcheries outside Hood Canal (Minter Creek and Keta Creek in southern Puget Sound, Tulalip and Bellingham Maritime in northern Puget Sound, and the Elwha River on the Strait of Juan de Fuca), which had received eggs or fish for several years from Hood Canal hatcheries, had allozyme frequencies similar to those in Hood Canal hatchery populations. In addition, Phelps et al. (1994:76) concluded from analyses of allozyme frequencies of fish from Fennel Creek and Sherwood, Rocky, and Coulter Creeks in southern Puget Sound that “several wild chum salmon populations outside Hood Canal . . . may have had substantial genetic influence from Hood Canal origin hatchery chum salmon.” Several management actions were taken because “the presence of these hatchery strains limit the application of mixed-stock analysis and potentially jeopardize wild gene pools through interbreeding” (Phelps et al. 1995:75). Among these actions were the replacement of Minter and Keta Creek populations with more genetically-similar southern Puget Sound hatchery fish, the application of a genetic mark to Tulalip Hatchery chum salmon to evaluate the extent of hybridization with natural populations, and the cessation of transfers of fish from the Elwha Hatchery to other locations (Phelps et al. 1995).

Autocorrelation analysis (see “Genetics,” p. 86) can also be used to assess the genetic effects of egg transfers by determining whether groups of populations are genetically more similar to each other than would be expected from random dispersion around the average frequency of an allele. As discussed in the “Genetics of Chum Salmon” (p. 86), natural populations separated by more than about 250 km did not typically show significant positive autocorrelation (Fig. 14), most likely because of isolation by distance. Positive autocorrelation between specific groups separated by more than 250 km may be evidence of an interaction between the groups mediated by artificial gene flow.

We, therefore, calculated Moran’s coefficient (I) between 8 geographic or hatchery groups of samples reported in Phelps et al. (1994) and Phelps (footnote 28) for 19 allozyme alleles. These groups included 1) British Columbia (N=18 samples), 2) northern Puget Sound (N=16), 3) southern Puget Sound (N=14), 4) Hood Canal natural populations (N=4), 5) outer coast of Washington (N=8), 6) populations that have received outplanting of Hood Canal fish (N=7), 7) Hood Canal hatcheries (N=5), and 8) hatcheries that have received Hood Canal eggs (N=4). A jackknife variance was used to calculate a 95% confidence interval to test for departure from the expected value, $I = -1/(N-1)$, where N is the total number of samples used in the analysis. For this analysis of 79 samples, the expected correlation between groups was I=-0.0128.

Average autocorrelations for pairwise comparisons between groups of natural populations (groups 1-5) were negative, with one exception. The 9 negative correlations reflect genetic differentiation between geographically distinct groups 1-5 (except groups 4 and 5). The single exception to the pattern of negative correlation between distinct groups of natural populations was a significant positive autocorrelation between Hood Canal and outer coastal natural populations. A positive, though not significant, average correlation was also found between outer-coast natural populations and Hood Canal hatcheries. These two positive correlations may indicate that egg transplants from Hood Canal to rivers on the coast have influenced allele frequencies in outer-coast populations.

Comparisons involving Hood Canal hatcheries, or hatcheries stocked with Hood Canal eggs, generally showed negative correlations with natural populations, except for positive but nonsignficant, correlations for comparisons with natural populations in southern Puget Sound. Positive correlations between these groups would not be expected because they are separated by at least 250 km. This pattern may reflect post-glacial colonization of these two areas by a common ancestral source population. Another possibility is that the similarity between populations in the two areas may reflect an earlier pathway between Sinclair Inlet in southern Puget Sound and Hood Canal during the Fraser glacial period (Burns 1985, Blair 1991). A connection may have also existed between southern Puget Sound and the Pacific Ocean when a glacial lake drained from what is now Budd Inlet, through the Chehalis Valley to the ocean (Burns 1985). This connection has resulted in other zoogeographic similarities between southern Puget Sound and the Chehalis River Basin (McPhail and Lindsey 1986). Alternatively, the genetic similarity between these groups may indicate a general influence of Hood Canal egg transfers into southern Puget Sound natural populations.

Evidence for the influence of hatchery transfers and outplantings on other populations can be found in comparisons involving Hood Canal hatcheries. Positive, significant correlations in allele frequencies were detected in the three possible comparisons between groups 6-8: Hood Canal hatcheries, populations receiving eggs from Hood Canal hatcheries, and hatcheries outside Hood Canal with a history of egg transfers from Hood Canal hatcheries. These positive correlations are consistent with the hypothesis that egg transfers between hatcheries and outplantings have genetically influenced the receiving populations.

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. With the exception of a general decline in body size of spawners, there is no clear evidence for effects of such risk factors for chum salmon in Washington and Oregon. Other factors may be important for individual populations, as noted in the ESU summaries below.

Approach

Previous Assessments

Previous reviews of the status of chum salmon populations have been conducted (Nehlsen et al. 1991, WDF et al. 1993, Nickelson et al. 1992, Kostow 1995). These reviews used a variety of methods and criteria for evaluating the status of salmon stocks. Nehlsen et al. (1991) considered the status of populations coastwide and evaluated their risk of extinction. They reported only the status of populations they considered to be at risk of extinction, categorizing populations as possibly extinct, at high risk of extinction, at moderate risk of extinction, or of special concern.

Nehlsen et al. (1991) considered populations “at high risk of extinction” to have likely reached the threshold for classification as endangered under the ESA. Stocks were placed in this category if they had declined from historical levels, were continuing to decline, or had spawning escapements of less than 200. Populations 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. Nehlsen et al. (1991) felt that populations in this category had reached the threshold for classification as threatened under the ESA. Populations were classified 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. Nehlsen et al. (1991) also included a partial list of populations that they believed to be extinct. The other reviews are limited to individual states and are thus more limited in area, but are intended as inventories of populations and are more complete in terms of coverage within the areas they cover.

Washington

WDF et al. (1993) classified stocks by origin (native, non-native, mixed, or unknown), production (wild, composite, or unknown), and status (healthy, depressed, critical, or unknown). However, the stock status designations in SASSI (WDF et al. 1993) are not considered a “risk assessment” by these authors because SASSI is a survey that did not address threats to the future of the populations listed (Ames footnote 15). Stock status was classified as healthy if recent production was consistent with current habitat conditions. However, WDF et al. (1993) combined hatchery production with natural production if a hatchery was located on a stream that supported natural spawning, and, because the report considered only recent production status, it did not consider possible negative impacts of hatchery production on natural populations. WDF et al. (1993) recognized 72 chum salmon stocks in Washington. Of these, 48 were rated healthy, 3 were rated depressed, 2 were critical, 18 were of unknown status, and 1 (Chambers Creek summer-run chum salmon) was considered extinct (Table 18). Only one stock is classified as extinct because the authors considered only recent and not historical extinctions. Half of the stocks of unknown status were from the Strait of Juan de Fuca and the west side of the Olympic Peninsula. The classification of stock status by WDF et al. (1993) differed substantially from that of Nehlsen et al. (1991) mostly because of differences in the intent of the two classifications.

Nehlsen et al. (1991) considered the Duwamish/Green River fall chum salmon to be at high risk of extinction because of habitat loss and degradation. WDF et al. (1993) divided chum salmon in this watershed into a possible remnant native stock (Duwamish/Green River) whose status was unknown and into a hatchery run (Crisp or Keta Creek) introduced from releases of Quilcene and Hood Canal hatchery stocks. The Crisp Creek status was listed as healthy,

Table 18. Status of Washington State chum salmon stocks assessed in previous reviews.

Basin/stock[a]	Run	Nehlsen et al. (1991[b])	WDF et al. (1993) Origin[c]	WDF et al. (1993) Production Type[d]	WDF et al. (1993) Status[e]
Sumas-Chilliwack	F		N	W	U
Nooksack					
North Fork	F		N	W	H
Mainstem/South Fork	F		N	W	U
Samish/ Independent	F		M	C	H
Skagit					
Mainstem	F		N	W	H
Sauk	F		N	W	H
Lower Tributaries	F		U	W	U
Stillaguamish					
North Fork	F		N	W	H
South Fork	F		N	W	H
Snohomish					
Skykomish	F		N	W	H
Snoqualmie	F		N	W	U
Wallace	F		N	W	H
Duwamish/Green	F	A	M	C	H
Crisp Creek	F		X	C	H
Puyallup					
Puyallup/Carbon	F		N	W	U
Fennel Creek	F		U	W	H
Hylebos Creek	F		U	U	U
Nisqually	W		N	W	H
		F	X		
South Sound					
Chambers Creek	S		N	W	X
Hammersly Inlet	S		N	C	H
Case Inlet	S		N	C	H
Blackjack Creek	S		N	W	H
Henderson Inlet	F		N	C	U
Totten Inlet	F		N	W	H
Eld Inlet	F		N	W	H
Skookum Inlet	F		N	C	H
Upper Skookum Creek	F		N	W	H
Johns/Mills Creek	F		M	W	H
Goldsborough/ Shelton Creek	F		N	W	H
Case Inlet	F		N	W	H
Carr Inlet	F		M	C	H
Gig Harbor/Ollala	F		M	C	H
Dyes Inlet/Liberty Bay	F		M	C	H

Table 18 (Continued).

Basin/stock[a]	Run	Nehlsen et al. (1991[b])	WDF et al. (1993) Origin[c]	Production Type[d]	Status[e]
Sinclair Inlet	F		N	W	H
Chambers Creek	W		N	W	H
	S	B			X
Hood Canal					
Hood Canal	S	B	N	W	C
Union	S		N	W	H
NE Hood Canal	F		M	C	H
Dewatto,	F		M	C	H
SE Hood Canal	F		M	C	H
Lower Skokomish	F		M	C	U
Upper Skokomish Late	F		N	W	H
W Hood Canal	F		M	C	H
Harnma Hamma Late	F		N	W	H
Duckabush Late	F		N	W	H
Dosewallips Late	F		N	W	H
Quilcene Late	F		M	C	H
Strait of Juan de Fuca					
Discovery Bay	S		N	W	C
Sequirn Bay	S		N	W	D
Dungeness/E Strait Tribs	F		N	W	U
Elwha	F	A+	N	W	U
Lyre	F		N	W	U
Deep/E &W Twin Cks.	F		N	W	H
Pysht	F		N	W	H
Hoko/Clallam/Sekiu	F		B	W	U
Sooes	F		X	C	U
Ozette	F	A+	N	W	U
Quillayute	F		N	W	U
Hoh	F		U	U	U
Queets	F		U	U	U
Quinault	F		M	C	H
Grays Harbor					
Humptulips	F		N	W	H
Chehalis	F		N	W	H
Willapa Bay					
North River	F		N	W	H
Willapa	F.		N	W	H
Palix	F		N	W	H
Nemah	F		N	W	H
Naselle	F		M	W	H
Bear	F		N	W	H
Columbia River		B			
Washougal River		A+			

Table 18 (Continued).

Basin/stock[a]	Run	Nehlsen et al. (1991[b])	WDF et al. (1993) Origin[c]	Production Type[d]	Status[e]
Grays River	F		N	W	D
Hardy Creek	F		N	W	H
Hamilton Creek	F		N	W	D
Walla Walla River		X			

[a] Tributaries and minor drainages combined.
[b] A+--possibly extinct; A--high risk, C--special concern, X--extinct.
[c] N--native, M--mixed, X--non-native, U--unknown.
[d] W--wild, C--composite.
[e] H--healthy, D--depressed, C--critical, U--unknown.

although all population-assessment data available are from hatchery rack counts and hatchery planting records. As reported in the South Puget Sound SASSI Appendix (WDF et al. 1993, Appendix 1—South Puget Sound, p. 191):

> Currently, most of the fish are seen between Burns and Crisp Creeks. Natural spawning does occur in this reach, but many of these fish may be hatchery fish headed for the Keta Creek facility. In fact, there is some doubt that any native fish exist . . . Efforts are underway to determine if any of the native fish remain.

Nehlsen et al. (1991) considered the Elwha and Ozette Rivers' fall chum salmon runs to be possibly extinct, whereas WDF et al. (1993) listed the status of these runs as unknown. Nehlsen et al. (1991) listed Nisqually and Walla Walla Rivers' fall chum salmon as extinct and the Washougal River fall chum salmon as possibly extinct; these stocks were not mentioned by WDF et al. (1993), because SASSI addressed only recent extinctions (Ames footnote 15). Nehlsen et al. (1991) considered Hood Canal and Chambers Creek summer chum salmon to be at moderate risk, whereas WDF et al. (1993) considered Chambers Creek summer chum salmon as extinct and Hood Canal summer chum salmon as critical. Finally, Nehlsen et al. (1991) considered lower Columbia River chum salmon to be at moderate risk; WDF et al. (1993) divided these fish into three separate stocks, two of which were classified as depressed and one as healthy.

Oregon

Within Oregon, Nehlsen et al. (1991) (Table 19) listed 11 chum salmon populations, in addition to the Lower Columbia River chum salmon population, which also extended into Washington (Table 18). They considered the Umatilla River population to be extinct, and populations in Tillamook Bay, Netarts Bay, and Nestucca Bay at moderate risk of extinction. They also identified seven stocks from Siletz Bay south which they considered to be at high risk of extinction.

Chilcote et al. (1992) listed an inventory of chum salmon runs in Oregon and evaluated them under the Oregon Wild Fish Policy (Chilcote et al. 1992) (Table 19). This policy has two compliance criteria: a hatchery criterion that requires naturally spawning populations to have no more than 10% strays from a genetically-dissimilar hatchery stock or 50% strays from a genetically-similar hatchery stock, and a numerical criterion that requires at least 300 average spawners. Kostow (1995) is a revision of Chilcote et al. (1992), with newer information on stock presence or absence. Chilcote et al. (1992) considered the percentages of hatchery strays and their genetic constitution in all chum salmon runs in Oregon in compliance with the hatchery criteria. Of 50 populations of chum salmon identified in Oregon, they considered 4 to be in compliance with the numerical criterion and 4 out of compliance. The remaining 42 populations were of unknown status.

Table 19. Status of Oregon State chum salmon stocks assessed in previous reviews.

		Chilcote et al. 1992	
		Compliance criteria	
Basin/Stock[a]	Nehlsen et al. 1991[b]	Hatchery[c]	Size[d]
Columbia River	B		
Umatilla River	X		
Youngs Bay			
Lewis & Clark River		Y	U
Youngs River		Y	U
Klaskanine River		Y	U
Wallooskee River		Y	U
Mill Creek		Y	U
John Day River		Y	U
Marys Creek		Y	U
Bear Creek		Y	U
Ferris River	Y	U	
Big Creek		Y	U
Fertile Valley Creek		Y	U
Gnat Creek		Y	U
Hunt Creek	Y	U	
Plympton Creek		Y	U
Clatskanie River		Y	U
Beaver Creek		Y	U
Green River	Y	U	
Nice Creek		Y	U
Fox Creek		Y	U
Goble Creek		Y	U
Tide Creek		Y	U
Milton Creek		Y	U
McBride Creek		Y	U
* Scappoose Creek		Y	U
Necanicurn River		Y	N
Nehalem River			
Below Hwy26 Bridge		Y	U
NF Nehalem River		Y	U
Tillamook Bay	B		
Miami River		Y	Y
Patterson Creek		Y	U
Doty Creek		Y	U
Vaughn Creek		Y	U
Kilchis River		Y	Y
Wilson River		Y	Y
Beaver Creek			
Trask River		Y	U
Tillamook River		Y	U
Bewley Creek			
Netarts Bay			
Netarts River	B		

Table 19 (Continued).

		Chilcote et al. 1992	
		Compliance criteria	
Basin/Stock[a]	Nehlsen et al. 1991[b]	Hatchery[c]	Size[d]
Jackson Creek		Y	U
Whiskey Creek		Y	U
Crown Z Creek			
Sand Lake			
Sand Creek		Y	U
Jewell Creek			
Andy Creek			
Nestucca Bay			
Nestucca River	B		
Horn Creek		Y	Y
Little Nestucca River			
Fall Creek		Y	U
Neskowin Creek		Y	U
Salmon River		Y	U
Siletz Bay			
Siletz River	A	Y	U
Drift Creek		Y	U
Yaquina Bay			
Wright Creek			
Beaver Creek			
Mill Creek			
Yaquina River	A	Y	U
Alsea River	A	Y	U
Yachats River		Y	U
Umpqua Estuary			
Umpqua River	A		
Smith River		Y	N
Coos Bay			
* Coos River	A	Y	N
Millicoma River			
Marlow Creek			
Coquille River		Y	N
Sixes River	A		
Elk River	A		

[a] Tributaries and minor drainages combined.

[b] A+--possibly extinct; A--high risk, C--special concern, X--extinct.

[c] Y--natural spawners are less than 50% genetically similar hatchery fish or 10% genetically dissimilar hatchery fish, N--not in compliance.

[d] Y--more than 300 spawners, N-- less than 300 spwners, U--unknown.

Nickelson et al. (1992) evaluated the status of coastal populations of chum salmon in Oregon. They classified populations as healthy if available spawning habitat was fully seeded and abundance trends were stable or increasing over the last 20 years. They classified populations as “of special concern” if they were believed to be composed of fewer than 300 spawners, or had a naturally spawning population that consisted of more than 50% strays from a genetically-similar hatchery stock or 10% strays from a dissimilar hatchery stock. Populations were classified as depressed if available spawning habitat was not fully seeded, abundance trends were declining over the last 20 years, or abundance trends in recent years were below the 20-year average. Nickelson et al. (1992) classified the status of 26 stocks; of these, 10 were considered healthy, 12 “of special concern,” and 4 of unknown status due to insufficient data.

The 1994 biennial report on wild fish status in Oregon (Kostow 1995) considered chum salmon populations in the Columbia River to be very depressed to extinct. Kostow (1995) also described the Nehalem River as having a population of several hundred adults, and the Necanicum River population as very small, unstable, and vulnerable. Chum salmon populations in Tillamook Bay, Netarts Bay, and the Nestucca River were described as the most substantial populations in Oregon, with Tillamook Bay having estimated escapements of 10,500 adults in 1992 and 7,500 adults in 1993. Chum salmon populations south of the Nestucca River were described as very depressed or extinct, with remnant populations in the Salmon, Alsea, Yaquina, Siletz, and Coos Bay River systems, and scattered adults occasionally seen in other basins (Kostow 1995).

California

Nehlsen et al. (1991) listed chum salmon runs in the Sacramento River and Klamath River as extinct.

Data Evaluations

Quantitative evaluations of data included comparisons of current and historical abundance of chum salmon, and calculation of recent trends in escapement. Historical abundance information for these ESUs is largely anecdotal. Time-series data were available for many populations, but the amount and quality of the data varied among ESUs. We compiled and analyzed this information to provide several summary statistics of the abundance of naturally spawning populations, including (where available) recent total spawning run size and escapement, percent annual change in total escapement, and recent naturally-produced spawning run size and escapement.

Although this evaluation used the best data available, they have several limitations, and not all summary statistics were available for all populations. For example, spawner abundance varies by state and region, and in some areas, (particularly where chum salmon are not presently abundant) abundance was generally not measured directly. Instead, abundance was often estimated from catch (which itself may not always have been measured accurately) or from limited survey data. In many cases, limited data were also used to separate hatchery production from natural production.

Information on stock abundance was compiled from records in a variety of state, federal, and tribal agencies. We believe this information to be complete in terms of long-term adult abundance records for chum salmon in the regions included in this review. Principal data sources were run reconstruction and fishery statistics from commercial, tribal, and recreational fisheries, and escapement estimates from stream surveys of spawning escapement. However, although the above provide the “best” estimates of chum salmon production, actual run-size may vary from these estimates. Specific problems are discussed below for each data type.

Data Types

Washington

Information on the abundance of natural chum salmon populations in Puget Sound includes fishery landings data and spawning escapement surveys. While chum salmon fisheries occur in several Puget Sound rivers, most chum salmon are harvested in saltwater, as fish return to different spawning areas. The relative run size in terminal areas and genetic mixed-stock analysis (MSA) indicate that various stocks are included in these mixed-stock fisheries (Graves 1989).

In the northern portion of Puget Sound, chum salmon escapement is estimated for river basins by scaling base-year mark-recapture estimates (Eames et al. 1981) by the ratio of total spawners in index areas to the index values in the base years. Estimates for individual stocks at a finer level are usually not available. In general, index counts are available, but the base-year data necessary to scale them at the stock level are lacking for some areas (Hendrick[32]). Data for southern Puget Sound are primarily from spawning ground surveys (where all, or nearly all, of the spawning habitat is surveyed) and from hatchery rack counts. Prior to 1976, spawning ground surveys were used primarily to define peak counts of live fish, and since then most estimates have been based on area under-the-curve (AUC) calculations derived from weekly spawning ground surveys. WDFW used the AUC method, after it was introduced in 1976, to estimate peak abundances for some locations in southern Puget Sound and Hood Canal with data reaching back to 1968 (Uehara[33]).

Hood Canal summer- and fall-run chum salmon estimates of escapement from 1968 to the present are based on the AUC methodology. Survey frequency was low prior to the mid-

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[32] D. Hendrick, Washington Department of Fish and Wildlife, 333 East Blackburn Rd., Mt. Vernon, Washington 98273. Pers. commun., November 1995.

[33] J. Uehara, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., November 1995.

1970s, and peak live spawner abundance and the full extent of spawning were often not reflected in the curves. This means that early calculations underestimate abundances.

Chum salmon escapement has not been monitored by tribal biologists on the west side of the Olympic Peninsula, and the only stock status data available were from landings. Chum salmon are generally not targeted in western Olympic Peninsula or tribal fisheries, and since the fisheries tend to occur near river mouths, it is not known to what extent the fish in the landings in a river originate from that river. In Grays Harbor, index counts of peak spawners were expanded to estimate total escapement, and in Willapa Bay, WDFW estimated escapement using AUC methodology from spawning ground surveys of adults (Brix[34]).

According to Washington fisheries co-managers (WDF et al. 1993), Columbia River chum salmon populations on the Washington side of the river were limited to Grays River, Hardy Creek, and Hamilton Creek. However, biologists from WDFW have also observed chum salmon in the Lewis, Cowlitz, and Kalama Rivers (Ames footnote 15). Fish spawn in limited areas of these streams, and spawning grounds have been surveyed annually since 1976. These surveys cover most of the spawning habitat in the streams surveyed, and counts at Bonneville Dam monitor chum salmon ascending the Columbia River beyond these streams. WDF et al. (1993) estimated that recent spawning escapement of chum salmon in the Columbia River was in the range of "a few thousand up to ten thousand."

Oregon

In Oregon, chum salmon spawning escapement has been monitored by ODFW using peak counts of live and dead fish in standard surveys in the Tillamook District since 1948 at Moss Creek, Clear Creek (Kilchis River), and the Little North Fork of the Wilson River. An additional survey site (Nestucca River) was added in 1950. The intention of ODFW was to monitor trends in escapement, and they have not attempted to quantify total escapement (Cooney and Jacobs 1994).

From 1957 through 1972, an impassible culvert was present near the mouth of Moss Creek, and from 1960 through 1982 one was present on Clear Creek. Also in 1960, logging and road slides clouded the water and hampered viewing in the Wilson River. In an attempt to improve the census of spawning fish, ODFW surveyed 11 more areas, and in 1976 reclassified 4 of these supplemental surveys as standard surveys. The degree to which the surveys tracked spawner abundance is questionable, because the amount of habitat has not been well monitored and there have been unrecorded changes in quality and quantity of the survey areas. Nevertheless, Nickelson et al. (1992) used the relationship between the survey data and commercial landings to estimate total escapement to Tillamook Bay. In 1992, ODFW added 21

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[34] R. Brix, Washington Department of Fish and Wildlife, 48 Devonshire Rd., Montesano, Washington 98563. Pers. commun., March 1997.

supplemental surveys in addition to its 8 standard surveys (Cooney and Jacobs 1994). Supplemental surveys were located from the North Coast District as far south as the Yaquina River. These supplemental surveys have been monitored since then (Klumph and Braun 1995). In addition, a trap constructed by Oregon State University on Whiskey Creek in Netarts Bay has been in operation since 1969 (Nickelson et al. 1992).

California

In California, chum salmon spawning escapement has not been monitored.

Run Size

In Washington, run size in Puget Sound was calculated by run reconstruction. Interceptions by Canadian fisheries were considered relatively minor and were not incorporated in the run reconstructions. Landings within Puget Sound were attributed to production units on the basis of geographic locations of the fisheries and spawning grounds, and tagging studies. Run reconstruction was also used to calculate run size in Grays Harbor and Willapa Bay. In other areas, run-size estimates were not available. Run size can be estimated by summing terminal catch and spawning escapement, because ocean interceptions are assumed to be negligible. However, in coastal rivers on the Olympic Peninsula, the Columbia River Basin (exclusive of the Washington side), and coastal Oregon streams, spawning escapement has not been estimated.

Fishery landings

Fishery landings were estimated more accurately than spawning escapement. However, landings contain less information on the abundance of individual stocks. While they are informative in monitoring the overall abundance of chum salmon in broad geographic regions within Puget Sound, the bulk of commercial fishing occurs on mixed stocks, and the current data have not as yet been resolved into component stocks. For coastal rivers on the west side of the Olympic Peninsula, these are the only data available and more accurately reflect landings from individual rivers.

Computed statistics

To represent current run size or escapement where recent data were available, we computed the geometric mean of the most recent 5 years reported (or fewer years if the data series was shorter than 5 years). We used only estimates that reflected 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. Where adequate data were available, trends in total escapement (or run size if escapement data were not available) were calculated for all data sets with more than 5 years of data, based on total escapement or an escapement index (such as fish per mile from a stream survey).

As an indication of overall trends in chum salmon populations in individual streams, we calculated average (over the available data series) percentage annual change in adult spawner indices within each river basin. Trends were calculated as the slope (a) of the regression of ln(abundance) against years corresponding to the biological model $N(t) = be^{at}$. Slopes significantly different from 0 ($P<0.05$) were noted. The regressions provided direct estimates of mean instantaneous rates of population change (a); these values were subsequently converted to percentage annual change, calculated as $100(e^{a-1})$. No attempt was made to account for the influence of hatchery-produced fish on these estimates, so the estimated trends included any supplementation effect of hatchery fish. Trend analysis can also be influenced by climate regime shifts and other factors.

Analysis of Biological Information by ESU

Puget Sound/Strait of Georgia ESU

The Puget Sound/Strait of Georgia ESU of chum salmon encompasses much diversity in life history, and includes summer, fall, and winter runs of chum salmon. WDF et al. (1993) identified 38 stocks with sufficient data to calculate trends in escapement within the area encompassed by this ESU: 10 had negative trends and 23 had positive trends (Table 20). All of the statistically significant trends ($P< 0.05$) were positive and the slopes of many negative trends were close to zero. One stock, the Chambers Creek population of summer chum salmon, met the WDF et al. (1993) definition of extinct, a stock currently being tracked that is believed to have been extirpated in its original range. The sum of the recent 5-year geometric means of these escapement trends, which are not exhaustive, indicate a recent average escapement of more than 300,000 natural spawners for the Puget Sound/Strait of Georgia ESU as a whole.

Commercial harvest of chum salmon has been increasing since the early 1970s throughout the state (Fig. 24) and the majority of this harvest has been from the Puget Sound/ Strait of Georgia ESU. The recent average chum salmon harvest from Puget Sound (1988-1992) was 1.185 million fish (WDFW 1995). This suggests a total abundance of about 1.5 million adult chum salmon. This increasing harvest, coupled with generally increasing trends in spawning escapement, provides compelling evidence that chum salmon are abundant and have been increasing in abundance in recent years within this ESU.

While most populations in this ESU appear to be healthy and increasing in abundance, there appears to be a potential for loss of genetic diversity within this ESU, especially in populations that display the most distinctive life histories. For example, four summer-run stocks from southern Puget Sound were identified by WDF et al. (1993). Of these four, one was classified as extinct, two were of mixed production, and all were relatively small. Of the three

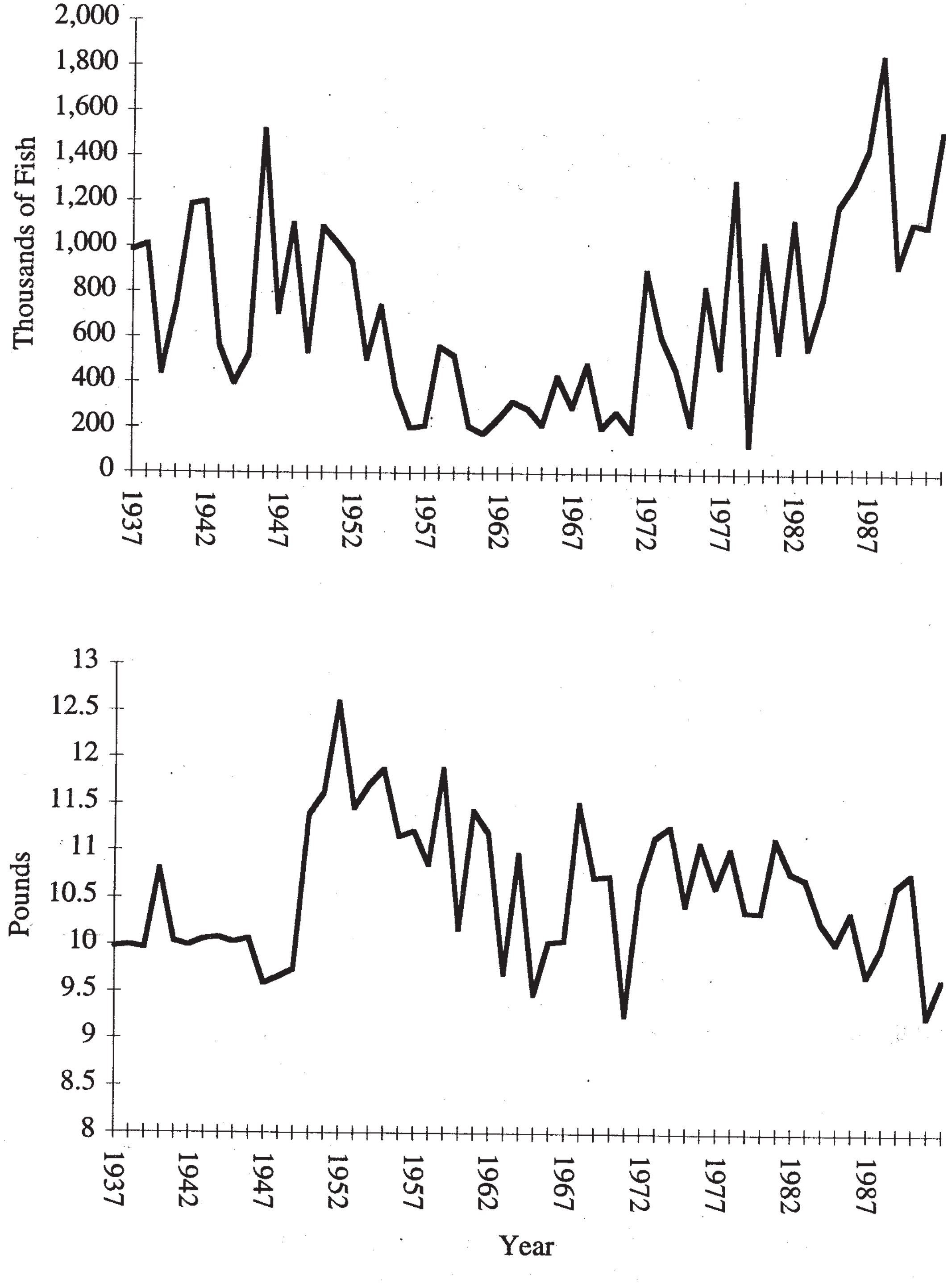

Figure 24. Total commercial landings and average weight of chum salmon caught in Washington waters from 1937 to 1991. Data from Palmisano et al. (1993).

Table 20. Abundance and trends of rated Washington State chum salmon stocks recognized in SASSI (WDF et al. 1993).

Stock[a]	Run time	Production	Abundance[b]	Trend (% change/yr)	
Sumas/Chilliwack	Fall	Natural	17	5.5	
North Fork Nooksack	Fall	Natural	21,424	2.6	
Samish/Independent	Fall	Mixed	6,424	-5.2	
Sauk	Fall	Natural	6,307	-2.0	
Mainstem Skagit	Fall	Natural	42,476	6.1	
N.F. Stillaguamish	Fall	Natural	44,996	2.5	
S.F. Stillaguamish	Fall	Natural	12,303	8.7	
Skykomish	Fall	Natural	15,100	3.9	
Wallace	Fall	Natural	1,830	9.0	*
Crisp Creek	Fall	Hatchery	250	11.5	
Fennel Creek	Fall	Natural	379	13.6	*
Nisqually	Winter	Natural	16,208	-0.7	
Chambers Creek	Summer	Natural	Extinct		
Hammersley Inlet	Summer	Mixed	7,728	1.1	
Case Inlet	Summer	Mixed	4,570	0.6	
Blackjack Creek	Summer	Natural	524	1.8	
Eld Inlet	Fall	Natural	2,473	54.9	*
Totten Inlet	Fall	Natural	16,563	5.0	*
Skookum Inlet	Fall	Mixed	3,984	15.0	*
Upper Skookum Creek	Fall	Natural	1,437	7.5	*
Johns/Mill Creek	Fall	Natural	13,241	2.2	
Goldsborough/Shelton	Fall	Natural	3,703	9.3	*
Case Inlet	Fall	Natural	2,157	4.4	*
Carr Inlet	Fall	Mixed	879	-2.3	
Gig Harbor/Ollala Creek	Fall	Mixed	3,889	8.6	*

Table 20 (Continued).

Stock[a]	Run time	Production	Abundance[b]	Trend (% change/yr)	
Dyes Inlet/Liberty Bay	Fall	Mixed	18,902	4.2	*
Sinclair Inlet	Fall	Natural	2,511	-0.3	
Chambers Creek	Winter	Natural	2,340	9.8	*
Northeast Hood Canal	Fall	Mixed	1,989	-2.5	
Dewatto	Fall	Mixed	2,904	4.0	
Southeast Hood Canal	Fall	Mixed	5,992	-2.2	
Upper Skokomish Late	Fall	Natural	5,144	-1.5	
West Hood Canal	Fall	Mixed	10,452	-2.4	
Hamma Hamma Late	Fall	Natural	7,046	-1.0	
Duckabush Late	Fall	Natural	3,242	13.2	*
Dosewallips Late	Fall	Natural	538	2.2	
Quilcene Late	Fall	Mixed	3,970	9.8	*
Dungeness/East River Tribs.	Fall	Natural	230	10.7	*
Hood Canal	Summer	Natural	508	-17.7	*
Union	Summer	Natural	275	6.6	*
Discovery Bay	Summer	Natural	268	-8.0	*
Sequim Bay	Summer	Natural	156	-1.6	
Deep Creek	Fall	Natural	279	11.3	*
Pysht	Fall	Natural	1,404	13.7	*
Quinault	Fall	Mixed	4,055	-3.3	
Humptulips	Fall	Natural	281	1.1	
Chehalis	Fall	Natural	3,971	5.0	
North River	Fall	Natural	6,612	3.0	
Willapa	Fall	Natural	112	-6.9	*
Palix	Fall	Natural	4,996	3.2	
Nemah	Fall	Natural	5,352	4.1	*
Naselle	Fall	Natural	3,693	2.4	

Table 20 (Continued).

Stock[a]	Run time	Production	Abundance[b]	Trend (% change/yr)
Bear	Fall	Natural	2,791	0.5
Grays	Fall	Natural	125[c]	1.8
Hamilton Creek	Fall	Natural	37[c]	−5.2
Hardy	Fall	Natural	102[c]	3.2

[a] Tributaries and minor drainages combined.
[b] Abundance reported as 5-year geometric mean.
[c] Values are fish per mile in index reaches rather than spawning population estimates.
*Denotes trends that differ significantly (P>0.95) from zero.

extant stocks, Blackjack Creek has a 5-year geometric mean spawning escapement of 524, Case Inlet has 4,570, and Hammersley Inlet has 7,728, with about 40,000 total summer chum salmon spawners in southern Puget Sound estimated in 1994. The latter two stocks had hatchery supplementation programs that were believed to be major contributors to the runs until they were discontinued in 1992 (WDF et al. 1993). The last brood year produced by these hatchery programs (1991 brood year) returned as adults at age-4 in 1995 and age-5 in 1996. While all three summer-run populations are apparently stable or increasing, they represent a small fraction of the ESU. The winter-run life history is represented by only two stocks. The Chambers Creek stock is increasing in abundance, and the Nisqually River stock is a relatively large run with a 5-year geometric mean escapement of more than 16,000 spawners. Both stocks are classified as wild production.

Hood Canal Summer-Run ESU

Analysis of biological information for the Hood Canal summer-run chum salmon ESU is more extensive than that for other ESUs. This extended analysis reflects the deliberations of the BRT in considering the dynamic changes in summer-run chum salmon abundance that have occurred in this ESU over the past several years.

Although summer chum salmon in this ESU have experienced a continuing decline over the past 30 years, escapement in 1995-96 increased dramatically in some streams (Fig. 25). Spawning escapement of summer chum salmon in Hood Canal (excluding the Union River) numbered over 40,000 fish in 1968, but was reduced to only 173 fish in 1989 (WDF et al. 1993). In 1991, only 7 of 12 streams that historically contained spawning runs of summer chum salmon still had escapements (Cook-Tabor 1994, WDFW 1996). Then in 1995, escapement increased to more than 21,000 fish in northern Hood Canal, the largest return in more than 20 years (WDFW 1996). These increases in escapement were observed primarily in rivers on the west side of Hood Canal (Fig. 26), with the largest increase in the Big Quilcene River where the USFWS has been conducting an enhancement program starting with the 1992 brood year (Tables 21 and 22). Streams on the east side of Hood Canal continued either to have no returning adults (Big Beef Creek, Anderson Creek, and the Dewatto River) or no increases in escapement (Tahuya and Union Rivers) (Fig. 26).

Summer runs of chum salmon in the Strait of Juan de Fuca (Snow and Salmon Creeks in Discovery Bay and Jimmycomelately Creek in Sequim Bay) are also part of this ESU. While these populations have not demonstrated the marked declining trend that has characterized the summer-run populations in Hood Canal in recent years, they are at very low population levels (Fig. 27). Further, though escapement of summer-run chum salmon to Salmon Creek increased in 1996, the other two populations in the Strait of Juan de Fuca did not show similar increases (Fig. 27), and the overall trend in the Strait populations was one of continued decline. WDF et al. (1993) considered the Discovery Bay population to be critical and the Sequim Bay population to be depressed (Table 18).

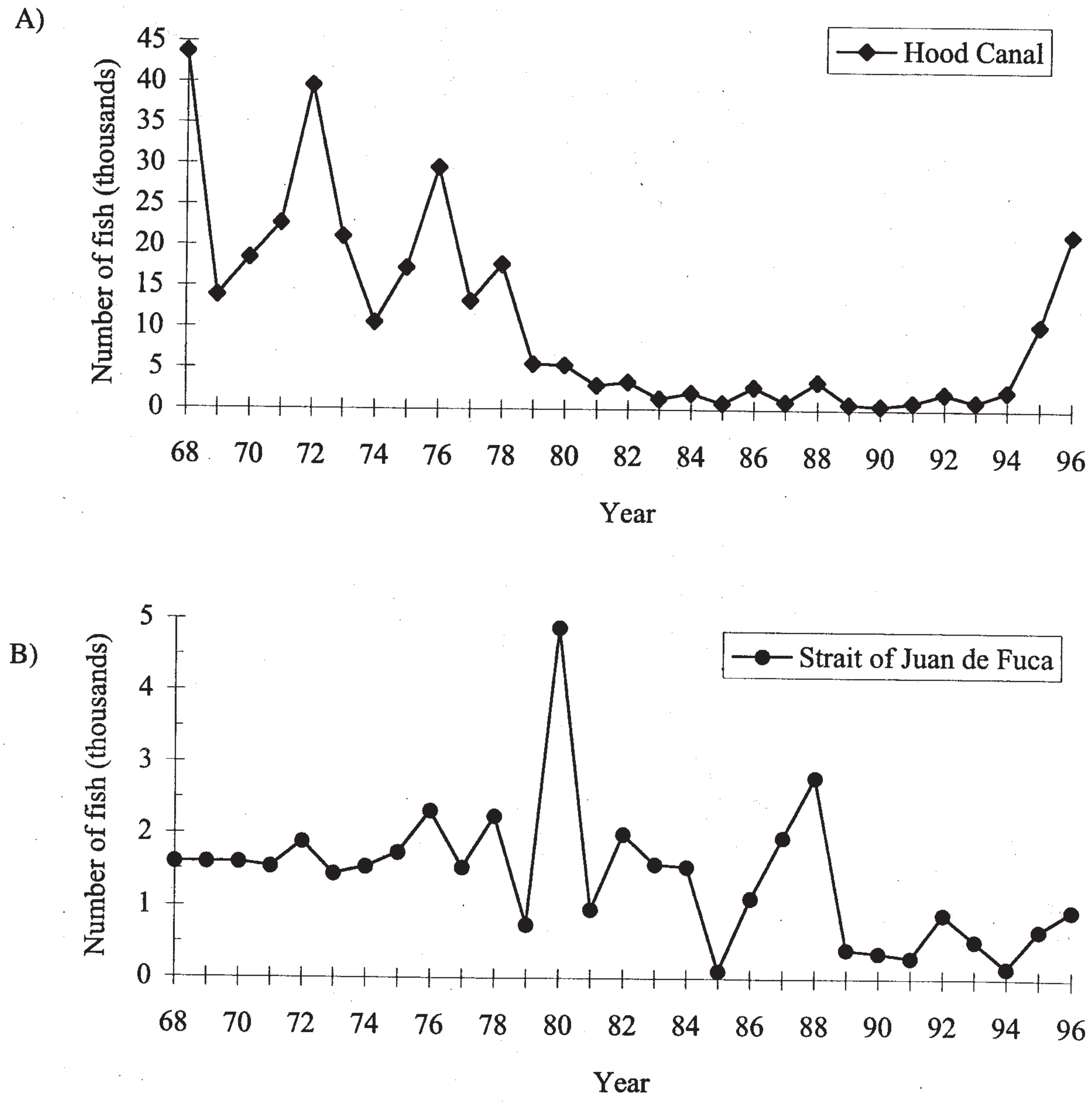

Figure 25. Spawning escapement of summer-run chum salmon, 1968 to 1996, to (A) Hood Canal streams and (B) Discovery and Sequim Bays in the eastern Strait of Juan de Fuca. Data from NMFS (1995).

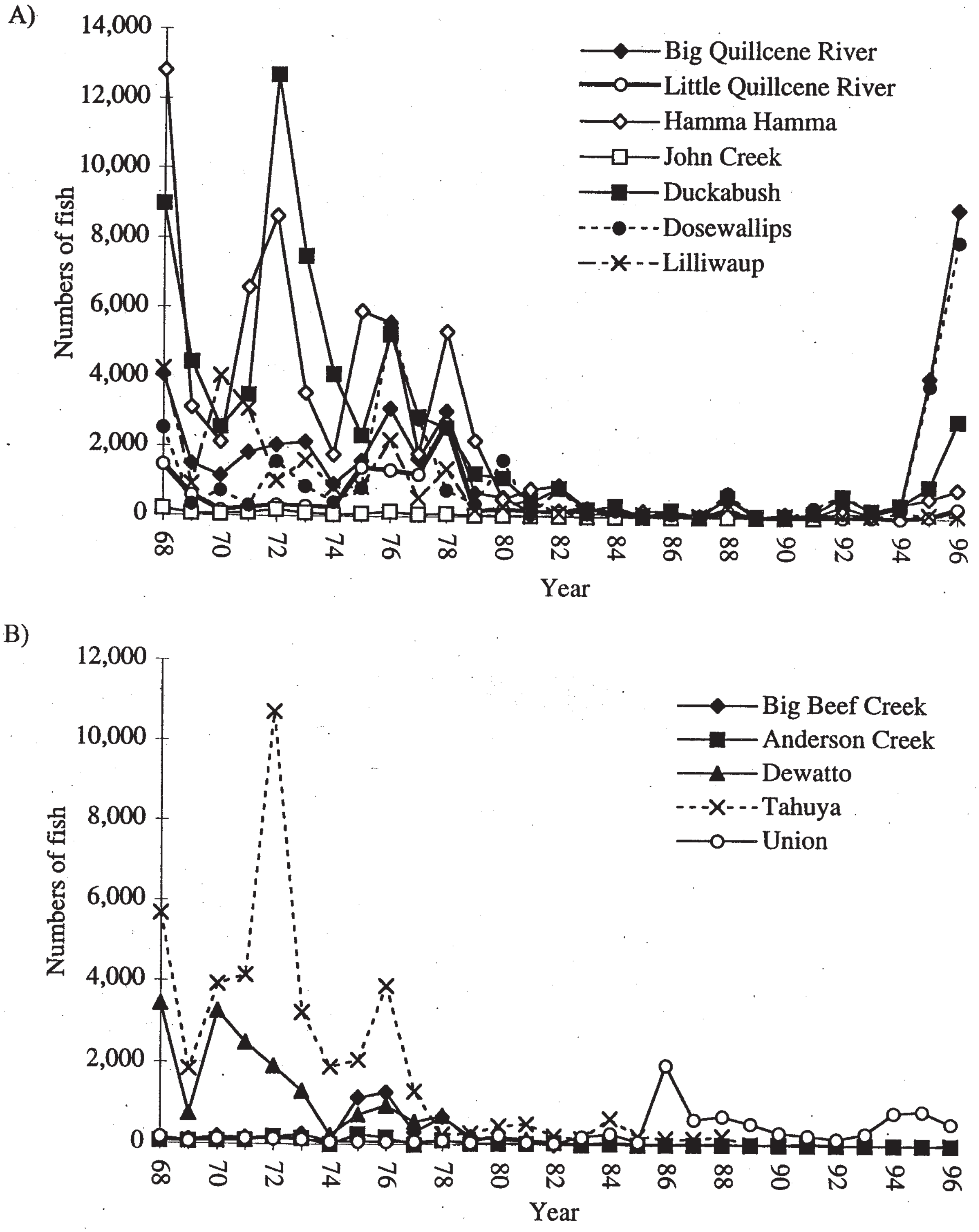

Figure 26. Spawning escapement of summer chum salmon to streams on (A) westside and (B) eastside of Hood Canal, 1968-1996. Data from NMFS (1995) and WDFW (1996).

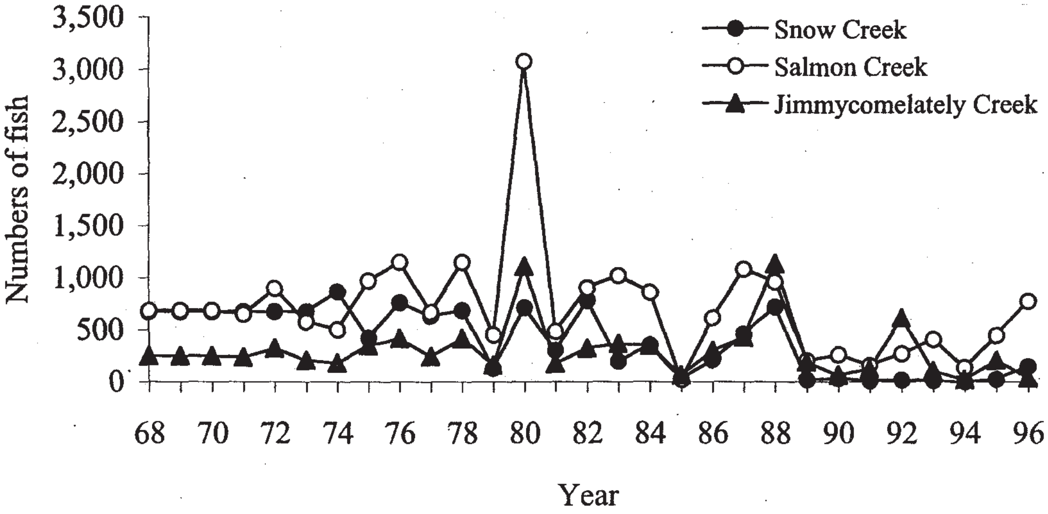

Figure 27. Escapement of summer-run chum salmon along the Strait of Juan de Fuca, at Discovery Bay (Snow and Salmon Creeks) and Sequim Bay (Jimmycomelately Creek). Data from NMFS (1995) and WDFW (1996).

Table 21. Broodstock collection data for Hood Canal summer chum salmon reared at Quilcene National Fish Hatchery 1992-96. Broodstock are collected from fisheries in Quilcene Bay, from spawning grounds on Big Quilcene River, and from fish that swim up the Big Quilcene River to a trap located at the Quilcene Hatchery. Data for 1996 broodstock and natural escapement are preliminary (WDFW 1996). AD=adipose fin clipped; CWT=coded wire tagged.

Brood year	Broodstock collected (nos.)			Observed escapement to Big Quilcene R.	Percent of total run collected	No. fed fry released	Release size (g)	Release date	No. of fish marked (% of total released)
	Males	Females	Total						
1992	224	188	412	405	50.3	216,441	1.05	4/13/93	53,067 (24.52%) AD + CWT
1993	19	17	36	101	26.3	24,784	1.46	3/30/94	unmarked
1994	161	170	331	317	51.1	343,550	1.06	3/27/95	unmarked
1995	243	256	499	4,100	10.1	441,167	1.06	3/29/96	unmarked
1996	426	322	758	8,688	8.0				

Several factors may have contributed to the dramatic increase in abundance seen in some Hood Canal streams in 1995 and 1996. These include hatchery supplementation, reduction in harvest rate, increase in marine survival, and improvements in freshwater habitat. Information relevant to these factors is discussed below.

Hatchery supplementation

USFWS began hatchery production of summer chum salmon in Quilcene Bay with the 1992 brood year (Table 21). In brood year 1992, 27.95% of the fry released from Quilcene Hatchery had their adipose fins removed, and most of these were tagged with micro- (half-size) coded wire tags (CWTs); in subsequent years, all releases have been unmarked. Marked fish returned as age-3 spawners in 1995 and as age-4 spawners in 1996. Examination of ratios of marked and unmarked fish provides some indication of the role of hatchery production in the population increases seen in some areas in 1995 and 1996.

Table 22 shows the number of adults surveyed in several areas in 1995 and 1996 and the number of those fish that were fin-clipped. These data were provided by WDFW and USFWS. Based on the proportion of marked and unmarked fish in the fishery in Quilcene Bay, returns to the hatchery, and returns to Big Quilcene River (considering only age-3 fish in 1995-96 and only age-4 fish in 1996), USFWS estimated that the survival of marked fish was only 21.4% that of unmarked fish in 1995 and 39.9% of unmarked fish in 1996. USFWS assumed in making these estimates that all fish sampled in Quilcene Bay and the Big Quilcene River originated from hatcheries. A major weakness with the USFWS method is that there was apparently no independent way to confirm this assumption. This method overestimates tagging mortality if unmarked fish of non-hatchery origin are included in the samples. While this error almost certainly occurred, we do not have a quantitative estimate of its magnitude. Bailey (1995) estimated the survival rate of adipose-clipped and micro-coded wire-tagged chum salmon fry from the Nitinat Hatchery released into Barclay Sound on the west coast of Vancouver Island was approximately 50% that of unmarked chum salmon. Given these assumptions, the estimated hatchery contributions to escapement to the Big Quilcene River were 32% of the 3-year-olds in 1995 and 63% of the 4-year-olds in 1996.

Table 22 presents 95% confidence limits on the largest number of marked fish that could have been present in each stream given the estimated spawning escapement, the number of carcasses examined, and the number of marks detected in 1996. The tabulated maximal number of marks represents the maximal number of marked fish that could have been present in the spawning escapement with less than 0.05 probability of observing no marked fish in the carcass surveys. These limits were calculated from a hypergeometric distribution, with the assumption that the carcasses in the surveys were drawn randomly from a population the size of the estimated escapement without replacement.

Table 22 also shows an estimate of the maximal number of hatchery fish that could have been present in those streams in 1996. These estimates were obtained by expanding the maximal number of marked fish by the effective mark rate. The latter value was obtained by adjusting the

Table 22. Summary of chum salmon carcasses examined for hatchery marks in selected Hood Canal streams in 1995 and 1996 (WDFW 1996, USFWS 1996).

Stream	Estimated escapement	Fish examined	Number of marked fish observed	Maximum number of marked fish possible[a]	Hypothetical maximum number of hatchery fish possible[b]
1995					
Quilcene Bay[c]		499	41		
Big Quilcene R.		808	26		
L. Quilcene R.		8	0		
Dosewallips		180	0		
1996					
Quilcene Bay[d]		822	85		
Big Quilcene R.		642	55		
L. Quilcene R.	274	125	0	5	45
Dosewallips R.	7,959	1,330	0	17	153
Duckabush R.	2,807	650	0	12	108
Hamma Hamma R.	820	200	0	11	99
Union R.	552	150	0	10	90
Total[b]	12,412	2,455	0	14	126

[a] The maximum number of marked fish that could have been in the population and still have at least a 5% chance of observing no marked fish.

[b] The value in the previous column expanded to include unmarked hatchery fish based on USFWS estimate of effective tagging rate. As discussed in text, this undoubtedly overestimates the number of hatchery fish, but by an unknown amount.

[c] Quilcene Bay number includes fish that returned to the hatchery.

[d] Total does not include fish from the fishery or from Quilcene Bay.

actual mark rate (28%) for relative marking survival (0.34 in 1996); the resulting estimate of effective marking rate is 0.11. The total estimate was obtained by pooling all samples, and placed an upper bound on the total number of possible strays assuming that all streams were equally likely to receive strays. The numbers of potential strays from the USFWS enhancement program was clearly too small to account for the observed increases in escapement to the Dosewallips, Hamma Hamma, and Duckabush Rivers.

Collectively, these results suggest the following conclusions about the effects of hatchery supplementation on adult returns in 1995 and 1996.

1. There is no way to evaluate accurately the contribution of hatchery fish to escapements outside Quilcene Bay without making assumptions about effective tagging rate, and there are no reliable estimates of that parameter. However, outside Quilcene Bay, it is difficult to attribute many of the 1996 returns to hatchery strays unless either a) biologists missed marked fish in areas outside the Bay at a much higher rate than they did in the Big Quilcene River, or b) virtually all marked fish died. There is no reason to believe that a) is true, and b) is contradicted by the presence of substantial numbers of marked hatchery fish in Quilcene Bay. Therefore, the most parsimonious conclusion is that most, perhaps all, 1996 adult returns of Hood Canal summer chum salmon to areas outside Quilcene Bay resulted from natural production.

2. If fish stray from the hatchery program in the Big Quilcene River into the Little Quilcene River, the aging rate must be very low (at least in 1996, since sampling was too low to draw conclusions in 1995) because no marked fish were found in natural spawning areas.

3. Available data are not particularly informative about the origins of fish sampled in Quilcene Bay. The USFWS method is based heavily on data for these fish, but it would lead to an unbiased estimate only if all of the fish were of hatchery origin. The method therefore cannot be used to evaluate the origins of these same fish.

4. There are similar difficulties in interpreting the data for the Big Quilcene River. It is possible that most or all of the adults that returned in 1996 were of hatchery origin, but this greatly depends on the level of marking mortality, and the level of bias or uncertainty associated with this estimate is unknown. The relatively low proportion of marked fish in 1995 suggests that a significant fraction of adults returning to the Big Quilcene River in that year was the result of natural production.

Harvest reduction

WDFW divides Hood Canal into five regions for fishery management and assessment (Fig. 3). Spawning populations of summer chum salmon are restricted to four of these regions: Area 12A, Dabob Bay and Quilcene Bays, includes marine waters to which Big Quilcene and Little Quilcene Rivers are tributaries; Area 12B, Central Hood Canal, includes the marine waters adjacent to other east and westside rivers such as Anderson Creek and the Dosewallips, Hamma

Hamma, and Duckabush Rivers; Area 12C, South Hood Canal, includes the population in marine waters adjacent to Lilliwaup Creek; and Area 12D, Southeast Hood Canal, includes the marine waters adjacent to Union River. Population responses in these four areas have been quite different, with increases in returning spawners apparent only in Areas 12A and 12B (Fig. 26) and Area 12D (Union) being stable.

Historically, summer chum salmon have not been a primary fishery target in Hood Canal, since harvests have focused on chinook, coho, and fall chum salmon. Summer chum salmon have a run timing that overlaps those of chinook and coho salmon, and they have been incidentally harvested in fisheries directed at those species (Tynan 1992). Prior to 1974, Hood Canal was designated a commercial salmon fishing preserve, with the only net fisheries in Hood Canal occurring on the Skokomish Reservation (WDF et al. 1973). In 1974, commercial fisheries were opened in Hood Canal and incidental harvest rates on summer chum salmon began to increase rapidly. By the late 1970s, incidental harvest rates had increased to 50-80% in most of Hood Canal and exceeded 90% in Area 12A during the 1980s (Fig 25B). In 1991, coho salmon fishing in the main part of Hood Canal was closed to protect depressed natural coho salmon runs. Commercial fisheries, targeting hatchery-produced coho salmon, continued in Quilcene Bay. Beginning in 1992, fishing practices in this fishery, including changes in gear, seasons, and fishing locations, were modified to protect summer chum salmon (WDFW 1996). Since then, the tribal and nontribal harvests of coho salmon during the summer chum migration have been by beach seine with the requirement that summer chum salmon be released or surrendered to the USFWS for broodstock in the interagency enhancement program at Quilcene National Fish Hatchery.

Exploitation rates on summer-run chum salmon in Hood Canal have been greatly reduced since 1991 as a result of closures of the coho salmon fishery and efforts to reduce the harvest of summer chum salmon (WDFW 1996). Between 1991 and 1996, harvests removed an average of 2.5% of the summer-run chum salmon returning to Hood Canal, compared with an average of 71% in the period from 1980 to 1989.

These harvest rates, and the reconstructed run sizes on which they are based, are imprecise and are probably overestimated in recent years, when summer-run chum salmon abundance has been depressed. Much of the imprecision and bias stems from the practice of using a fixed cutoff date to attribute chum salmon in fishery landings to the summer or fall run (Lampsakis footnote 19). Because a fixed cutoff date is used to assign chum salmon to the summer or fall run, and the runs overlap, some fish will always be misclassified. With year-to-year change in run timing, the fraction of fish misclassified can vary considerably. Even if the fraction of each misclassified run remains constant, as abundance changes, the number of fish misclassified changes. Because the summer run has declined relative to the fall run, the number of fall-run chum salmon misclassified as summer run in recent years has probably been greater than the number of summer-run chum salmon misclassified as fall run. Consequently, the cutoff date used to distinguish summer run from fall run is presently being reevaluated by state and tribal biologists. This may have led to an overestimation of harvest rates calculated with WDFW adult accounting periods. Tribal biologists advocate using an earlier cutoff date to delineate the summer run from the fall run to compensate for the change in relative abundance of the two runs in Hood Canal. In spite of these caveats, the reconstructed run sizes and harvest rates based on them are the best data available to evaluate the effects of harvest and changes in population productivity.

While changes in harvest rates coincide to some degree with changes in run size, there are some important differences. In general, run sizes declined in the 1970s and 1980s as harvest rates increased to relatively high levels, rebounding in 1995 and 1996 after harvest was largely curtailed (Fig. 28). Reductions in harvests alone are insufficient to account for the population rebounds in Dabob Bay and Central Hood Canal, and no populations in south Hood Canal and Southeast Hood Canal have rebounded.

Harvest in Canadian waters

Summer-run chum salmon are still harvested incidentally in British Columbia in pink and sockeye salmon fisheries in the Strait of Juan de Fuca (Area 20) and Johnstone and Georgia Straits (LeClair 1995, 1996; PSMFC data 1997, Tynan 1995, 1997). Summer-run chum salmon are also taken in troll fisheries off the west coast of Vancouver Island (PSMFC data 1995). Net and troll fisheries in these areas target Fraser River sockeye and coho salmon but incidentally harvest chum salmon. Bycatch of chum salmon in Canadian Area 20 in the period from 1968 to 1995 has estimated 2,803 fish (Tynan 1995, 1997). These harvests have traditionally been allocated between U.S. and British Columbia populations using the proportions determined from genetic mixed-stock analysis (MSA) estimates in samples of fall chum salmon caught in later fisheries that were directed at chum salmon (PSC Joint Chum Technical Committee 1996).

Recently, fishery managers have begun to suspect that Hood Canal and Strait of Juan de Fuca summer-run chum salmon may be the majority of chum salmon migrating through Area 20 in August and early September when Area 20 fisheries for sockeye and pink salmon occur (WDFW 1996). Genetic MSA was used to estimate the proportion of Hood Canal summer chum salmon in the Area 20 catch (LeClair 1995, 1996). Estimates indicated that Hood Canal and Strait of Juan de Fuca summer-run chum salmon accounted for 31% of the Area 20 catch in 1995 and 68% of the catch in 1996 (WDFW 1996). This corresponded to estimated harvest rates on Hood Canal fish of ~3% in 1995 and ~1.5% in 1996, and on Strait of Juan de Fuca fish of ~17% in 1995 and ~2% in 1996.

Marine survival

Changes in survival, whether in the marine or freshwater life-history phases, would be reflected in changes in the number of spawners or potential spawners produced per parent (cohort replacement rate). The predominant age at which individual broods of Hood Canal summer chum salmon mature is variable, ranging from 92% age-3 to 83% age-4 for the 1968 to 1985 brood years (Tynan 1992). However, the mean age of maturation during this period was 3.6

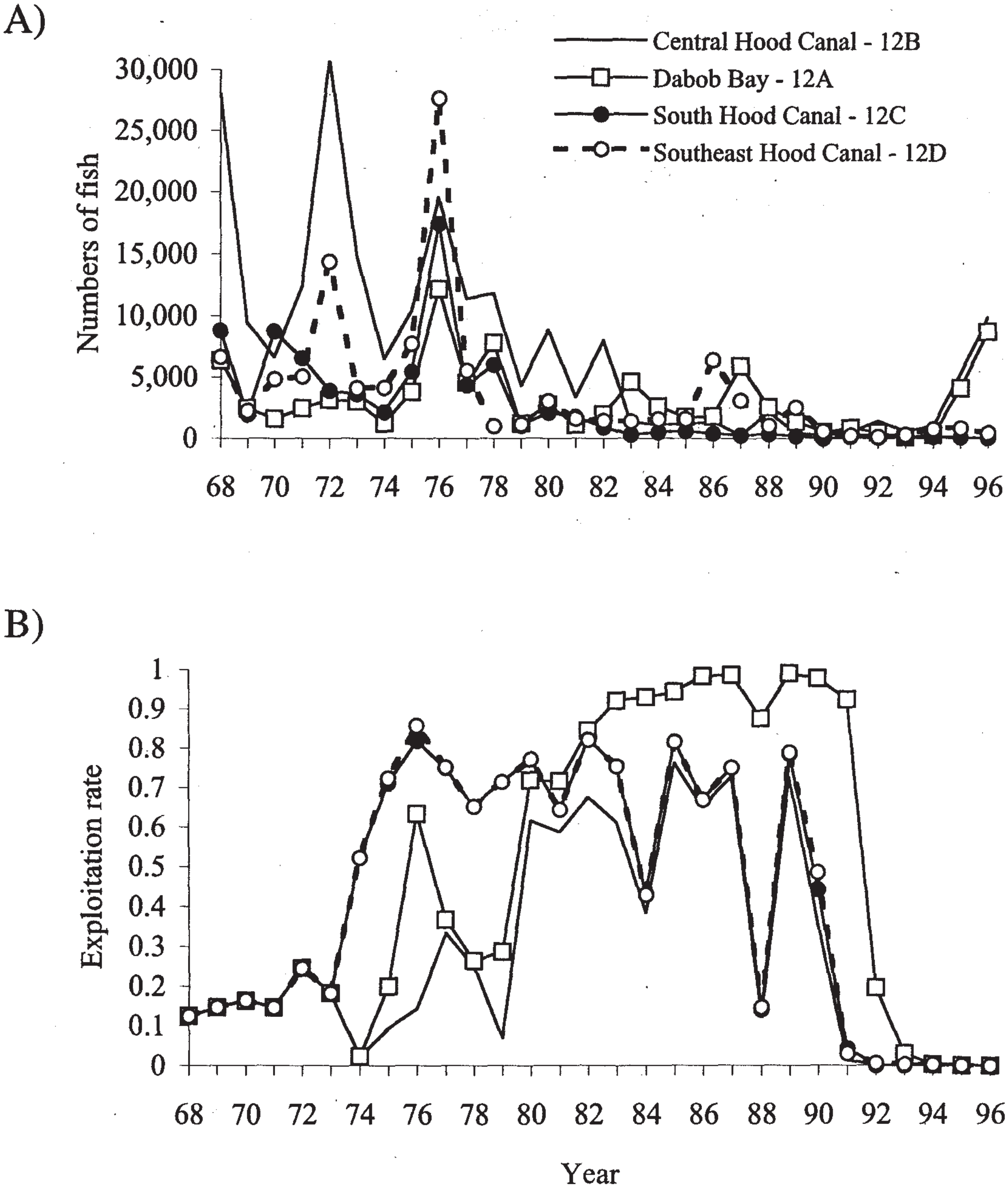

Figure 28. Hood Canal summer-run chum salmon (A) run size and (B) exploitation rates estimated by run reconstruction in WDFW harvest management areas (12A - 12D), 1968 to 1996. Data from NMFS (1995) and WDFW (1996).

years, so we have used spawning escapement 4 years earlier as the measure of parental abundance for a given year's run. This erroneously attributes some production to adjacent year's escapement, but differences in year to year escapement are relatively small compared to the total contrast in escapement levels.

Using the WDFW run reconstruction database (Big Eagle et al. 1995), updates from WDFW (Haynes[35]), and the escapement numbers for 1996, it is possible to reconstruct the size of terminal runs and the exploitation rate (Fig. 28) of Hood Canal summer chum salmon through 1996. Reconstructed terminal runs represent the best available data on stock productivity. Although the scale of run reconstruction is coarse and there are potential errors and biases in attributing catch to runs in management sub-areas (discussed in preceding sections on harvest), changes in harvest rates have been so large that these biases are relatively small.

A plot of spawners-per-spawner 4 years earlier (Fig. 29) suggests that substantial increases in the cohort replacement rates did not occur until the 1990s. However, if we consider the number of recruits-per-spawner (Fig. 30), which accounts for the effects of incidental harvest, it appears that there were increases in productivity in the early 1980s. These increases coincided with a climatic regime shift in the north Pacific Ocean during the late 1970s that has generally been viewed as beneficial to chum salmon (Francis and Mantua In press). However, apparent productivity did not increase uniformly. The largest increases in productivity were apparent only for the populations in Dabob Bay, with populations in the central portion of Hood Canal showing little increase in productivity until after 1990. The timing and magnitude of apparent productivity changes, and the inconsistencies between different areas within Hood Canal, suggest the unlikelihood that changes in marine productivity contributed substantially either to the decline in Hood Canal in the late 1970s or to the recent rebound in some of the populations.

Record numbers of chum salmon returned to many areas of Alaska and the Pacific Northwest in 1995 and 1996. In this ESU, some streams have also had large returns of summer chum salmon, while other streams have not. Possible explanations are that 1) any changes in marine survival for this ESU are being overwhelmed either by differences in survival during freshwater or by estuarine life-history phases, or 2) summer chum salmon in Hood Canal have ocean migration patterns different than other chum salmon, or 3) other factors such as susceptibility to diseases.

Freshwater Survival

Density dependence—The apparent increases in population productivity in Hood Canal have coincided with depressed spawning escapements. One possible explanation for this is that density-dependent mortality is occurring in freshwater habitats. If density-dependent effects in

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[35] J. Haynes, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, Washington 98504. Pers. commun., November 1996.

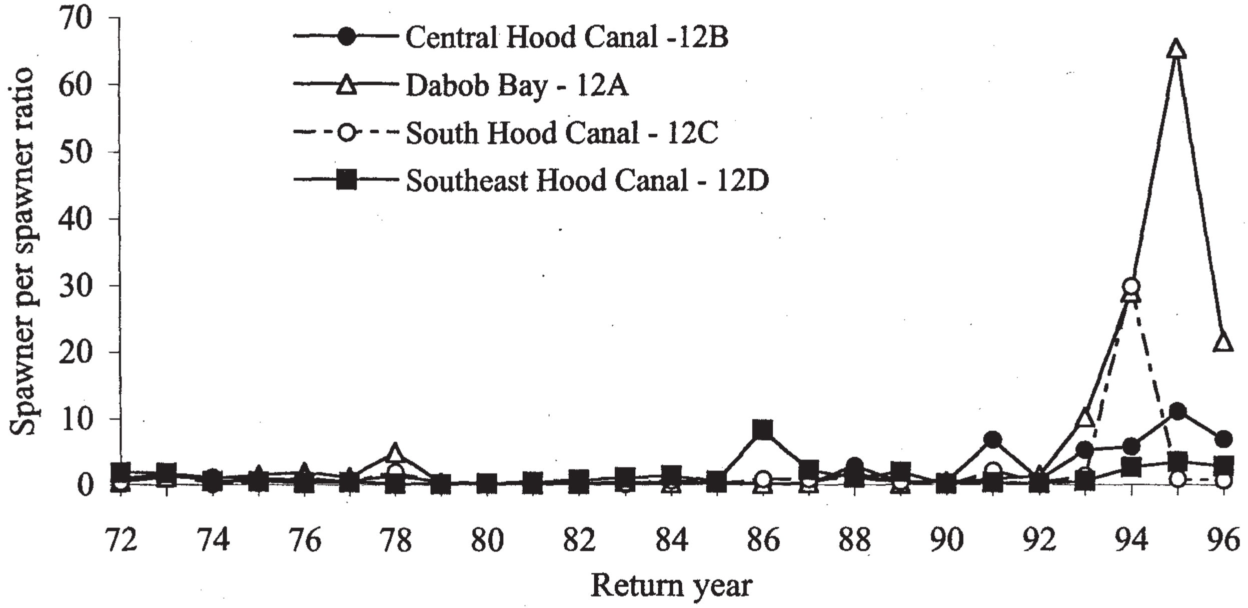


Figure 29. Comparison of summer chum salmon spawner to spawner ratios, by year, for four Hood Canal harvest management regions (12A, B, C, and D). Spawner to spawner ratio is the number of fish that return to spawn in one year, divided by the number of fish that returned to spawn in the same area 4 years previously.

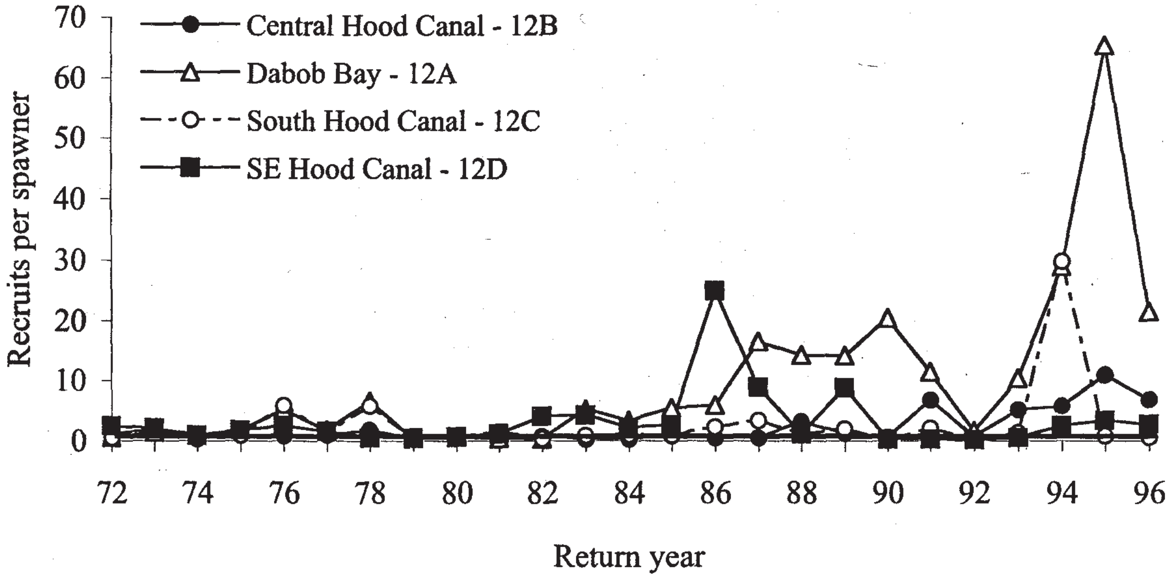


Figure 30. Recruits per spawner for summer chum salmon in Hood Canal WDFW Harvest Management Areas (12A - 12D). Solid straight line represents replacement level. Data from NMFS (1995) and WDFW (1996).

freshwater or estuaries are reducing survival rates, a decline in recruits-per-spawner with increasing escapement would be expected. There is some suggestion of this depensation in Dabob Bay and central Hood Canal rivers (Fig. 31), but little support for this hypothesis in Lilliwaup Creek (Area 12C, South Hood Canal) or the Union River (Area 12D, Southeast Hood Canal) (Fig. 32). However, if density-dependent effects occur in central Hood Canal tributaries, they must do so at very low abundances, because most areas do not show any suggestion of increased productivity except at extremely low escapement levels. Bias in reconstructed run size, which tends to be greatest at low abundance, also confounds estimates of abundance. This tends to give the appearance of density dependence. If density dependence were responsible for the observed recent patterns of productivity in the streams, it would be difficult to explain the large number of summer chum salmon in the late 1960s and 1970s, unless habitat capacity has changed since then. At present, existing data cannot determine whether density dependence has contributed to the recent rebound in abundance.

Possible ecological effects of artificial propagation—Hatcheries that produce salmon are usually part of fisheries management programs designed to augment natural production and to mitigate the impact of ecological damage by human alterations of the natural habitats. However, hatchery productions can also have an unintentional ecological influence on natural populations (Allendorf and Ryman 1987).

In Hood Canal, several salmonid species are released annually from hatcheries (Fig. 33). Although ecological impacts of these releases have not been extensively studied (reviewed in Tynan 1997), a number of authors have expressed varying opinions about the repercussions of these releases on natural summer- and fall-run chum salmon in Hood Canal and other regions. As an example, Washington's fishery co-managers have suggested that the extensive use of artificial propagation in Hood Canal may have adversely affected Hood Canal summer-run chum salmon (WDF et al. 1993:37):

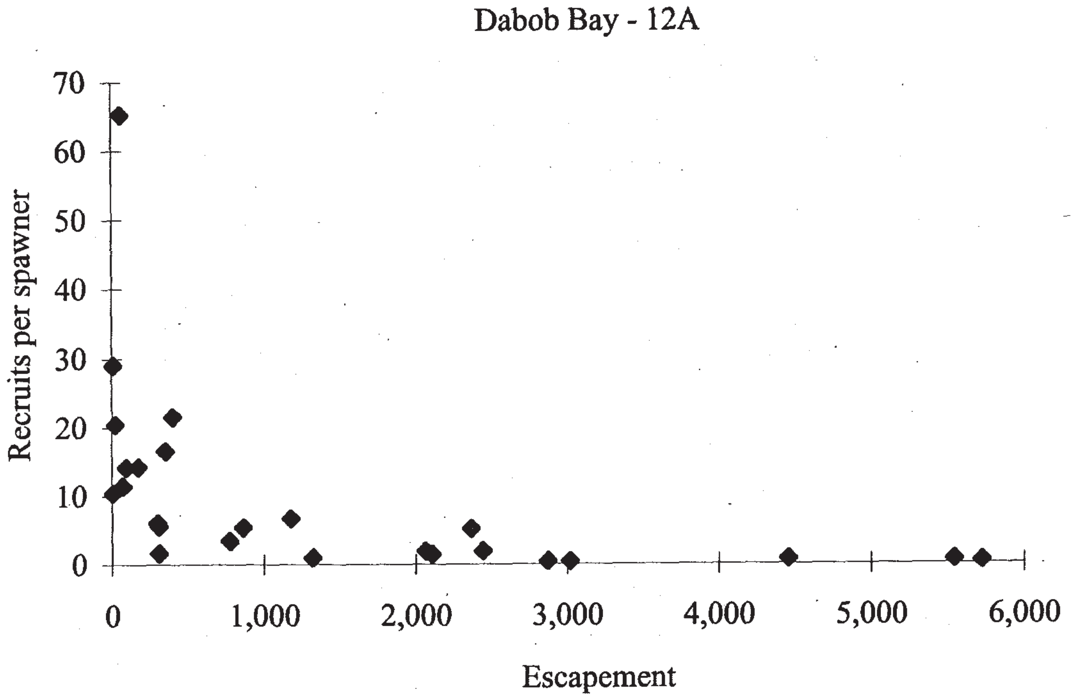
> There are large coho, chinook and [fall] chum rearing and release programs at several Hood Canal hatcheries which may cause increased competition and predation on summer chum.

In addition, the USFWS Western Washington Fishery Resource Office (Cook-Tabor 1994:11) suggested:

> Indirect or direct competition between hatchery produced fall chum and naturally produced summer chum is likely. It is possible the higher densities of small-sized hatchery released juveniles over-exploit the zooplankton population, thus limiting the foraging success of juvenile summer chum salmon in Hood Canal.

These issues were also addressed by Gallagher (1979:95):

> The similarities in pattern of variation in the total run and brood return of both the hatchery and wild stocks of Puget Sound chum salmon suggest that (1) a major component of the mechanism controlling the abundance of chum-salmon stocks takes place in the early marine environment,



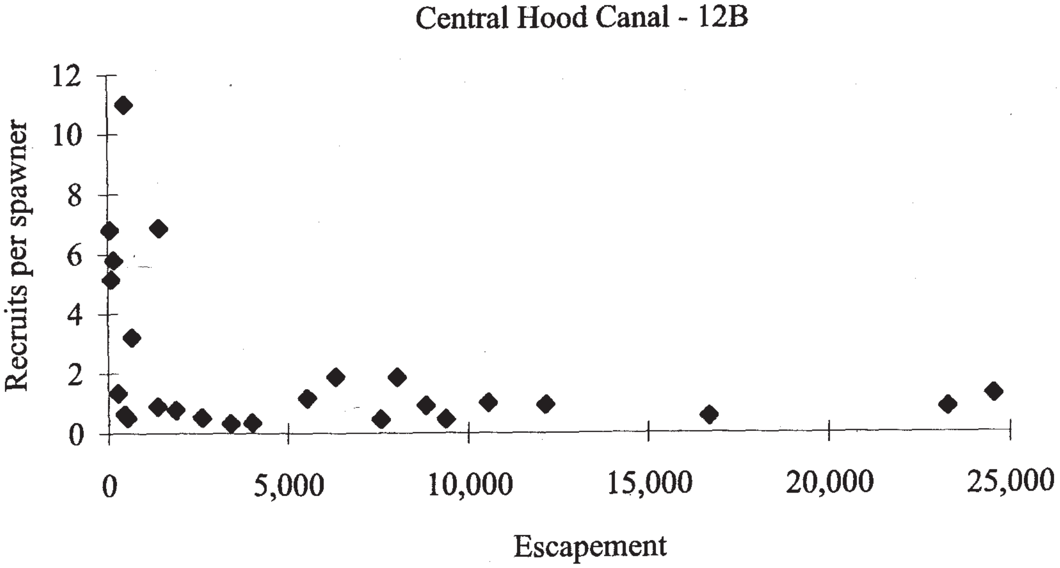
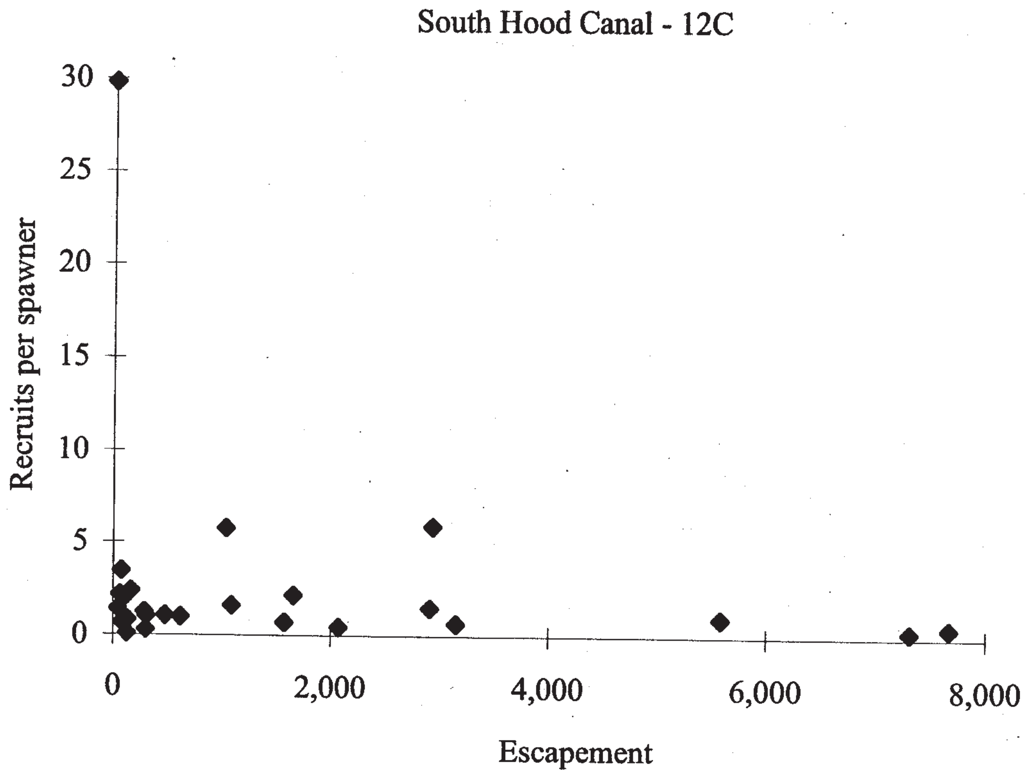


Figure 31. Recruits per spawner as a function of escapement of summer chum salmon to Dabob Bay and central Hood Canal, 1968 to 1994. Data from NMFS (1995).



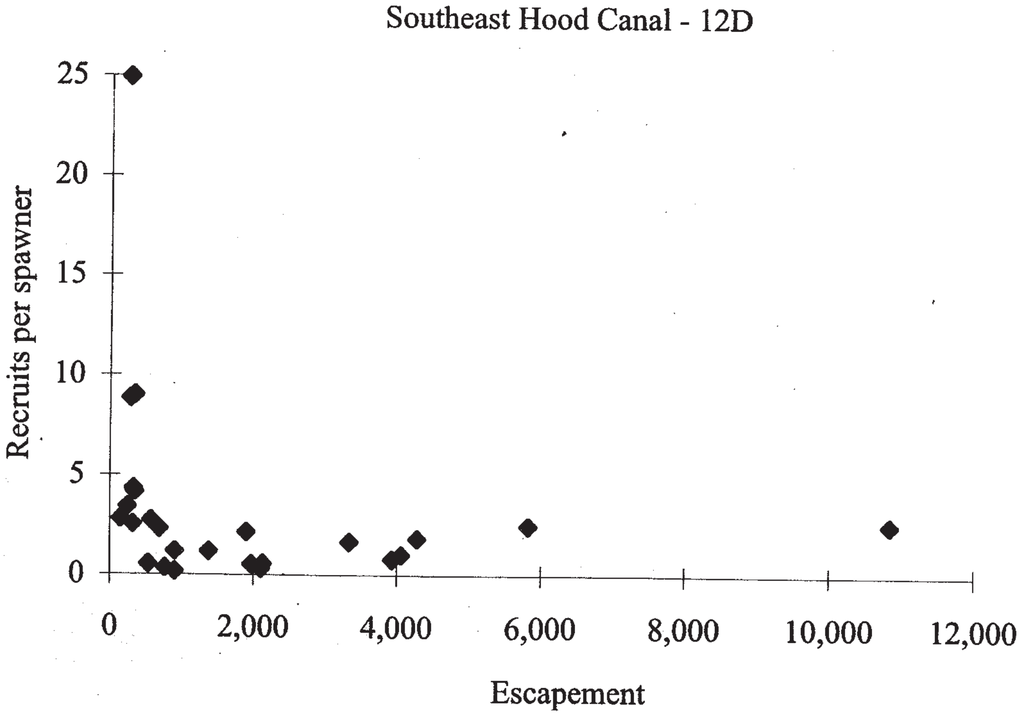


Figure 32. Recuits per spawner as a function of escapement of summer chum salmon to south Hood Canal and southeast Hood Canal, 1968 to 1994. Data from NMFS (1995).

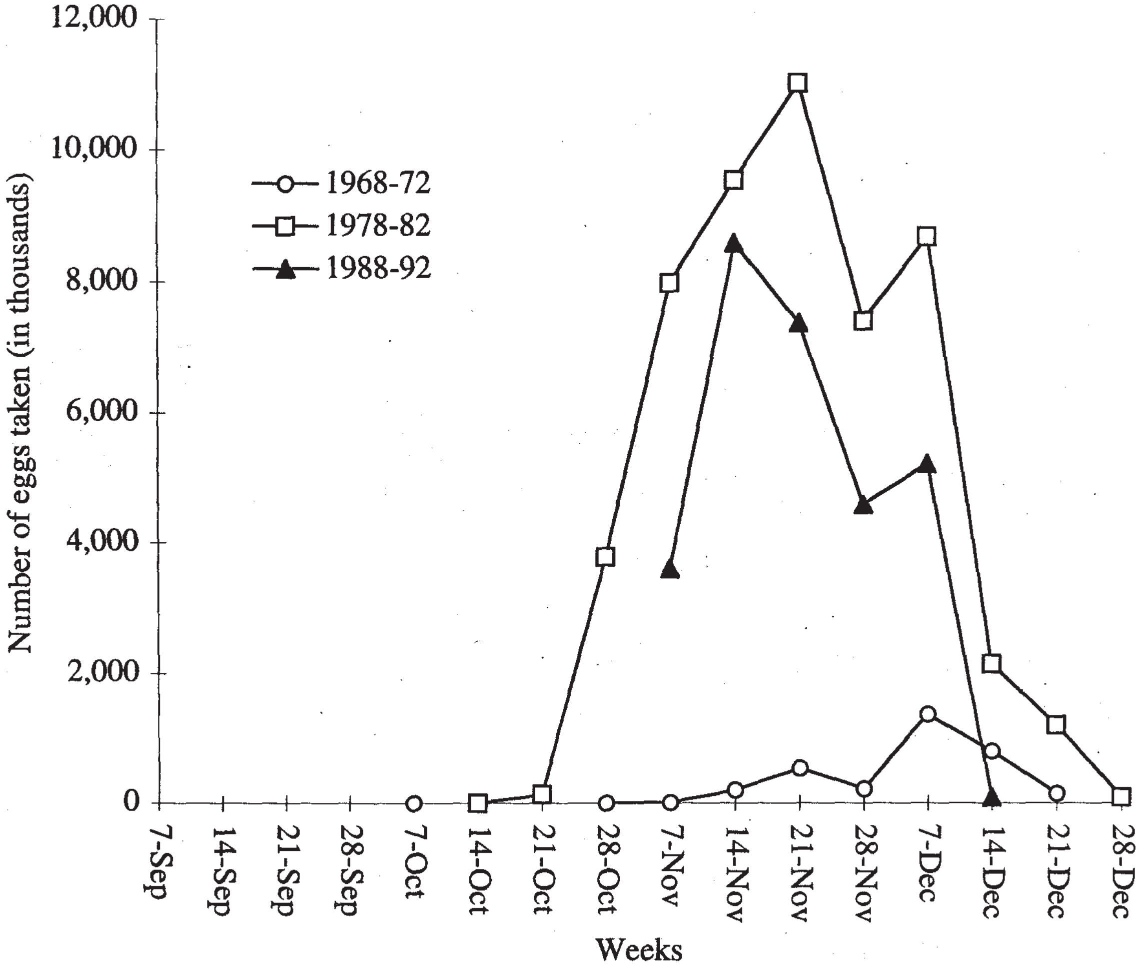


Figure 33. Average number of fall chum salmon eggs taken at the WDFW Hood Canal Hatchery each week for three 5-year periods, 1968-1992. Data from NRC (1995).

> and (2) given the presence and absence of pink salmon in odd and even years, that component may involve competition for limited food resources . . . By introducing large numbers of hatchery [fish] . . . into this ecosystem, however, a food-limited competitive interaction may be induced. Although such an interaction may account, in part, for the fluctuations in the hatchery chum data, it may also stress an ecosystem that seems to have evolved an equilibrium of population regulation and coexistence. Such a stress could prove devastating to the already *seriously depressed pink and chum wild stocks of Puget Sound* [original emphasis].

More recently, in Tynan's (1997:viii) extensive review of available information on chum salmon in Hood Canal, he hypothesized that hatchery-produced salmon may affect naturally-produced summer chum salmon in the Hood Canal and the Strait of Juan de Fuca regions in several ways, including the shared use of many of the same ecological resources. He has proposed an extensive research program to investigate this issue.

In contrast, Ames (1983) did not find evidence for any adverse effects between Hood Canal hatchery and natural chum salmon based upon correlations of production in the 1970s and 1980s. In addition, calculations by Fuss and Fuller (1994:45) on hatchery chum salmon production and the carrying capacity of Hood Canal indicated that "large numbers of hatchery juveniles do not appear to be negatively impacting naturally produced fry in Hood Canal."

Most hatchery fall chum salmon are released into Hood Canal at about the same time that naturally-produced fall chum salmon fry emerge from the gravel (April and May) (WDFW 1995) However, beginning in the 1970s, some fall-run chum salmon juveniles were released from hatchery programs into Hood Canal earlier than they would have entered if naturally produced (Table 23). These fish were released before the end of March, about a month before the historical peak of natural fall-run fry downstream migration (Koski 1975; Young 1986a,b). Historically, outmigration to seawater of fry from natural fall-run and summer-run chum salmon in Big Beef Creek was separated by about 35 days, with nearly 50% of natural summer-run fry emerging from the gravel and moving downstream by 21 March, and about 50% of natural fall-run fry emerging by 25 April (Koski 1975). Between 1975 and 1991, an average of 8.1 million chum salmon per year were released from hatcheries in Hood Canal before the end ofMarch (out of a total of ~37.2 million hatchery fall chum salmon released annually into Hood Canal) (Table 23). A consequence of these earlier timed releases is that the separation in outmigration timing between summer and fall chum has been lessened.

This advance in the time of release of hatchery fall-run chum salmon has not been intentional and may be a consequence of a successful hatchery program and improved hatchery incubation techniques. Koski (1975) reported that average water temperature during incubation of natural-run fall chum salmon was about 6°C, with emergence occurring in about 146 days. WDFW Hoodsport and George Adams Hatcheries incubated chum salmon eggs in constant-temperature (8°C) well water (Fuss and Seidel 1987, Fuss et al. 1993), allowing fall-run chum salmon eggs to hatch in about 120 days. As early as the mid-1970s, peak abundance of juvenile chum salmon in nearshore areas of Hood Canal often appeared to be associated with hatchery releases, sometimes as early as mid-March (Tynan 1997). Therefore, some hatchery fall chum salmon fry can now migrate downstream almost a month sooner than natural fall-run fry, because

Table 23. Annual liberations of fed and unfed early-fall chum salmon fry (Finch Creek Stock) from WDFW hatcheries in Hood Canal, Washington, 1970-94. (Data from Crawford 1997.)[1]

Release Year	**Unfed Fry**			**Fed Fry**			
	Total	Pre Apr. 1	% Total	Total	Pre Apr. 1	% Total	Avg. FPP[2]
1970	188,748	0	0%	795,040	0	0%	-
1971	0	0	0%	1,447,406	0	0%	-
1972	508,000	112,000	22.0%	855,110	0	0%	-
1973	64,600	64,600	100%	974,568	0	0%	-
1974	323,600	0	0%	2,012,198	0	0%	-
1975	0	0	0%	9,408,285	0	0%	-
1976	0	0	0%	8,465,125	0	0%	-
1977	85,000	0	0%	13,594,756	507,825	3.7%	650
1978	0	0	0%	7,939,467	1,324,075	16.7%	547
1979	5,230,000	475,000	9.1%	24,376,329	13,424,882	55.1%	684
1980	6,068,700	3,524,300	58.1%	33,041,394	1,781,700	5.4%	900
1981	5,842,192	0	0%	30,498,031	11,847,861	38.8%	704
1982	0	0	0%	16,859,884	4,253,000	25.2%	530
1983	7,921,700	2,500,000	31.6%	27,983,444	5,113,000	18.3%	649
1984	0	0	0%	28,325,669	5,000,000	17.7%	578
1985	4,374,157	1,445,000	33.0%	45,955,845	13,978,300	30.4%	869
1986	5,483,300	2,684,600	49.0%	31,051,700	9,010,100	29.0%	795
1987	6,400,600	0	0%	33,999,500	13,240,200	38.9%	640
1988	5,763,900	3,033,900	52.6%	34,358,600	14,189,700	41.3%	680
1989	5,284,500	5,284,500	100%	29,932,600	5,172,600	17.3%	916
1990	6,106,500	3,853,000	63.1%	28,415,000	10,410,200	36.6%	697
1991	0	0	0%	19,619,100	4,000,000	20.4%	733
1992	7,175,500	7,175,500	100%	31,463,600	12,508,300	39.8%	657
1993	8,744,000	8,494,000	97.1%	30,908,200	20,073,200	64.9%	494
1994	2,990,600	0	0%	30,215,050	7,294,000	24.1%	616
Ave.	3,142,224	1,545,856	49.2%	20,899,836	6,125,158	29.3%	686

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[1] Hatchery production data from WDFW Hatcheries Program, March 21, 1997.

[2] Fish per pound.

the warmer hatchery water speeds development and growth.

A second reason why fall chum salmon juveniles could be released in March into Hood Canal is that the Hood Canal Hatchery complex has been highly successful in producing adult returns of fall-run chum salmon. Advancement of peak spawn timing is a common development in successful hatchery programs worldwide and has previously been observed in artificially propagated coho salmon (Flagg et al. 1995) and steelhead (Tipping 1984). A successful hatchery program usually increased the number of returning adult spawners throughout the time of the spawning run. The return of greater numbers of fish early in the run allows hatchery personnel to complete the hatchery's egg take earlier in the season (Fig. 34). From 1968 to 1972, the time of peak spawning of fall chum salmon at the hatchery occurred, on average, the first week of December. However, 10 years later, the time of peak spawning was reported to occur in mid-November (Fig. 34). A possible consequence of this change in spawning time is that in past years the separation of 35 days between peak spawn dates of fall- and summer-run chum salmon reported by Koski (1975) in Big Beef Creek, or the 71-81 day difference reported by Young (1986a,b) in other streams in Hood Canal, had been reduced to about 14 days (Fig. 34, Table 24). In recent years no fall chum salmon have been released from hatcheries into Hood Canal in March (Crawford 1997), and presumably a clear separation between outmigration timing of summer and early fall chum salmon has been reestablished.

Biologists at WDFW (Crawford 1997) also point out that these differences in spawn-timing have not caused an overall change in time or pattern of adult fall chum salmon returning to Hood Canal or the hatchery. They analyzed the weekly total rack counts at the Hood Canal Hatchery at Hoodsport from 1953 (first year of operation) through 1996 and averaged the data over 5-year blocks. These data were then converted to 10, 50, and 90% run completions (Table 25). From Crawford (1997:2):

> The 50% completion date has been remarkably stable over the last 36 years (1961-96), occurring approximately during the period of November 18 through November 30. Discounting the influence of the of the September/October timed fish during the first two time periods (1953-1960 and 1961-1965), there is an apparent shift in the timing of the 50% completion date to just over a week earlier for the fall run fish. Over the last 21 years (1976-1996), the 10%, 50%, and 90% completion timing have shown almost no variability.

As indicated, analysis of the rack count data did show some variation in peaks of chum salmon returns to the hatchery during the 1950s and 1960s, with returns occurring in September and October. Crawford (1997:2) suggested the cause of these early peaks might be:

> The timing of this [1953-1960 early] peak is consistent with summer chum timing, and the most likely explanation is that prior to the 1970s, Finch Creek supported a modest summer chum salmon run. Other possible, but less likely, explanations for the occurrence of summer fish in Finch Creek would be either straying from the summer chum populations in other Hood Canal streams, or that these fish resulted from pink/chum hybridization experiments that were conducted at Hoodsport Hatchery in those years.

There have also been large changes in the numbers of juveniles of summer- and fall-run

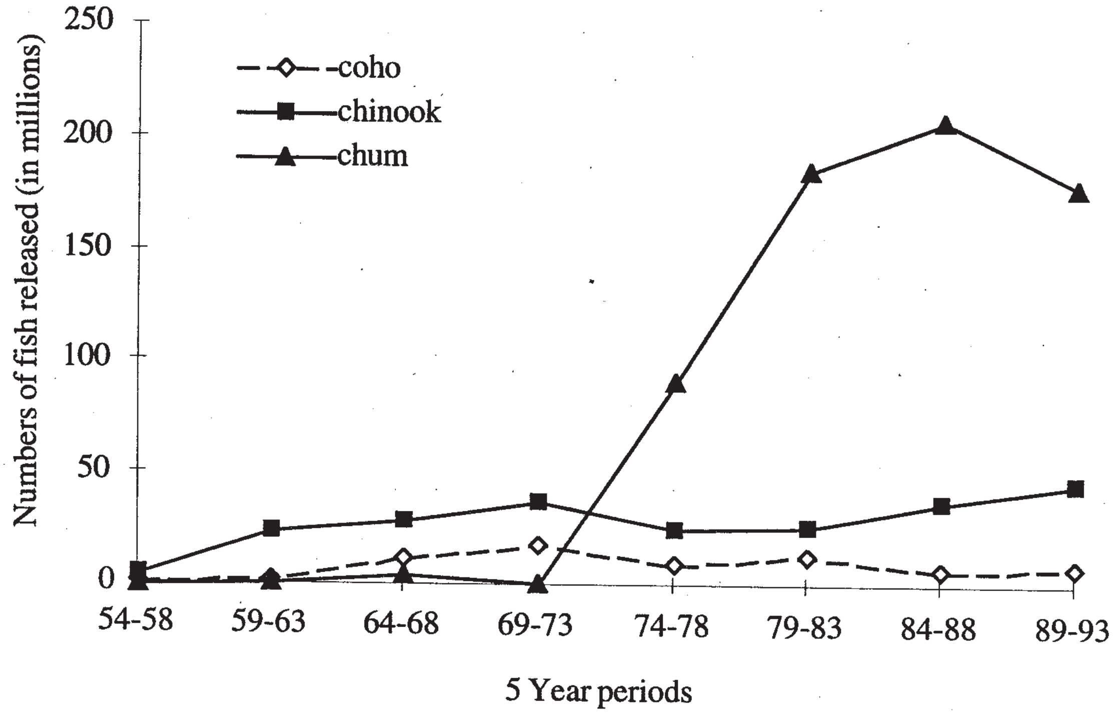


Figure 34. Numbers of chum, coho, and chinook salmon released annually from hatcheries into Hood Canal, 1954 to 1993. Data from NRC (1995).

Table 24. Interval between peak spawning of summer and fall chum salmon in Hood Canal streams, 1983 and 1984. Data from Young (1986a,b).

Stream	50% dates of spawning completion in 1983		Interval in days between peaks	50% dates of spawning completion in1984		Interval in days between peaks
	Summer-run	Fall-run		Summer-run	Fall-run	
Tahuya R.	4 Oct	15 Dec	72	2 Oct	1 Dec	60
Hamma Hamma R.	26 Sep	25 Dec	90	29 Sep	28 Dec	91
Duckabush R.	25 Sep	13 Dec	79	4 Oct	12 Dec	66
Dewatto R.				4 Oct	9 Dec	67
Big Mission Cr.				10 Oct	19 Nov	40
Union R.				20 Sep	22 Nov	63
Lilliwuap Cr.				3 Oct	22 Dec	80
Dosewalips R.				28 Sep	13 Dec	76
Little Quilcene R.				23 Sep	22 Dec	90
Average date of 50% spawning completion	29 Sep	18 Dec	81 days	30 Sep	10 Dec	71 days

Table 25. Percentage and date of return of the total number of chum salmon that returned to the rack (gate) at the Hood Canal Hatchery in 5-year blocks, 1953 to 1996. (Note that the first and last blocks are 8 and 6 years, respectively). Data from Crawford (1997).

Return Years	10% Complete	50% Complete	90% Complete
1953-60	Sept. 17	Oct. 5	Nov. 30
1961-65	Sept. 24	Nov. 26	Dec. 22
1966-70	Nov. 15	Nov. 30	Dec. 11
1971-75	Nov. 12	Nov. 28	Dec. 13
1976-80	Nov. 8	Nov. 20	Dec. 4
1981-85	Nov. 5	Nov. 18	Dec. 6
1986-90	Nov. 5	Nov. 20	Dec. 4
1991-96	Nov. 5	Nov. 23	Dec. 5

adult chum salmon in Hood Canal prior to April over the last 25 years (Fig. 35). To compare the ratio of summer and fall chum salmon fry in Hood Canal, we developed an estimate of the number of summer chum salmon fry in the Canal based upon the number of adult returns. An average of 1,935 summer-run chum salmon were estimated to have returned per year to Hood Canal between 1979 (start of decline of summer chum salmon) and 1991 (from WDF et al. 1993). If these fish had a female-to-male ratio of 1.4 to 1 (Young 1986a,b), about 1,128 females would have been available to spawn in the Hood Canal tributaries. Since the average fecundity of summer-run females in Hood Canal was estimated to be about 3,500 eggs (Koski 1975), with mean survival from egg deposition to migration of about 10% (Crawford 1997), we estimate that about 400,000 natural summer-run chum salmon fry entered Hood Canal prior to April in those years. Based upon these estimates, the number of hatchery-reared, fall-run juveniles released into Hood Canal hatchery streams would have outnumbered natural summer-run chum salmon juveniles by about 20 to 1. As most naturally-produced fall chum salmon in Hood Canal enter seawater only after the beginning of April (WDF et al. 1993), these calculations suggest that in recent years, many more fall chum salmon juveniles now enter Hood Canal prior to April than they did when the majority of fall chum salmon production was natural.

Hatchery fall-run fry that enter Hood Canal prior to April also appear to be larger than natural summer-run fry monitored by Koski (1975) in Big Beef Creek. Hatchery fall-run fry released in March averaged between 0.56 and 1.0 g (Fuss et al. 1993), whereas Koski (1975) estimated that natural summer-run fry averaged about 0.35 g and natural fall-run fish about 0.37 g at the time of freshwater outmigration. Larger chum salmon juveniles in Hood Canal are more efficient at capturing prey than are smaller juveniles and hence can grow faster (Wissmar and Simenstad 1988). However, zooplankton, the chief food of juvenile chum salmon, are not abundant until late spring after the onset of phytoplankton blooms (Strickland 1983). This lack of phytoplankton in early spring, together with observations from outmigration studies on chum salmon in Hood Canal (Bax 1982, Bax 1983a; and see “Life-History and Ecological Information,” p. 34), suggests that chum salmon fry outmigrate quickly. Even so, the less abundant and physically smaller summer-run juveniles may experience competition for scarce food from larger fall-run hatchery juveniles. Historically, this competition presumably would have been avoided because the summer chum salmon would have emerged and entered Hood Canal before fall chum salmon juveniles were present (Koski 1975).

WDFW (Crawford 1997:32) argued that this focus on the ratio of fall to summer chum salmon entering Hood Canal misses a more critical issue regarding “potential limitations” on summer chum salmon. This issue is “what level of <u>all</u> chum stocks migrating prior to March might be limiting to summer chum?” They suggested that “it is important to recognize the fact that differences in prey and estuarine migration areas exist between chum migrating as swim-up fry, and therefore duration of interaction in the estuary, must also be considered.”

WDFW further argued (p. 34):

> It seems likely that in some recent years the numbers of hatchery fall chum salmon fry released prior to April into Hood Canal (as high as 28.6 million in 1993) exceeded the probable numbers of wild summer chum salmon fry that resulted in any one year from the escapements that have

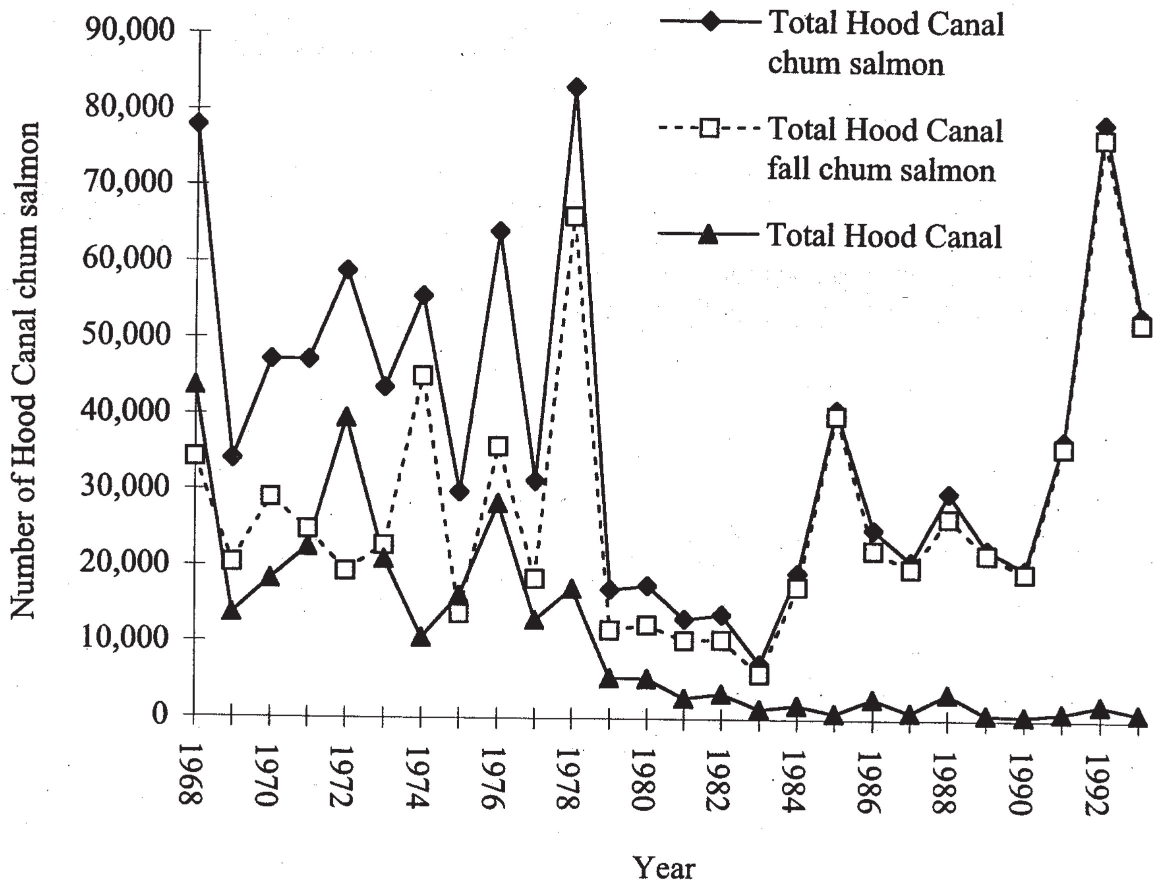
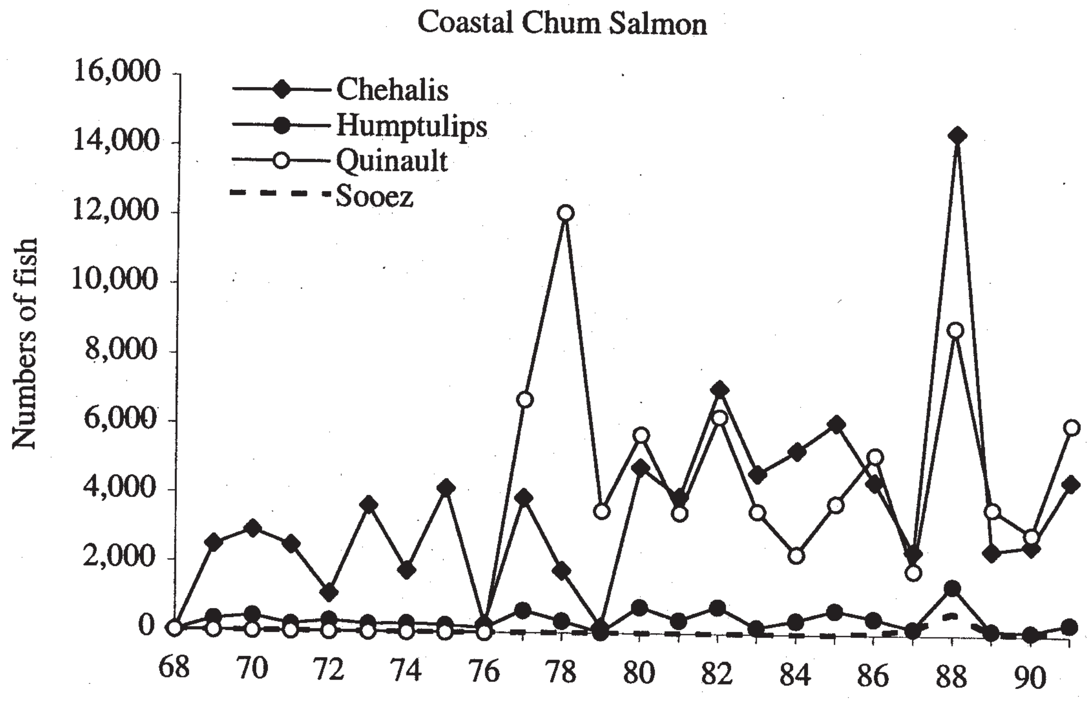


Fig 35. Run size of adult summer and fall chum salmon in Hood Canal, 1968 to 1993. Data from NRC (1995).

> occurred between 1968 and 1996. From the tabulated material below, the highest potential wild summer chum fry outmigration of 8.97 million fish would have resulted from the 1968 parent escapement of 43,720 spawners. Since this value is derived using an average freshwater survival of 10%, one could speculate that the highest possible fry value resulting from 43,720 spawners under ideal freshwater conditions could have been 30.7 million summer chum salmon fry; using the highest individual survival (34.4%) reported in Bakkala (1970). However, such ideal conditions are unlikely to have occurred in the last 29 years, and the 28.6 million hatchery fall chum salmon fry released in 1993 almost surely exceeded the maximum numbers of wild summer chum fry recruiting to Hood Canal in any year in the same time period.
>
> Is this situation reducing the survival of summer chum salmon through competition for rearing space or food resources? There is no research specifically on this problem, but the available data suggest an answer. The early releases of 28.6 million hatchery fall chum fry in 1993 should have had the greatest, and most observable, impact on summer chum (1992 brood) success of any year in the data base. The 1992 wild summer chum escapement was only 2,076 spawners, which would have resulted in a theoretical 420,000 fry recruitment to Hood Canal (see above). The 1992 brood summer chum have in fact been phenomenally successful, making up the majority of the fish in the large returns in 1995 (age-3 fish) and 1996 (age-4 fish). Contrary to the attempt . . . of [this Status Review] draft to implicate hatchery chum salmon releases in the decline of summer chum stocks, a stronger case could probably be made that the early release of large numbers of hatchery fry buffers wild summer fish against predation losses, and actually increases survival. **With the information at hand, however, it is inappropriate to speculate on the possibility of either positive or negative impacts of the hatchery fall chum releases** [original emphasis].

Pacific Coast ESU

The Pacific Coast ESU of chum salmon includes a broad geographic range over the coastal regions of three states, and data on chum salmon in the ESU have been collected from several tribal, state, and federal agencies. Consequently, the types of data collected vary considerably. On the Strait of Juan de Fuca, spawning escapement estimates are available only for Deep Creek and the Pysht River. Tribal harvest data are the only data available for coastal rivers on the Olympic Peninsula (Fig. 36). Tribal harvests of chum salmon on the coast of the Olympic Peninsula generally declined prior to the mid-1960s and have been relatively stable at lower levels since then. On the Quinault River, these estimates of tribal chum salmon harvest have been converted to run size and escapement using information from the hatchery coho salmon fishery on the Quinault River. Escapement estimates in Grays Harbor and Willapa Bay are available for individual stocks (Fig. 37). The spawning escapements for these populations show no strong recent trends in the more abundant populations but generally appear to be increasing (Table 20). These trend data are far from exhaustive, but indicate about 35,000 spawners as a lower bound on the escapement of chum salmon on the Washington coast. The harvest of chum salmon from coastal fisheries combined has averaged 96,000 fish per year from 1988 to 1992 (WDFW 1995). This suggests an abundance level that is an order of magnitude smaller for the Washington coastal portion of this ESU than for the Puget Sound/Strait of Georgia ESU, but which is still on the order of 150,000 adults.



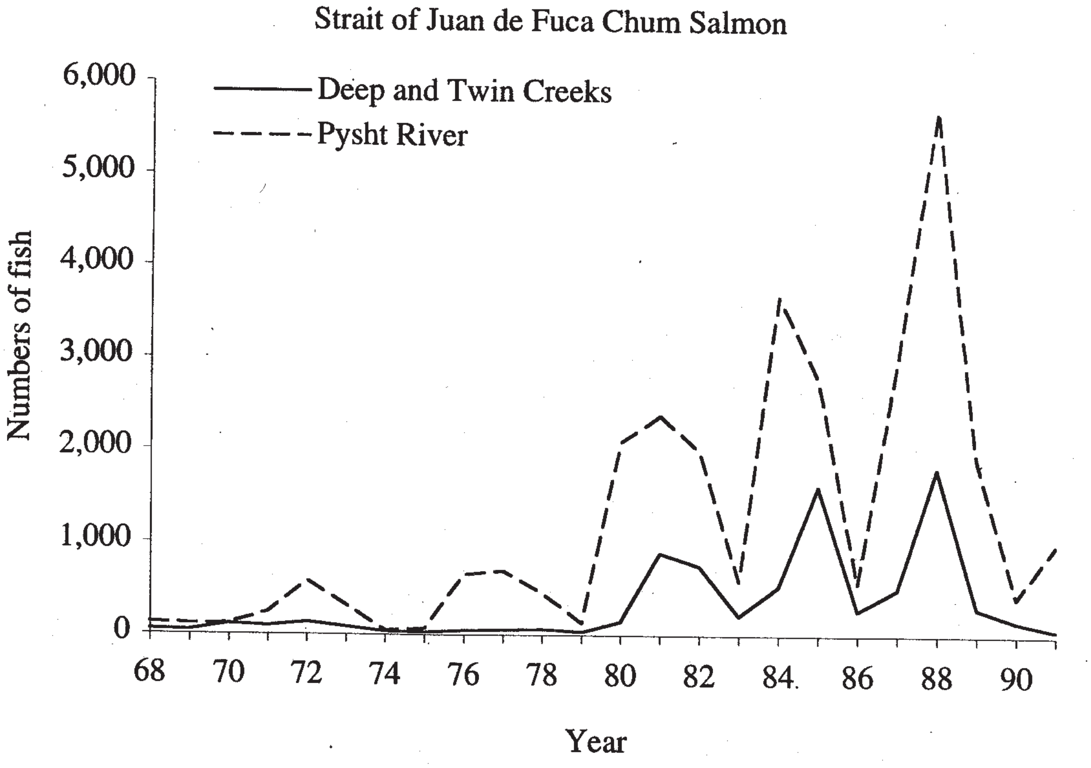


Figure 36. Tribal harvest of fall-run chum salmon in coastal Washington rivers and along the Strait of Juan de Fuca, 1968 to 1990. Data from NMFS (1995).

Few data are available on chum salmon south of the Columbia River. Tillamook Bay is the southernmost location that supported substantial chum salmon harvests in recent times. Intermittent historical landing data are available for Oregon rivers farther south. In response to declines of the runs in Tillamook Bay, Oregon closed the commercial fishery for chum salmon in 1962. Though the connection between estimates of abundance from spawner surveys and actual spawner abundance is somewhat tenuous, there has been no substantial increase in the number of spawners in stream surveys since the halt of commercial fishing. Spawner surveys in the Tillamook District show substantial year-to-year variability with little correspondence of the variability among individual spawner surveys (Fig. 38). Estimates of total escapement to the Tillamook Bay have been relatively stable since the end of the commercial fishery in 1962 (Fig. 39), with a geometric mean of 12,500 spawners for the period from 1987 to 1991. Whiskey Creek in Netarts Bay also shows no clear trend in spawner counts, although this population is supplemented with hatchery fish (Fig. 40).

Columbia River ESU

The Columbia River historically contained large runs of chum salmon that supported a substantial commercial fishery in the first half of this century (Fig. 41). These landings represented a harvest of more than 500,000 chum salmon in some years. There are presently neither recreational nor directed commercial fisheries for chum salmon in the Columbia River, although some chum salmon are taken incidentally in the gill-net fisheries for coho and chinook salmon, and there has been minor recreational harvest in some tributaries (WDF et al. 1993). Hymer (1993, 1994) and WDF et al. (1993) monitored returns of chum salmon to three streams in the Columbia River (Fig. 42) and suggested that there may be a few thousand, perhaps up to 10,000, chum salmon spawning annually in the Columbia River basin. Kostow (1995) identified 23 spawning populations on the Oregon side of the Columbia River but provided no estimates of the number of spawners in these populations.

An estimate of the minimal run size for chum salmon returning to both the Oregon and Washington sides of the Columbia River has been calculated by summing harvest, spawner surveys, Bonneville Dam counts, and returns to the Sea Resources Hatchery on the Chinook River in Washington (ODFW and WDFW 1995). This suggests that the chum salmon run size in the Columbia River has been relatively stable since the run collapsed in the mid-1950s (Figs. 43 and 44). The minimal run size in 1995 was 1,500 adult fish.

Summary and Conclusions of Risk Analysis

The ESA 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

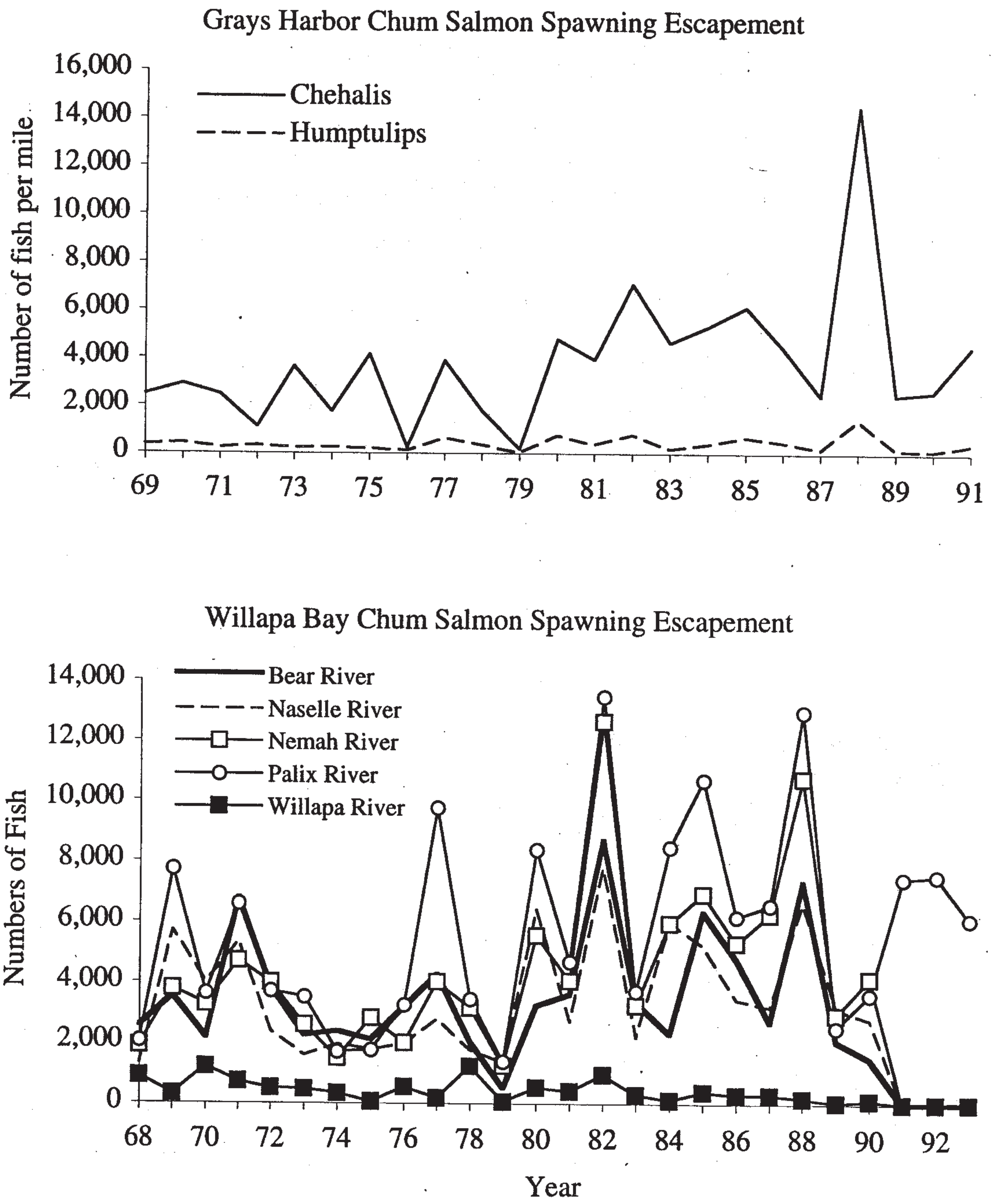
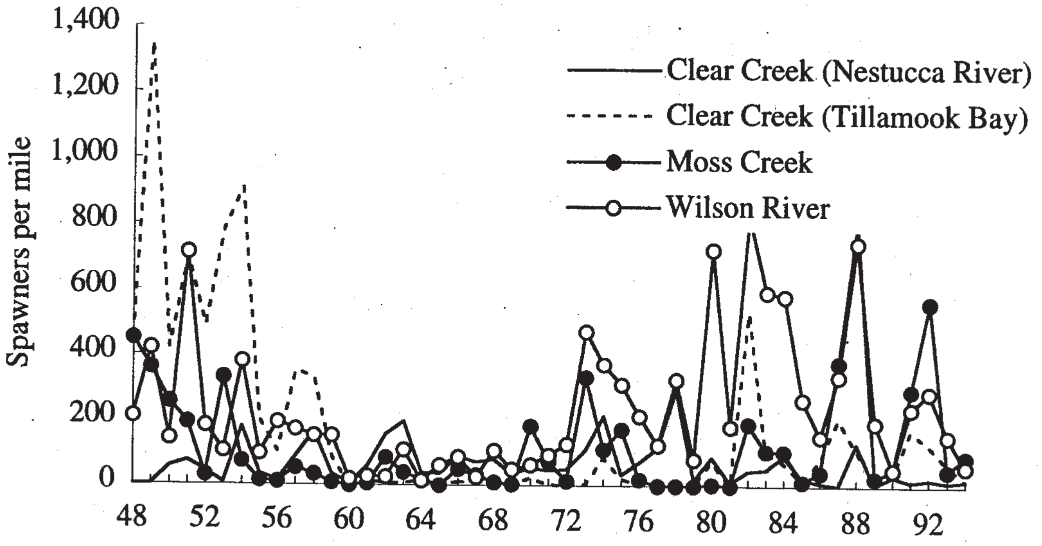
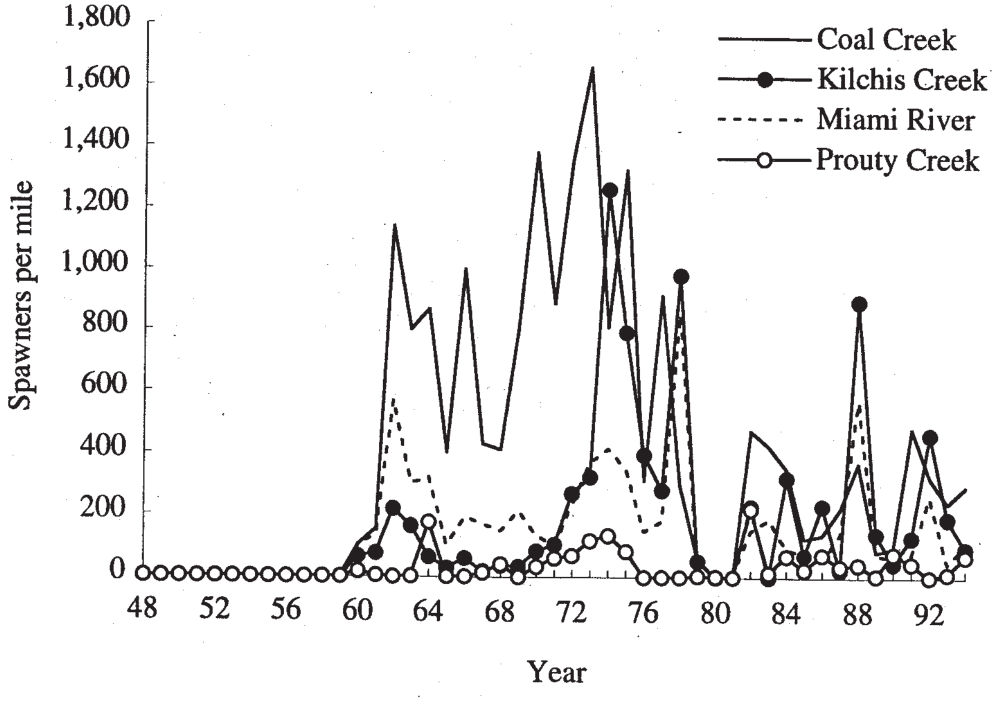


Figure 37. Chum salmon spawning escapement to rivers in Grays Harbor and Willapa Bay. Data from WDF et al. (1993).



Tillamook District Chum Salmon Surveys



Tillamook Chum Salmon Supplemental Surveys

Figure 38. Chum salmon spawner counts from standard (top) and supplemental (bottom) spawner surveys in index streams in the Tillamook District, 1948-1994. Data from Cooney and Jacobs (1994) and Kostow (1995).

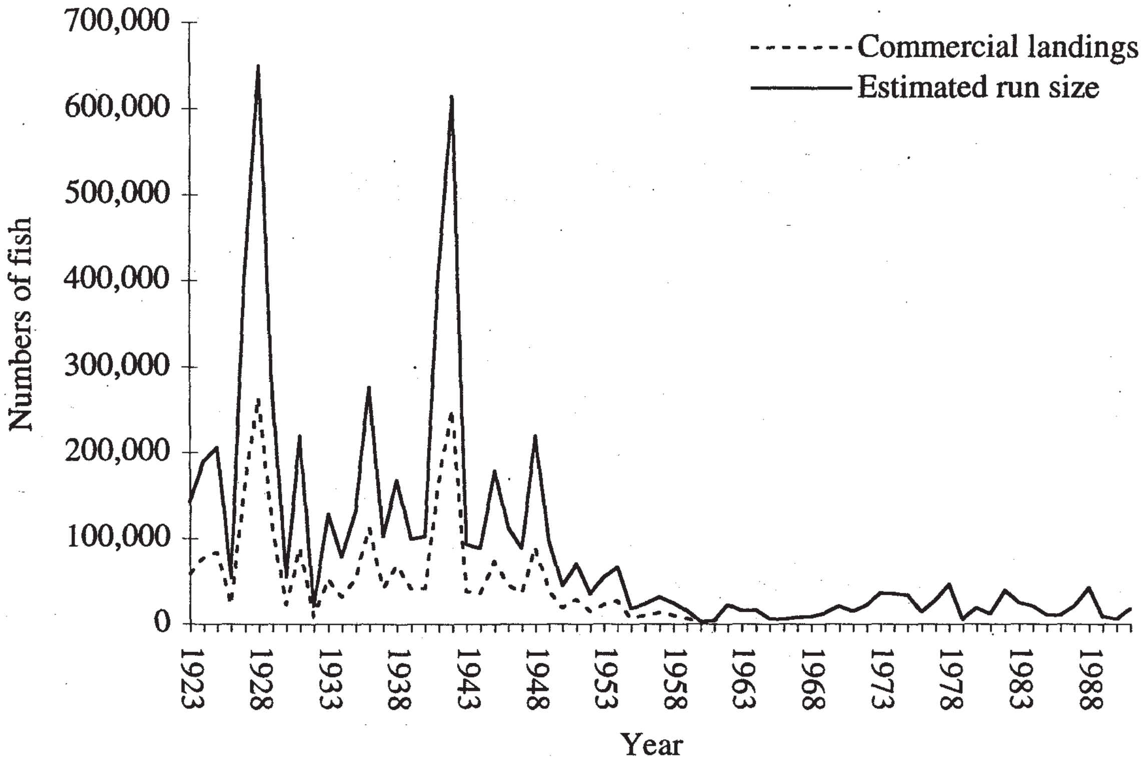


Figure 39. Commercial catch and run size of chum salmon in Tillamook Bay. Data from Nickelson et al. (1992).

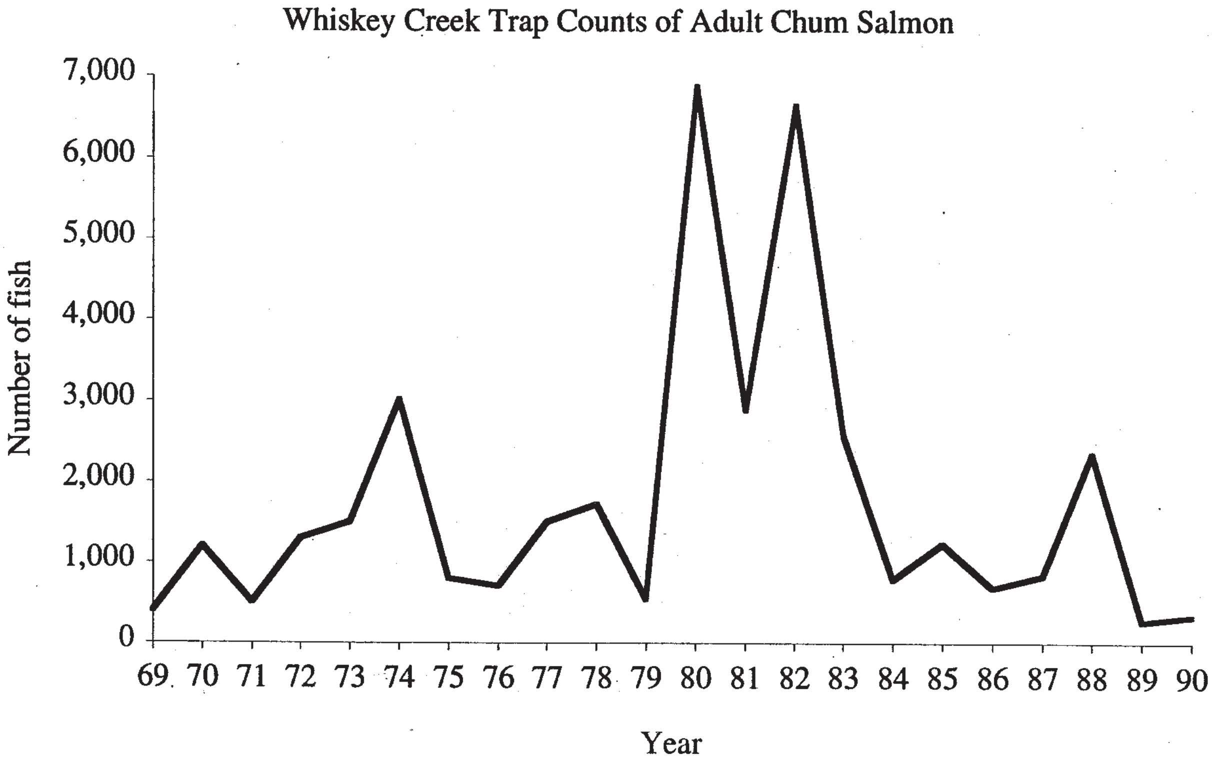


Figure 40. Netarts Bay chum salmon adult counts at Whiskey Creek trap, 1969-1990. Data from Nickelson et al. (1992).

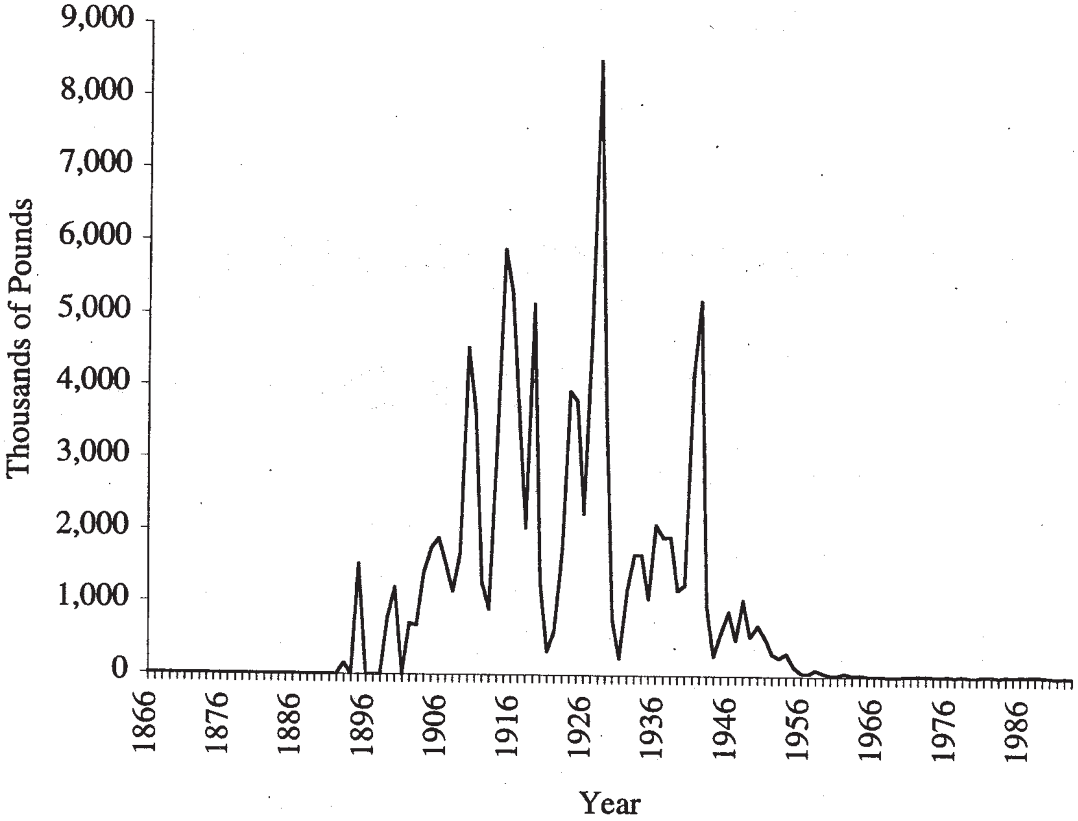


Figure 41. Commercial landings of chum salmon in the Columbia River, 1886-1993. Data from NMFS (1995).

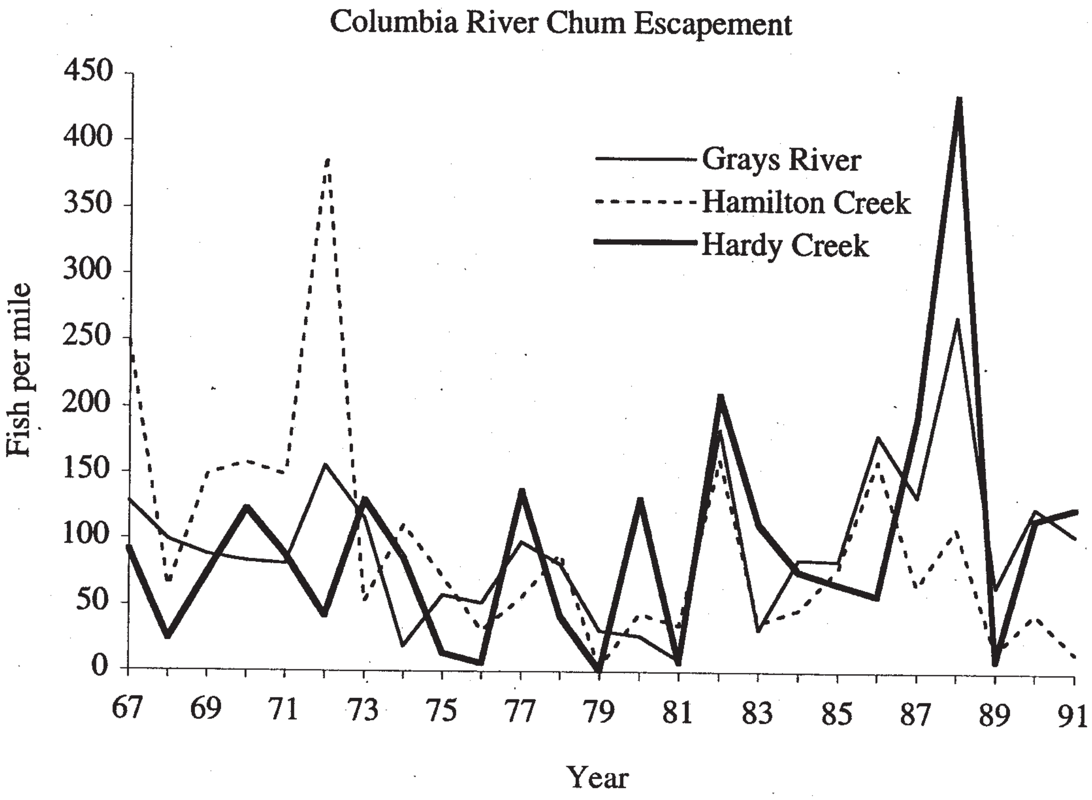


Figure 42. Spawning escapement of chum salmon to three streams on the Washington side of the Columbia River. Data from WDF et al. (1993).

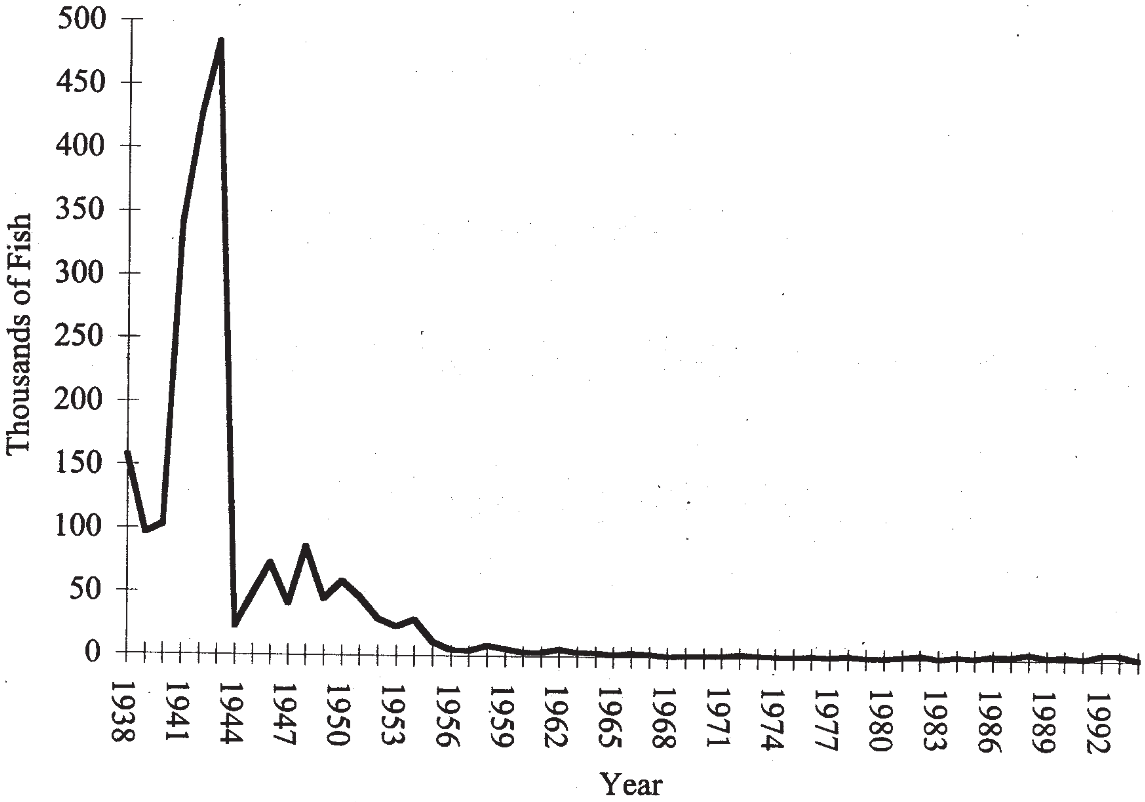


Figure 43. Minimal run size for chum salmon, 1938 to 1994, in the Columbia River, calculated by summing harvest, spawner surveys, Bonneville Dam counts, and returns to the Sea Resources Hatchery on the Chinook River in Washington. Data from ODFW and WDFW (1995).

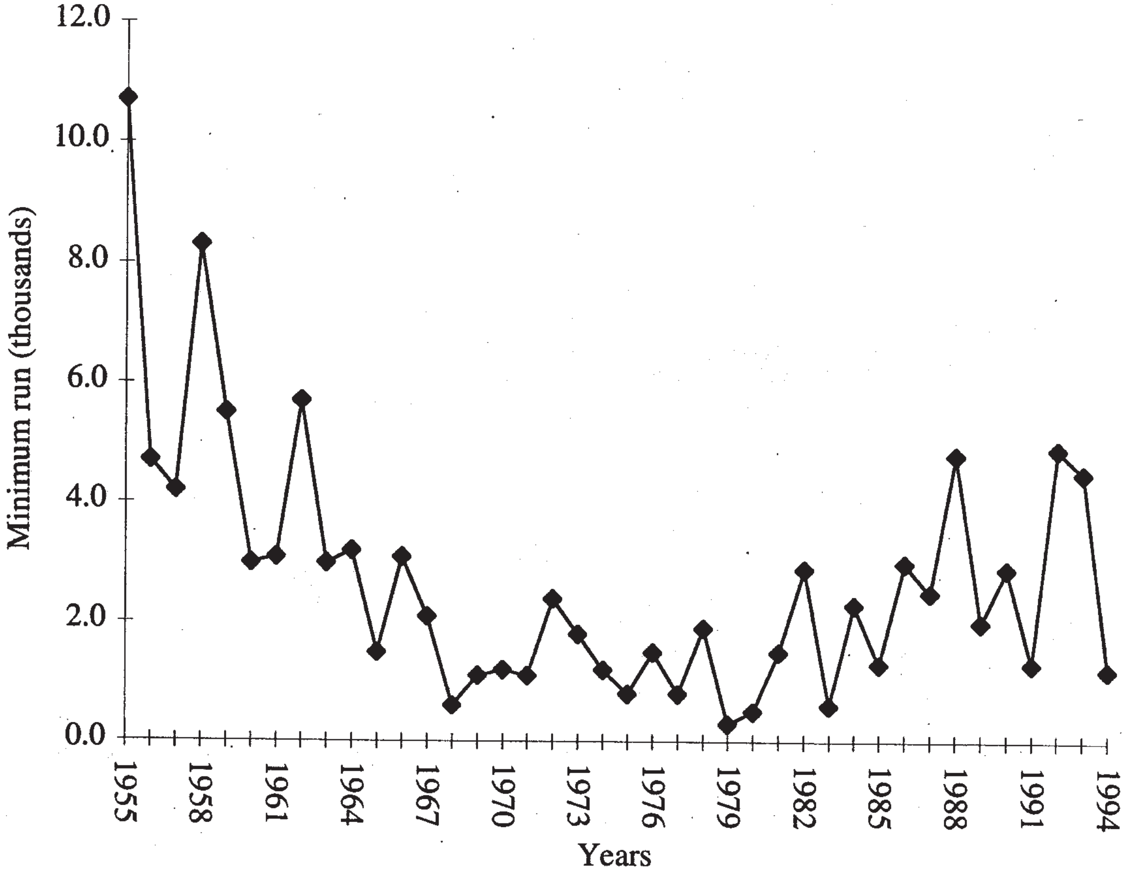


Figure 44. Minimal run size for chum salmon, 1955 to 1994, (subset of previous figure), in the Columbia River, calculated by summing harvest, spawner surveys, Bonneville Dam counts, and returns to the Sea Resources Hatchery on the Chinook River in Washington. Data from ODFW and WDFW (1995).

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; 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").

After evaluating patterns of abundance and other risk factors for chum salmon from these four ESUs, the BRT reached the following conclusions.

Puget Sound/Strait of Georgia ESU

The BRT concluded that this ESU is neither presently at risk of extinction nor likely to become endangered in the foreseeable future. Current abundance is at or near historic levels, with a total run size averaging more than 1 million fish annually in the past 5 years. The majority of populations within this ESU have stable or increasing population trends, and all populations with statistically significant trends are increasing.

This ESU encompasses a great deal of diversity in chum salmon life-history patterns, including summer, fall, and winter runs. The BRT expressed concern that the summer-run populations in this ESU spawn in relatively small, localized areas and therefore are intrinsically vulnerable to habitat degradation and demographic or environmental fluctuations. Concern was also expressed about effects on natural populations of the high level of hatchery production of fall chum salmon in the southern part of Puget Sound and Hood Canal and the high representation of non-native stocks in the ancestry of hatchery stocks throughout this ESU. The BRT was also concerned that although the Nisqually River winter-run population is fairly large and apparently stable, the Chambers Creek population is much smaller and spawns in a restricted area. Conservation of populations with all three recognized run-timing characteristics is important to maintaining diversity within this ESU.

Hood Canal Summer-Run ESU

The BRT concluded that this ESU is in danger of extinction. In 1994, when petitions were filed with NMFS to list summer chum salmon in Hood Canal, of 12 streams in Hood Canal identified by the petitioners as recently supporting spawning populations of summer chum salmon, 5 may already have become extinct, 6 of the remaining 7 showed strong downward trends in abundance, and all were at low levels of abundance. The populations in Discovery Bay and Sequim Bay were also at low levels of abundance with declining trends. Threats to the continued existence of these populations include degradation of spawning habitat, low water flows, and incidental harvest in salmon fisheries in the Strait of Juan de Fuca and coho salmon fisheries in Hood Canal.

In 1995 and 1996, new information was supplied by WDFW (1996) and by the USFWS (1996) that demonstrated substantial increases of returning summer chum to some streams. A hatchery program initiated in 1992 at the Quilcene National Fish Hatchery was at least partially responsible for adult returns to the Quilcene River system, but it appears that 1996 spawners returning to other streams in Hood Canal were primarily (and perhaps entirely) the result of natural production. These streams (e.g., the Duckabush, Hamma Hamma, and Dosewallips) have thus demonstrated considerable resilience in rebounding dramatically from very depressed levels of abundance in recent years.

The rapid increase of summer-run populations in northern Hood Canal following the reduction in incidental harvest in 1991 and 1992 is considerably more encouraging than the lack of response of Columbia River and Tillamook Bay populations even though directed fisheries were eliminated in those areas many years ago.

There remain, however, serious concerns about the overall health of this ESU. First, the population increases were limited in geographic extent, occurring only in streams on the west side of Hood Canal. Several streams on the eastern side of Hood Canal continue to have no spawners at all, and even returns to the Union River were down in 1996. Union River, located at the southeastern end of the Canal, was classified as a healthy stock by WDFW in the SASSI report. In the Strait of Juan de Fuca portion of this ESU, only one of three creeks that have recently contained summer chum salmon runs showed an increase in adult returns in 1996.

Second, the strong returns to the west-side streams were the result of a single strong year class (1992), which returned as 3-year-old fish in 1995 and as 4-year-old fish in 1996. Also, the declines in most of these populations have been severe and have spanned two decades. Coastwide, many chum salmon populations had unusually large returns in 1995 and 1996, but there is no indication from the historical record to suggest that such high productivity can be sustained. In addition, in this ESU, summer chum salmon populations have shown a great deal of variability in productivity and run size in recent years, and this extreme variability can itself be a significant risk factor.

Third, greatly reduced incidental harvest rates in recent years probably contributed to the increased abundance in west-side Hood Canal streams. However, these reductions have been implemented because of greatly reduced abundances of the target species (coho salmon), rather than as a conservation measure for summer chum salmon. If coho salmon in the area rebound, and fishery management policies are not implemented to protect summer-run chum salmon, these populations would again face high levels of incidental harvest. Finally, harvest of summer chum salmon in Strait of Juan de Fuca fisheries is primarily incidental to targeted harvest of Fraser River sockeye salmon. If the run of Fraser River sockeye in the Strait of Juan de Fuca is strong, and abundance of summer chum salmon is low, the relative impact of incidental take in the fishery will be stronger on this ESU than it has been in recent years.

In conclusion, although the BRT agreed that the 1995-96 data on summer chum salmon from this ESU provided a more encouraging picture than was the case in 1996, most members concluded that this ESU was still at significant risk of extinction. A major factor in this conclusion was that, in spite of strong returns to some streams, summer chum salmon were either extinct or at very low abundance in more than half of the streams in this ESU that historically supported summer-run populations. A minority of the BRT concluded that the new data indicated somewhat less risk of extinction, but that the ESU was still likely to become endangered in the foreseeable future. Only one member believed that the large returns to some Hood Canal streams indicated that this ESU as a whole was not at significant extinction risk.

Pacific Coast ESU

The BRT concluded that this ESU is not presently at risk of extinction or endangerment. An important factor in this conclusion was the abundance of natural populations in Grays Harbor and Willapa Bay, which presently have escapements of tens of thousands of adults per year. Elsewhere on the Olympic Peninsula, available data suggest that populations are depressed from historical levels but relatively stable. Populations in the Tillamook District, the major chum-salmon-producing area on the Oregon coast, are also at much lower abundance than they were historically, with no apparent trends in abundance. The primary cause of the depressed status of Oregon coastal populations appears to be habitat degradation.

Although there has been considerable hatchery enhancement in some areas and some transfer of stocks within this ESU, overall hatchery production has been relatively minor compared with natural production, and hatchery programs have primarily used fish from local populations. On the Oregon coast, both public and private chum salmon hatcheries were phased out by 1990, and all current chum salmon production in this area is natural.

The BRT identified some areas of concern for the status of this ESU. Neither the historic nor the present southern limit of distribution and spawning of chum salmon is known with certainty. Thus, it is unclear whether the geographic range has been reduced. Tillamook Bay populations appear to be stable at low abundance. ODFW has recently increased monitoring efforts for chum salmon on the remainder of the Oregon coast, but at present the time series is too short to provide much insight into trends in abundance. Although populations from the northern Washington coast and the Strait of Juan de Fuca do not appear to be at critically low levels, their generally depressed status is also a concern and should be monitored. Finally, more definitive information about the relationship between hatchery and natural fish in Willapa Bay and Grays Harbor tributaries would allow a more comprehensive evaluation of the viability of natural populations in these areas.

Columbia River ESU

The BRT concluded that the Columbia River ESU is presently at significant risk, but team members were divided in their opinions of the severity of that risk. Historically, the Columbia River contained chum salmon populations that supported annual harvests of hundreds of thousands of fish. Current abundance is probably less than 1% of historic levels, and the ESU has undoubtedly lost some (perhaps much) of its original genetic diversity. Presently, only three chum salmon populations, all relatively small and all in Washington, are recognized and monitored in the Columbia River (Grays River, Hardy and Hamilton Creeks). Each of these populations may have been influenced by hatchery programs and/or introduced stocks, but information on hatchery-wild interactions is unavailable.

Because of the well-known aversion of chum salmon to surmounting in-river obstacles to migration, the effects of the mainstem Columbia River hydropower system have probably been more severe for chum salmon than for other salmon species. Bonneville Dam presumably continues to impede recovery of upriver populations. Substantial habitat loss in the Columbia River estuary and associated areas presumably was an important factor in the decline and also represents a significant continuing risk for this ESU.

Although current abundance is only a small fraction of historical levels, and much of the original inter-populational diversity has presumably been lost, the total spawning run of chum salmon to the Columbia River has been relatively stable since the mid 1950s, and total natural escapement for the ESU is probably at least several thousand fish per year. Taking all of these factors into consideration, about half of the BRT members concluded that this ESU is at significant risk of extinction; the remainder concluded that the short-term extinction risk was not as high, but that the ESU is at risk of becoming endangered.

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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 alternative form of a gene that can occur at the same location (locus) on homologous chromosomes. Many alleles may exist for a particular locus in a population, but a single individual can carry no more than two alleles at a diploid locus.

allozymes

The alternative forms of an enzyme produced by different alleles andoften 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. Hatchery rearing practices for chum salmon differ from those of most other salmonid species in that juvenile chum salmon are released directly from hatcheries as 1- or 2-month-old **fed fry**, although **unfed fry** (defined as all fish released at less than 0.4 g) are also occasionally released. This is possible because chum salmon juveniles have characteristics of both the **fry** (young juveniles adapted to freshwater) and **smolt** (juveniles that are physiologically prepared to undergo the migration into saltwater) salmonid life-history stages and can almost immediately enter seawater after the **alevin** stage.

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**.

egg boxes

Stream-side boxes where fertilized salmon eggs are incubated until the fry stage, when the juveniles swim out of the box and enter the stream.

electrophoresis

Electrophoresis is a physical process that refers to the movement of charged particles in an electric field. The process has been developed as a analytical tool to detect genetic variation revealed by charge differences on proteins or DNA. Data provided by electrophoresis can provide insight into levels of genetic variability within populations and the extent of genetic differentiation between them.

escapement

The fish in a run that "escape" all fisheries and return to the freshwater spawning area.

evolutionarily significant unit (ESU)

A "distinct population" of Pacific salmon defined as 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. However. chum salmon juveniles share characteristics of both the fry and smolt stages and can enter seawater almost immediately after becoming fry. Hatcheries usually release chum salmon after 1- or 2-months of feeding as **fed fry**, although **unfed fry** (defined as all fish released at less than 0.4 g) are also occasionally released. Egg boxes allow volitional release juveniles as **unfed fry**.

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.

molecular genetic phylogenics

The evolutionary history of an organism or taxonomic group determined by the study of the molecular aspects of genetic mechanisms and the control of metabolic processes by genetic material.

multidimensional scaling

This is a graphing technique that can be used to represent genetic distances between samples in two or three dimensions, which helps to visualize similarities and differences between different groups or samples. See **dendrogram**.

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.

phenotype

The phenotype is the appearance, or other measurable characteristic, of an organism resulting from the interaction of the genotype and the environment.

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.

protein electrophoresis

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

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.

remote site incubator (RSI)

An egg incubation system developed primarily for chum salmon. RSIs can hold 5,000 to 125,000 eggs.

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 - To go through the physiological process that prepares a juvenile anadromous fish to survive the transition from freshwater to saltwater.

noun - A juvenile anadromous fish which has smolted.

Chum salmon differ from most other salmonids in that they have characteristics of both **fry** and **smolt**s immediately after **swim up**.

swim up

The time in the life cycle of salmon when **alevin**s, having absorbed their yolk sacs, transition into fry by swimming from the gravel of the **redd** into the water column.

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).”

WDFW

Washington Department of Fish and Wildlife (**WDFW**) is a co-manager of **salmonid**s and salmonid fisheries in Washington State with **WWTIT** and other fisheries groups. The agency was formed in the early 1990s by the combination of Washington Department of Fisheries (WDF) and Washington Department of Wildlife (WDW).

WWTIT

Western Washington Treaty Indian Tribes (**WWTIT**) is an organization of Native American tribes with treaty fishing rights recognized by the United States government. WWTIT is a **co-manager** of **salmonid**s and salmonid fisheries in western Washington in cooperation with **WDFW** and other fisheries groups.

Appendix

Appendix 1. Summary of chum salmon artificial production outplants (eggs and unfed fry, and fed fry) in Washington waters - 1952-93. SASSI designation and the total hatchery and stock status, with the year(s) in which hatchery plants occurred, the origin of the hatchery stock, life stage at out-planning plants occurring by stream within each SASSI stock area. Data provided by H. Fuss and T. Tynan, Washington Department of Fish and Wildlife, P.O. Box 43151, Olympia, WA 98504. Pers. Commun., April 1997.

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
N F Nooksack	native/wild	healthy							
Anderson Creek			1985		fed fry	40,000		40,000	
Kendall Creek			1979,81,85-93	1978,80	fed fry	3,830,865	3,186,000	7,016,865	Hood Canal, Skykomish Stocks comprised non-local plants.
Ten Mile Creek			1982		fed fry	32,288		32,288	
Main/S F Nooksack		unknown							
Baker Creek				1988,89,90	25% unfed fry; 75% eggs		383,300	383,300	Whatcom Creek Stock
Nooksack River	native/wild			1953	all unfed fry		602,150	602,150	Samish Stock
Rutsatz Slough				1978,93	52% eggs, 48% unfed fry	118,000		118,000	Nooksack Stock
Main/S F Nooksack	native/wild	unknown							
Baker Creek			1982,83,85		fed fry	245,000		245,000	
Bertrand Creek			1986		fed fry	60,000		60,000	
Deer Creek			1982		fed fry	7,680		7,680	
Double Ditch			1982		fed fry	15,360		15,360	
Fishtrap Creek			1982,91		fed fry	35,360		35,360	
Kamm Ditch			1982		fed fry	20,000		20,000	
McCauley Creek			1985		fed fry	20,000		20,000	
Nooksack River			1983,90	1953	fed fry	994,700	338,844	1,333,544	Samish Stock planted one year.
Rutsatz Slough			1979,82,83,85,86, 88,91		fed fry	2,401,202		2,401,202	
S F Nooksack			1976		fed fry	242,529		242,529	
Samish/Independent		unknown							

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	
						Local	Non-Local		Broodstock source/Comments
Beaverton Valley	not in SASSI			1976,77,79, 80,91	all unfed fry		1,705,500	1,705,500	Nooksack, George Adams and "unknown" stocks; no indigenous run.
Bob Smith Creek	mixed/ composite		1991	1992	100% eggs	195,795	247,000	442,795	Whatcom Creek Stock
Chuckanut Creek	mixed/ composite			1977,79,80, 81,90, 91	all unfed fry		989,750	989,750	unknown + Samish Stock, Hood Canal, Whatcom Creek
Clearbrook Inn				1993	unfed fry		13,251	13,251	Cowling Creek
Colony Creek	mixed/ composite		1990,91	1954	85% unfed fry, 15% eggs	245,800	227,160	472,960	Samish Stock
Dakota Creek	mixed/ composite			1976	all unfed fry		61,810	61,810	unknown stock
Eldridge Spring				1991	all unfed fry		103,200	103,200	Whatcom Creek Stock
Fragrance Creek				1988	all unfed fry		97,000	97,000	Whatcom Creek Stock
Friday Creek			1954,56,65,67	1986	all unfed fry	126,210	200,000	326,210	Whatcom Creek + Samish Stock
False Bay Creek			1989,92		eggs	292,300		292,300	Whatcom Creek
Oyster Creek	mixed/ composite			1976,77,78, 79,80	all unfed fry	321,000	243,225	564,225	Hood Canal Stock
Padden Creek	mixed/ composite			1988-91	64% unfed fry		625,100	625,100	Whatcom Creek Stock
Parsons Creek				1993	all unfed fry		362,500	362,500	Samish Stock
Samish River	mixed/ composite		1952,61,92	1961,65	80% unfed fry; 20% eggs	361,232	79,200	440,432	Samish Stock
Smith Creek			1990	1985,86,88, 89,93	82% eggs, 18% fry	50,000	229,000	279,000	Nooksack, Whatcom Creek
Whitehall Creek			1991	1979,81	all unfed fry	187,500	210,000	397,500	Hood Canal Stock
Samish/ Independent	mixed/ composite	unknown							
Beaverton Valley				1973,78,88	fed fry		659,100	659,100	unknown, Whatcom Creek stocks comprised non-local plants.
Blaine Reservoir				1978,82,83	fed fry		792,000	792,000	unknown, Nooksack stocks comprised non-local plants.
Bob Smith Creek			1993		fed fry	197,900		197,900	
Bowmans Bay				1952,55,57	fed fry		320,560	320,560	Samish non-local stock planted.

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Chuckanut Bay			1985		fed fry	85,000		85,000	
Chuckanut Creek			1983,85	1978	fed fry	500,000	86,250	586,250	"unknown" assumed non-local plant.
Colony Creek			1983,88		fed fry	22,500		22,500	
Dakota Creek				1979,80	fed fry		1,488,000	1,488,000	Hood Canal Stock
Friday Creek			1978,79,85,87-89, 91	1973,74,90	fed fry	2,953,573	3,996,400	6,949,973	Hood Canal, Quilcene, Whatcom Creek
Lummi Bay			1979,81-83,87-93	1974-80,82, 88	fed fry	6,312,772	8,759,442	15,072,214	Quilcene, Whatcom Creek, Hood Canal
Oyster Creek			1983		fed fry	15,000		15,000	
Samish River			1952,55,57,58,59, 60,62-64	1959,63	fed fry	5,231,242	1,923,709	7,154,951	"unknown" assumed non-local plant.
Squalicum			1993		fed fry	99,191		99,191	
Squalicum Creek			1988	1982,85,87	fed fry	2,000	60,075	62,075	
Whatcom Creek			1980,82-84,93	1983-93	fed fry	10,446,826	1,087,580	11,534,406	
Whitehall Creek			1983	1978,80	fed fry	15,000	191,065	206,065	unknown, Hood Canal
Mainstem Skagit	mixed/ composite	healthy							
Bacon Creek			1979		eggs	7,656		7,656	local-origin plants of Skagit stock
Clark Creek			1954,82,91		unfed fry	501,504		501,504	local-origin plants of Skagit stock
Mainstem Skagit	mixed/ composite	healthy							
Clark Creek			1972,76-78,82, 87-90	1971-74,76	fed fry	4,760,909	14,097,047	18,857,956	Hood Canal, Quilcene non-local plants.
Newhalem Creek				1976	fed fry		201,390	201,390	Quilcene
Park Slough			1986		fed fry	131,400		131,400	
Skagit River			1976-79		fed fry	782,642		782,642	
					fed fry				
Sauk		healthy							
Camp Creek				1987	all eggs		4,848	4,848	Stillaguamish Stock
Lower Skagit Tributaries	unknown/ wild	unknown							
Swinomish Slough			1976,77,78		all unfed fry	243,569		243,569	local-origin plants of Skagit stock

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Mundt Creek				1956	all unfed fry		270,000	270,000	Samish Stock
Lower Skagit Tributaries	unknown/ wild	unknown							
Armstrong Creek			1979,80,81,88,89, 92,93		fed fry	1,903,281		1,903,281	
Indian Slough				1992	fed fry		52,562	52,562	Skagit River origin.
Kiket Bay			1992		fed fry	50,381		50,381	
N F Skagit			1952		fed fry	4,800		4,800	
Swinomish Channel				1991-93	fed fry		916,267	916,267	Clark Creek, Skagit
Mainstem Stillaguamish	not in SASSI								
Armstrong Creek			1981		all unfed fry	190,000		190,000	Stillaguamish Stock
Stillaguamish			1982		all unfed fry	32,500		32,500	Stillaguamish Stock
Church Creek			1987		all eggs	5,009		5,009	Stillaguamish Stock
Harvey Creek			1986		all unfed fry	60,000		60,000	Stillaguamish Stock
N F Stillaguamish	native/wild	healthy							
Fortson Creek			1982,84,85		19% unfed fry; 81% eggs	880,000		880,000	Stillaguamish Stock
N F Stillaguamish	native/wild	healthy							
Ashton Creek			1982,84		fed fry	361,500		361,500	
Squire Creek			1985		fed fry	914,100		914,100	
N F Stillaguamish			1990		fed fry	351,798		351,798	
Church Creek			1986		fed fry	52,200		52,200	SASSI notes that these streams (Church, Harvey, Stillaguamish)should be listed as NF Stillaguamish areas, as that was the area from which these plants originated (pending additional information).
Harvey Creek			1978,84-87		fed fry	4,002,521		4,002,521	
Stillaguamish			1982,83		fed fry	802,475		802,475	
S F Stillaguamish	native/wild	healthy							
Siberia Creek			1988,90,91,92		all eggs	56,000		56,000	Stillaguamish Stock
Jim Creek			1982		all unfed fry	184,680		184,680	Stillaguamish Stock

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
S F Stillaguamish	native/wild	healthy							
Jim Creek			1978,80,85		fed fry	193,005		193,005	
Unnamed (0319)			1987,88		fed fry	24,000		24,000	
Skykomish	native/wild	healthy							
Sky Slough			1984		fed fry	598,000		598,000	
Skykomish River			1982,83		fed fry	953,000		953,000	
Wallace	native/wild	healthy							
May Creek			1986,93		all unfed fry	330,300		330,300	Wallace River Stock
Wallace	native/wild	healthy							
Wallace River			1977	1974,76,77	fed fry	45,510	7,274,694	7,320,204	
Olney Creek				1993	fed fry		149,500	149,500	
Tulalip & Mission Creeks	not in SASSI **								** Wild chum not present - Tulalip tribal hatchery programs established local stock.
Tulalip Creek			1976-78,88,93		fed fry	12,888,667		12,888,667	
Tulalip Bay			1982-84,86,87	1975-77,79-82	fed fry	15,308,000	7,144,025	22,452,025	Quilcene stock origin for non-locals
Mission Creek			1985,89,90-92	1976	fed fry	21,086,000	974,600	22,060,600	
Lake Washington	not in SASSI								
Portage Bay				1976	all unfed fry		5,600	5,600	unknown non-local stock
Lake Washington	not in SASSI **								** Wild chum not present in system.
Lake Washington			1989		fed fry	500		500	
North Creek			1993	1975	fed fry	120		120	
Portage Bay			1977		fed fry	12,000		12,000	
Ship Canal			1979		fed fry	5,500		5,500	
Venema Creek				1983-92	fed fry		305,800	305,800	Elson and Minter Ck transfers; stream drains to saltwater, independent of Lk Washington

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Duwamish/Green River		unknown							
Burns Creek	mixed/ composite			1952,75,76	all unfed fry		50,696	50,696	Finch Creek Stock
Des Moines Creek	not in SASSI			1991,92	all eggs		17,500	17,500	Minter Creek Stock
Green River	mixed/ composite		1984		all unfed fry	201,600		201,600	Green R Stock
Miller Creek				1991,92	all eggs		17,500	17,500	Minter Creek + Elson Stock
Duwamish/ Green River	mixed/ composite	healthy							
Big Soos Creek				1960	fed fry		246,500	246,500	Bonneville Hatchery transferred in during one year
Black River				1978	fed fry		20,000	20,000	Finch Creek
Crisp Creek			1978,90-93	1981,83,87, 88	fed fry	3,075,919	4,884,317	7,960,236	Finch Creek/Hood Canal introduced, then Cowling supplanted
Elliot Bay				1976-78,83,85-87, 89-92	fed fry		506,164	506,164	unknown, Elson Creek, Minter Creek - Seattle Aquarium educational program
N F Newaukum			1985	1990	fed fry	311,400	204,436	515,836	Cowling Creek Stock introduced one year
Springbrook Creek				1976	fed fry		12,000	12,000	Finch Creek
Puyallup/ Carbon	native/wild	unknown							
Canyon Falls Creek				1976-78	fed fry		318,732	318,732	George Adams, Hood Canal
Clarks Creek			1986,88,89	1984-87,90, 91	fed fry	299,942	1,574,984	1,874,926	Chambers Creek, Garrison Springs late stock transferred
Diru Creek			1993		fed fry	1,090,591		1,090,591	
Fennel Creek				1977	fed fry		456,400	456,400	Hood Canal Hatchery-origin plant for one year
Fox Creek			1988		fed fry	15,260		15,260	
Hyelbos Creek				1976-80,83	fed fry		690,482	690,482	George Adams, Hood Canal, Late Stock
Le Dout Creek			1988		fed fry	11,990		11,990	
Niesson Creek			1988		fed fry	13,352		13,352	

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Puyallup River			1982		fed fry	20,700		20,700	
Swan Creek			1988	1976-79,91	fed fry	37,060	458,333	495,393	
Unnamed (0013)			1986,93	1991	fed fry	93,793	96,894	190,687	Chambers Creek late stock non-local
Unnamed (0016)				1990	fed fry		1,107	1,107	Chambers Creek late stock non-local
Diru (0028)			1988	1992	fed fry	4,529	305,253	309,782	Chambers Creek late stock non-local
Wapato Creek				1979,80	fed fry		31,639		George Adams, Hood Canal
Chambers									
Chambers Cr. lates	native/wild	healthy	80,91		all unfed fry		293,640	293,640	Egg box program
Chambers Cr. falls	falls - not in SASSI			61,79	all unfed fry		116,400	410,040	No native falls present. Hood Canal+Bonneville;
Flett Creek	lates - native		86-88,90-93		41.5% unfed fry; 58.5% eggs	687,700		687,700	Garrison Springs
Chambers	native/wild	healthy							
Chambers Creek			74, 76-80, 82, 93	59, 60	fed fry	7,665,920	524,669	8,190,589	Bonneville Hatchery
Puget Creek				93	fed fry		12479	12,479	Diru Creek - winter stock
Ponce de Leon			90		fed fry	4000		4,000	
Nisqually River Drainage		falls - unknown lates - healthy+ C36							
Clear Creek	falls - not in SASSI			81	all unfed fry		510,541	510,541	Kennedy Creek Stock
Halverson Creek	lates - native		84		all eggs	49,960		49,960	Nisqually River Stock
Horn Creek	lates - native		88,89		all eggs	49,200		49,200	Nisqually River Stock
Johnson Creek	lates - native		81,82,84-86		75 % unfed fry; 25% eggs	826,362		826,362	Nisqually River Stock
Kalama Creek	falls - not in SASSI			80,81	88% eggs	192,275	1,443,635	1,635,910	Kennedy Creek Stock
Lacamas Creek	lates - native		83,84,85,86,88		all eggs	406,095		406,095	Nisqually River Stock
Muck Creek	lates - native		84,85,87,88		71% eggs, 29% unfed fry	413,664		413,664	Nisqually+Kalama Creek

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	
						Local	Non-Local		Broodstock source/Comments
Nisqually River	lates - native		60,61,91	60	12.0% eggs	414,680	49,880	464,560	Bonneville+ ancient wild+Kalama Creek
Ohop Creek	lates - native		84-87		all eggs	214,055		214,055	Nisqually River Stock
Stream 110021	lates - native		87		all eggs	70,000		70,000	Nisqually River Stock
Unnamed (0015)	falls - not in SASSI			84	47% unfed fry; 53% eggs		491,612	491,612	Kennedy Creek Stock
Unnamed (0019)	lates - native		87		all eggs	114,300		114,300	Nisqually River Stock
Unnamed (0057)	lates - native		90		all unfed fry	31,000		31,000	Nisqually River
Yelm Creek	lates - native		86,87,88,91,93		all eggs	189,764		189,764	Nisqually+Kalama Creek
Johnson Creek	lates - native		83		all eggs		125,175	125,175	Nisqually Stock
Nisqually River Drainage	native/wild	healthy							
Halverson Creek			80		fed fry	203,072			late chum
Johnson Creek			79, 80		fed fry	502,400			late chum
Kalama Creek			76-79, 90	81	fed fry	2,975,888	197,490		Kennedy Creek fall chum out-planted one year
Muck Creek			79, 87		fed fry	630,260			late chum
Nisqually River			79, 89-91		fed fry	593,302			late chum
McCallister Creek				76-78	fed fry		11,003,430	11,003,430	Hood Canal falls/Johns Creek summers; returns harvested and not allowed to spawn; program terminated.
Henderson Inlet		unknown							
McAllister Creek--Unnamed Tribs	not in SASSI			89, 90	50% unfed fry; 50% eggs		100,200	100,200	Elson Creek
Woodland Creek	mixed/ composite		87-89	92	all eggs	779,500	50,000	829,500	Minter Creek,Elson
Woodard Creek	mixed/ composite			90, 92, 93	all eggs		190,000	190,000	Minter Creek
Henderson Inlet	mixed/ composite	unknown							
Woodland Creek				90	fed fry		950	950	Minter Creek
Budd Inlet	not in SASSI								

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Adams Creek			84,85	86	100% eggs	701,140		701,140	Elson Creek; no indigenous population
Dobbs Creek			88,90		97% unfed fry; 3% eggs	174,700		174,700	Elson Creek
Leingang			85	86	all eggs	507,160		507,160	Elson Creek; no indigenous population
Budd Inlet	not in SASSI								
Deschutes River				59	fed fry		284,850	284,850	Wild chum not present; Bonneville Hatchery out-plant - one year
Eld Inlet		healthy							
Allison Springs	not in SASSI		83		all unfed fry	70,000		70,000	Allison Springs
Eld Inlet	native/wild	healthy							
Allison Springs				76, 78, 79	fed fry		3,338,050	3,338,050	Hood Canal, Quilcene stock planted at WDFW hatchery - program terminated.
Totten Inlet		healthy							
Brenner Creek	not in SASSI			84,85,86,88, 89	all eggs		680,626	680,626	Elson Creek; no indigenous population
County Line Creek	not in SASSI			84,85	all eggs		198,533	198,533	Elson Creek; no indigenous population
Holiday Valley Creek	not in SASSI			84,85,88,89	all eggs		509,841	509,841	Elson Creek; no indigenous population
Kennedy Creek	native/wild		76,78-82	77	all unfed fry	15,668,189	327,000	15,995,189	Egg box program discontinued in 1991; one year of Mill Creek X Kennedy Creek hybrids.
Schneider Creek	not in SASSI			86,90	25.7% eggs		497,656	497,656	Elson Creek
Totten Inlet				90	all eggs		10,000	10,000	Elson Creek
Totten Inlet	native/wild	healthy							
Totten Inlet (unnamed stream)	not in SASSI			89	fed fry		10,000	10,000	Elson Creek
Skookum Inlet		healthy							

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Unnamed (9006)	not in SASSI		83,84,85		21% unfed fry; 79% eggs	261,213		261,213	Elson Creek
Unnamed (0027)	not in SASSI		90,92		all unfed fry	40,000		40,000	Elson Creek
Bishop Creek	not in SASSI		84		all eggs	87,000		87,000	Elson Creek
Unnamed (0026)	not in SASSI		85		all eggs	80,178		80,178	Elson Creek
Unnamed(0084)	not in SASSI		83-85		all eggs	292,548		292,548	Elson Creek
Skookum Inlet	mixed/ composite	healthy							
Elson Creek			78-80, 82-93	78-83	fed fry	29,223,551	4,756,822	33,980,373	Transferred in Johns Creek (1 brood cycle) & Chambers Ck (1 year); Squaxin Island tribal hatchery program
Johns/Mill Creeks		healthy							
Cranberry Creek	not in SASSI		76,82,85,86	87, 88	74% unfed fry; 26% eggs	4,651,999	2,013,610	6,665,609	Elson Creek, Johns Creek
Johns Creek	mixed/ wild		77,91		all unfed fry	1,588,525		1,588,525	Johns Creek - falls
Jones Creek	not in SASSI			83,84,85,86	all eggs		559,464	559,464	Elson Creek
Malaney Creek	not in SASSI			87,88	all eggs		420,024	420,024	Elson Creek
Shelton Creek	not in SASSI			88, 90	50% unfed fry; 50% eggs		8,000	8,000	Elson Creek
Uncle John Creek	not in SASSI			85,86,87,88, 89	all eggs		686,792	686,792	Elson Creek
Jarrell Creek	not in SASSI			93	all eggs		125,000	125,000	Elson Creek
Johns/Mill Creeks		healthy							
Johns Creek--Summers	native/ composite		76, 78-88, 90		fed fry	26,693,970		26,693,970	Johns Creek native supplementation program
Johns Creek -- Falls	mixed/ wild		78-83	78, 79	fed fry	539,625	9,756,207	10,295,832	Two years of plants of Hood Canal Stock, returning adults were not allowed to spawn; Squaxin mitigation plants of Johns fall stock; 1978-83.

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Goldsborough/ Shelton	native/wild	healthy							
Shelton Creek				89	fed fry		3,200	3,200	Elson Creek
Case Inlet		healthy							
Coulter Creek	mixed/ composite		90,91		all unfed fry	209,800		209,800	Coulter Creek
Sherwood Creek	native/wild		76-78,80,82,85, 86	78	all unfed fry	4,168,286	246,900	4,415,186	One Hood Canal year; the rest were summer chum egg box program discontinued in 1987.
Case Inlet		healthy							
Sherwood Creek	native/ composite		79		fed fry	32,500		32,500	
Coulter Creek-- Summers	native/ composite		79-91	82	fed fry	15,429,977	478,200		Johns Creek transferred in one year
Coulter Creek--Falls	native/wild			78, 80	fed fry		580,716		Garrison Springs, McAllister, Minter X Hood, Skykomish origin falls.
Carr Inlet		healthy							
Burley Creek	mixed/ composite		89		all eggs	5,000		5,000	Elson Creek
Herron Creek	not in SASSI		89,90		all eggs	2,480		2,480	Minter Creek
McCormick Creek	not in SASSI		93		all eggs	90,000		90,000	Minter Creek
Minter Creek	mixed/ composite		51-54,78,83	78, 83	97.9% unfed fry; 2.1% eggs	16,653,980	344,700	16,998,680	Minter Creek, Hood Canal and Elson Creek stocks in succession.
Nelyaly Creek	not in SASSI		83,85,86,93	78	70.6% unfed fry, 29.4% eggs	80,000	5,000	85,000	Hood Canal
Purdy Creek	not in SASSI		93		all eggs	112,000		112,000	Minter Creek
Carr Inlet	mixed/ composite	healthy							
Burley Creek			91	89	fed fry	2,500	2,000	4,500	Elson Creek
Herron Creek			94	91	fed fry	1,000	485	1,485	Elson Creek
Hupp Springs	not in SASSI		81-86	80	fed fry	11,574,111	3,524,000	15,098,111	Wild chum not present; Garrison Springs Stock transferred in - one year.

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Lackey Creek			59, 76		fed fry	415,092		415,092	
Minter Creek - WDFW Hatchery	not in SASSI **		56-59, 61-63, 74, 76, 79--93	70, 74-79	fed fry	40,325,948	18,586,712	58,912,660	Hokkaido, Hood Canal, Minter X Hood, Quilcene stocks; Elson now broodstock established
Unnamed (0070)			93		fed fry	550			
Gig Harbor/Olalla		healthy							
Crescent Creek	not in SASSI			76	all unfed fry		85,000	85,000	unknown
Donkey Creek	not in SASSI		79-81,86,87,89,93	76-78	55.6% unfed fry; 44.4% eggs	4,836,326	884,870	5,721,196	Donkey Creek, Hood Canal/Minter and Elson Creek in succession.
Gig Harbor	not in SASSI			90	all eggs	600,000		600,000	Elson Creek
Mosher Creek	not in SASSI			93	all eggs		5,000	5,000	Cowling Creek
Olalla Creek	mixed/ composite		88,89,90		all eggs	45,000		45,000	Elson, Minter Creek
Gig Harbor/Olalla	mixed/ composite	healthy							
Crescent Creek				88, 89, 91	fed fry		380,000	380,000	Elson Creek, Minter Creek
Donkey Creek			75	76	fed fry	37,000	97,000	134,000	unknown
Gig Harbor				92	fed fry		26,000	26,000	Minter Creek
Olalla Creek			91, 93		fed fry	23,500			
Dyes Inlet/Liberty Bay		healthy							
Agate Pass			85,86,88,89,90		all eggs		280,000	280,000	Minter + Elson Creek
Barker Creek	mixed/ composite		85,87,88,90-93		66% unfed fry; 34% eggs		1,465,669	1,465,669	Cowling Creek
Big Scandia	not in SASSI		85-93		85% unfed fry; 15% eggs		4,158,751	4,158,751	Cowling Creek
Chico Creek	mixed/ composite		86		all eggs		1,092,662	1,092,662	Cowling Creek
Clear Creek	not in SASSI		77,85-93		33% unfed fry; 67% eggs		5,711,311	5,711,311	Cowling Creek, Grovers, Hood Canal
Clearbrook Inn	not in SASSI		93		all unfed fry		13,251	13,251	Cowling Creek Stock
Dickerson Creek	not in SASSI		86-93	79,80,84,85	63% unfed fry; 37% eggs	1,031,970	3,762,554	4,794,524	Cowling Creek+Chico Creek

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Dogfish Creek	mixed/ composite		86-92		60% unfed fry; 40% eggs		3,001,323	3,001,323	Cowling Creek
Indianola Creek	not in SASSI		82	80,81	all unfed fry	16,500	125,000	141,500	Chico Creek+Cowling
Keyport Lagoon	not in SASSI			59,62	all unfed fry	1,230,894		1,230,894	unknown+Quilcene
Kitsap Creek	not in SASSI			91	all eggs	100,000		100,000	George Adams
L Scandia	not in SASSI		85-88		87% unfed fry; 13% eggs		447,980	447,980	Cowling Creek
Steele Creek	not in SASSI		86-90,92		23% unfed fry; 77% eggs		734,745	734,745	Grovers Creek
Strawberry Creek	not in SASSI		86,87		63% unfed fry; 37% eggs		94,860	94,860	Cowling Creek
Unnamed (0250)	not in SASSI		88		all eggs		455,840	455,840	Cowling Creek
Unnamed (0283)	not in SASSI		85,87		49% unfed fry; 51% eggs		205,492	205,492	Cowling Creek
Unnamed (0284)	not in SASSI		88		all eggs		42,300	42,300	Cowling Creek
Unnamed (0286)	not in SASSI		85		all unfed fry		85,779	85,779	Cowling Creek
Dyes Inlet/Liberty Bay	native/ composite	healthy							
Barker Creek			89		fed fry	105,374		105,374	
Big Scandia			83, 84		fed fry	331,520		331,520	
Clear Creek			83	74	fed fry	40,000	250,400	290,400	Quilcene
Cowlings Creek - tribal hatchery			77-93		fed fry	10,202,175		10,202,175	East Kitsap-origin broodstock.
Dickerson Creek			82, 83		fed fry	649,459		649,459	
Dogfish Creek			83, 93	74	fed fry	312,906	250,400	563,306	Quilcene transferred in one year
Grovers Creek				76	fed fry		60,500	60,500	Quilcene transferred in one year
Keyport Lagoon			58	58, 64	fed fry	1,068,408	1,175,740	2,244,148	Quilcene, Samish - saltwater impondment culture
Kitsap Creek			92		fed fry	100,000		100,000	
Little Clam Bay				73	fed fry		1,690	1,690	Hood Canal
Unnamed (0325)			93		fed fry	500			
Sinclair Inlet		healthy							
Unnamed (0205)	not in SASSI		86,87		all unfed fry	483,182		483,182	Gorst Creek

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Gorst Creek	native/wild		84,85		62% unfed fry; 38% eggs	264,909		264,909	Gorst Creek
Blackjack Creek	native/wild		84	57	all unfed fry	24,310	50,000	74,310	non-local stock = Samish
Anderson Creek	native/wild		87		all unfed fry	54,317		54,317	Gorst Creek
Sinclair Inlet	native/wild	healthy							
Curley Creek				93	fed fry		1,800	1,800	Minter Creek
Northeast Hood Canal		healthy							
Anderson Creek	mixed/ composite		78-80,82,85-89, 91-93		71% unfed fry; 29% eggs	3,787,200		3,787,200	Egg box program using Hood Canal/George Adams/Chambers; discontinued
Hawk's Hole	not in SASSI			90,91	all eggs		134,500	134,500	Finch Creek+Cowling
Big Beef Creek	mixed/ composite		79,80,82	76-78,82,84	58% unfed fry; 42% eggs	336,592	4,437,499	4,774,091	unknown +BBC+HC
Johnson	not in SASSI			86	all eggs		457,500	457,500	Cowling Creek
Little Boston	not in SASSI		76		all unfed fry	1,025,981		1,025,981	Quilcene
Northeast Hood Canal	mixed/ composite	healthy							
Anderson Creek			70, 84, 86		fed fry	350,000		350,000	
Big Beef Creek			79-83	76, 78	fed fry	911,396	657,600	1,568,996	"unknown stock" assumed to be non-local
L Boston Creek	not in SASSI		76-78, 81-93		fed fry	11,697,143		11,697,143	Enetai/Quilcene stock established for Port Gamble tribal hatchery production
Port Gamble	not in SASSI		76-82, 84, 86, 88-90		fed fry	13,817,388		13,817,388	Enetai/Quilcene stock established for Port Gamble tribal hatchery production
Southeast Hood Canal		healthy							
Caldervin Creek	mixed/ composite		86,88,91-93		77% unfed fry; 23% eggs	2,174,600		2,174,600	Finch Creek
Chinom Creek	not in SASSI		92,93		all eggs	300,000		300,000	Finch Creek
Cortney Creek	not in SASSI		85-88		25.6% unfed fry; 74.4% eggs	1,335,300		1,335,300	Finch Creek/ Hood Canal

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Little Shoofly	not in SASSI			92	50% unfed fry; 50% eggs		500,000	500,000	George Adams
Stimson Creek	mixed/ composite		78-80,86-89,91-93	82	74.5% unfed fry	2,061,100	37,000	2,098,100	Garrison,Finch Creek
Tahuya River	mixed/ composite		78-80,82,84-86, 88,89,91-93	82	92.5% unfed fry; 7.5% eggs	11,515,154	906,000	12,421,154	Finch Creek,Allison; egg box program, terminated 1995.
Twanoh Creek	mixed/ composite		78-80,82,85-89, 91-93		54% unfed fry; 46% eggs	2,131,600		2,131,600	Hood Canal/ Finch Creek; egg box program.
Union River	mixed/ composite		78-80,87,89,91-93	57	74% unfed fry; 26% eggs	4,351,950	50,000	4,401,950	McKernan, Samish; egg box program, terminated 1995.
Southeast Hood Canal	mixed/ composite	healthy							Hood Canal hatchery complex-origin plants
Twanoh Creek			84		fed fry	147,000		147,000	
Caldervin Creek			79		fed fry	493,580		493,580	
Cortney Creek			84		fed fry	144,000		144,000	
Little Shoofly			70		fed fry	57,600		57,600	
Rendsland Creek			70		fed fry	100,000		100,000	
Shoofly Creek			70		fed fry	57,600		57,600	
Stimson Creek			84		fed fry	120,000		120,000	
Tahuya River			84, 93		fed fry	142,200		142,200	
Union River			89		fed fry	225,000		225,000	
Unnamed (0504)			88, 91, 93		fed fry	132,450		132,450	
Lower Skokomish River		unknown							
Skokomish River	mixed/ composite		73		all unfed fry	113,600		113,600	Hood Canal
Purdy Creek	mixed/ composite		62,82		all unfed fry	2,509,578		2,509,578	Hood Canal
Enetai Creek	not in SASSI		81		all unfed fry	311,549		311,549	Enetai
Lower Skokomish River	mixed/ composite	unknown							
Purdy Creek			79	78, 80-82, 85	fed fry	9,250	83,773	93,023	

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Enetai Creek			76-93		fed fry	35,680,397		35,680,397	Skokomish tribal hatchery - Walcott/Quilcene stock origin, considered local, as no wilds.
Purdy Creek			76, 79, 80, 82-86, 89-90, 91-93		fed fry	102,408,500		102,408,500	George Adams hatchery - Finch Ck stock origin, considered local.
Skokomish River			70		fed fry	216,000		216,000	
Weaver Creek			78-93		fed fry	141,308,972		141,308,972	McKernan hatchery - Finch Ck stock origin, considered local.
Upper Skokomish River		healthy							
Vance Creek	native/wild		71,72,87		53.2% unfed fry; 46.8% eggs	865,600		865,600	Hood Canal
N F Skokomish	native/wild		71		all unfed fry	112,000		112,000	Finch Creek
West Hood Canal		healthy							
Clark Creek	mixed/ composite		88		all eggs	250,000		250,000	Finch Creek
Eagle Creek	mixed/ composite		78-80,82,84-86, 89,91,93		89% unfed fry; 11% eggs	15,065,257	810,100	15,875,357	Minter Creek
Hood Canal			93		all eggs	125,000		125,000	Finch Creek
Finch Creek	not in SASSI		54,79,84		6% unfed fry; 94% eggs	2,018,700		2,018,700	McKernan
Jorstad Creek	mixed/ composite		88		82% unfed fry; 18% eggs	2,445,525		2,445,525	Finch Creek/ Hood Canal
L Lilliwaup/Lilliwaup	mixed/ composite		78-80,82,84-89, 91-93		67.8% unfed fry; 32.2% eggs	8,652,300		8,652,300	Finch Creek, egg box program, terminated 1995.
Sund Creek			87		all eggs	353,000		353,000	Finch Creek
Unnamed (0218)			87		all eggs	479,000		479,000	McKernan
West Hood Canal	mixed/ composite	healthy							
Eagle Creek			71, 73, 84		fed fry	1,040,590			
Hill Creek			70		fed fry	42,000			

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Finch Creek Hatchery -- Falls	not in SASSI		58, 60-62, 65-93		fed fry	276,785,611			Broodstock of Finch Creek native origin; all production considered local.
Finch Creek Hatchery -- Summers	not in SASSI			76	fed fry		563,287		Shelton Hatchery summers planted one year
Hamma Hamma River									
John Creek	native/wild	healthy	78,80,84-89,91-93	82	71.8% unfed fry; 28.2% eggs	10,363,333	504,500	10,867,833	Finch Creek, egg box program, terminated 1995.
Hamma Hamma River	native/wild	healthy							
John Creek			70	73	fed fry	100,000	297,500		Quilcene planted one year
Duckabush River		healthy							
Johnson Creek	native/wild		78-80,82,84-86, 89,91-93		86.5% unfed fry; 13.5% eggs	9,957,341		9,957,341	Finch/ Hood Canal
Fulton Creek	not in SASSI		78-80,82,84-89, 91-93		75.1% unfed fry; 24.9% eggs	9,150,816		9,150,816	Finch/ Hood Canal, egg box program, terminated 1995.
Unnamed (0370)			84		all eggs	100,000		100,000	Hood Canal
Duckabush River	native/wild	healthy							
Johnson Creek			84		fed fry	981,000			
McDonald Creek			70		fed fry	49,600			
Dosewallips River		healthy							
Unnamed (0504)	not in SASSI		91		all eggs	125,000		125,000	Finch Creek
Quilcene		healthy							
Tarboo Creek	mixed/ composite			91,92	50% eggs; 50% unfed fry		500,000	500,000	Finch Creek
Thorndyke Creek	mixed/ composite			87, 89, 91,92	32.1% unfed fry; 67.9% eggs		770,000	770,000	Finch Creek
Walcott Slough			82		all unfed fry	618,050		618,050	Quilcene
Quilcene	mixed/ composite	healthy							

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Walcott Slough			71, 75-84		fed fry	27,193,604			Native, late-timed fall broodstock
Big Quilcene River - QNFH			80-85, 87-93		fed fry	23,408,633			QNFH - Walcott stock transferred in; established and considered local
Little Quilcene				70, 74, 78	fed fry		1,161,354		Hood Canal, Quilcene NFH stocks outplanted three years.
Quilcene Bay			86		fed fry	2,503,091			
Tarboo Creek			73, 74		fed fry	463,900			
Thorndyke Creek			88		fed fry	125,000			
Chimacum Creek									
Ludlow Creek	not in SASSI			84,86-89	all eggs		16,105	16,105	Finch Creek fall chum
Chimacum Creek	not in SASSI			89	all eggs		16,105	16,105	Finch Creek fall chum
Jimmycomelately	not in SASSI			51	all unfed fry		129,500	129,500	Quilcene
Snow Creek	not in SASSI			69	all unfed fry		188,748	188,748	Hood Canal
Dungeness/Eastern Tributaries		unknown							
Dungeness River	native/wild			51	all unfed fry		1,099,855	1,099,855	Quilcene
Hurd Creek				69	all unfed fry		750,000	750,000	Hood Canal
Dungeness/Eastern Tributaries	native/wild	unknown							
Dungeness River			78		fed fry	600,000			
Hurd Creek			63		fed fry	66,848			
Chimacum Creek				84, 86, 88, 93	fed fry		23,200		George Adams
Ludlow Creek				85, 86	fed fry		30,000		Hood Canal, McKernan
Salmon Creek - summers		critical	92-95		fed fry	85,786			Wild stock supplementation program using native Salmon Creek summers.
Elwha River		unknown							
Elwha River	native/wild		80,81,83,85	76	all unfed fry	165,402	613,580	778,982	Plants of Quilcene chum did not impact native chum
Elwha River	native/wild	unknown							

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Elwha River			79-85	76- 81	fed fry	2,345,738	8,538,137		unknown, Enetai, Quilcene, Walcott
Port Angeles Harbor			83		fed fry	68			
Lyre River		unknown							
Lyre River	native/wild			69	all unfed fry		188,748	188,748	Hood Canal
Hoko/Clallum/Seiku		unknown							
Sail River	not in SASSI			79	all unfed fry		157,396	157,396	Quilcene
Hoko/Clallam/Seiku	native/wild	unknown							
Neah Bay				87	fed fry		59,738		Walcott Slough
Sail River				77, 78	fed fry		174,000		unknown
Sol Duc									
Beaver Creek	not in SASSI			63	unfed fry		25,050	25,050	unknown, likely Minter
Sol Duc	not in SASSI								
Beaver Creek				63	fed fry		50,344		Minter Creek
Sooes River		unknown							
Waatch Creek	not in SASSI			78	all unfed fry		40,000	40,000	unknown; native stock supplanted by Hood Canal stock
Sooes River	nonnative/ cultured	unknown							
Educket Creek				86, 87	fed fry		649,702		Walcott Slough
Sooes River			81-83, 85, 86, 89, 91-93	76-78, 82-84, 86	fed fry	3,346,498	8,793,122		
Waatch Creek			84	58, 78, 79, 81, 82	fed fry	435,073	2,859,444		unknown, Chambers Creek, Quilcene, Dungeness
Hoh River		unknown							
Hoh River	unknown			78	all unfed fry		308,000	308,000	unknown
Hoh River	native/wild	healthy							
Hoh River				77, 78	fed fry		185,000		unknown

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
Quilleyute River	native/wild	unknown							
Quilleyute River				79, 84, 85	fed fry		322,500		Finch Creek, Walcott Slough
Quinault River		healthy							
Lake Quinault	mixed/ composite		84	84, 85	all unfed fry	5,700	1,270,000	1,275,700	Elson Creek,Quinault stocks - native run may be hybridized
Quinault River	mixed/ composite	healthy							
Cook Creek			72, 77, 79-83-91, 93	71, 78	fed fry	21,743,786	4,057,840		National Fish Hatchery production
Lake Quinault			76-79, 81-87, 92, 93	84	fed fry	3,389,456	761,490		Elson Creek stock transferred in one year - poor survival
Quinault River			88-91		fed fry	531,122			
Ten o'Clock Creek			76, 78, 80	76, 77	fed fry	3,024,000	1,604,048		
Queets	unknown	unknown							
Phelan Creek				76	fed fry		990,000		Walcott Slough
Salmon River				77, 79	fed fry		1,577,500		Quinault, Walcott Slough
Raft River	not in SASSI								
Raft River				77	fed fry		676,000		Walcott Slough
Chehalis		healthy							Infrequent introductions unsuccessful
E F Hoquiam River	native/wild			78, 79	all unfed fry		1,487,445	1,487,445	Hood Canal
E F Satsop	native/wild		64,67,68,79	73	all unfed fry	1,527,775	932,059	2,459,834	Satsop, SatsopxHood Canal
M F Satsop	native/wild		61		all unfed fry	63,000		63,000	Simpson
Mill Creek	not in SASSI			76,79	all unfed fry		171,000	171,000	Hood Canal, unknown
Satsop Springs	not in SASSI		87		all eggs	296,000		296,000	Satsop Springs
Wishkah River	native/wild			78, 79	all unfed fry		1,936,634	1,936,634	Hood Canal
Chehalis	native/wild	healthy							
E F Hoquiam River				76-78	fed fry		687,200		unknown, Hood Canal, Satsop X Hood Canal
E F Satsop			74, 75, 78, 83, 84	78	fed fry	1,471,004	659,962		Nemah

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years) Local	# Released (All Years) Non-Local	Total	Broodstock source/Comments
M F Satsop			59, 60		fed fry	1,958,800			
Satsop Springs			76, 77, 80, 82, 85, 86	81, 82	fed fry	4,127,790	2,720,944		Nemah, Satsop X Hood Canal
Satsop River				57, 58, 62, 63	fed fry		1,590,959		Simpson
Wishkah River			80, 92, 93		fed fry	386,000			
North River		healthy							
Beaver Creek	not in SASSI			63	all unfed fry		25,050	25,050	unknown
North River	native/wild	healthy							
North River				90-92	fed fry		992,000		Nemah
Willapa Bay		healthy							
Electric Light	not in SASSI			90	all unfed fry		30,000	30,000	Nemah
Elk Creek	not in SASSI			90, 91	13% unfed fry; 87% eggs		467,000	467,000	Nemah
Fork Creek	not in SASSI		58,59	68	all unfed fry	3,950	25,344	29,294	Nemah,ancient wild stocks
S F Willapa	native/wild			86	all eggs		100,000	100,000	Nemah
Skidmore Slough	not in SASSI			86	all eggs		100,000	100,000	Nemah
Ward Creek	not in SASSI			90	all unfed fry		60,000	60,000	Nemah
Willapa River	native/wild			86,88, 90	5% unfed fry; 95% eggs		315,000	315,000	Nemah,Naselle
Rue Creek/ WF Rue Creek	not in SASSI			85,86	all eggs		2,160,440	2,160,440	Nemah, Ellsworth
Unnamed (0272)	not in SASSI			90	unfed fry		20,000	20,000	
Unnamed (0299)	not in SASSI			90	unfed fry		15,000	15,000	
Unnamed (0431)	not in SASSI			86	eggs		100,000	100,000	
Unnamed(0554)	not in SASSI			82	unfed fry		413,670	413,670	
Unnamed(0250)	not in SASSI			90	unfed fry		20,000	20,000	Nemah
Willapa Bay	native/wild	healthy							
Johnson Slough			60	72, 73	fed fry	47,586	310,000		
Skidmore Slough				90	fed fry		25,000		Nemah
Trap Creek			61		fed fry	90,852			
Willapa River			60	57, 90	fed fry	106,260	780,975		Nemah
Humptulips	native/wild	healthy							
Stevens Creek			76, 78-85	77, 78, 82	fed fry	7,706,547	4,164,666		Hood Canal, Nemah

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Palix River		healthy							
Niawiakum River				86, 90	23% unfed fry; 77% eggs		130,000	130,000	Nemah
Palix River	native/wild			90	all unfed fry		100,000	100,000	Nemah
Palix River	native/wild	healthy							
Canyon Creek				72	fed fry		31,050		Nemah
Fork Creek			61		fed fry	49,268			ancient wild stocks
Nemah River		healthy							No genetic influence from imported stocks
M Nemah River	native/wild		82,86	79,81,83-85	43.9% unfed fry; 56.1% eggs	844,000	1,297,700	2,141,700	Hood Canal,Ellsworth
N Nemah	native/wild		72,90,92		11% unfed fry; 89% eggs	393,520		393,520	Nemah
S Nemah River	native/wild		90		all eggs	500,000		500,000	Nemah
Williams Creek	native/wild		79,90		72% eggs; 28% unfed fry		125,600	175,600	Nemah+Williams creek; egg box program
Nemah River	native/wild	healthy							
M Nemah River			64, 65, 69		fed fry	2,722,405			
N Nemah			57-63, 66-68, 70-88, 93	60	fed fry	39,022,660	575,280		unknown
S Nemah River			93		fed fry	176,256			
Williams Creek			60, 61		fed fry	1,482,880			
Naselle River		healthy							native characteristics not influenced
Dell Creek	mixed/wild		81	77,79	all unfed fry	202,000	835,000	1,037,000	unknown, Hood Canal, Elsworth
Ellsworth Creek	mixed/wild		76,79,81,83-86	76,79	51.5% unfed fry; 49.5% eggs	1,932,317	775,000	2,707,317	Ellsworth Creek, Hood Canal; egg box program
Johnson Creek	mixed/wild			85	all eggs		840,000	840,000	Nemah
Naselle River	mixed/wild		85	85	all unfed fry	58,800	98,000	156,800	Naselle, Nemah River
Russian Creek	mixed/wild		86	84,85	86.5% eggs, 13.5% unfed fry	855,000	1,000,000	1,855,000	Nemah,Willapa, Ellsworth
Naselle River	mixed/wild	healthy							

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Dell Creek				78	fed fry		450,000		Nemah
Ellsworth Creek			78	77, 78	fed fry	420,000	1,780,000		unknown, Nemah
Naselle River			81, 83-86, 88	79, 80, 82-86	fed fry	10,059,532	14,279,383		Nemah, Nemah X Willilams, Williams Creek
Bear River		healthy							
Bear River	native/wild			76, 77	all unfed fry		900,000	900,000	unknown
Spyder Creek	native/wild		79,80	78	all unfed fry	569,833	38,300	608,133	Bear River,unknown
Grays River		depressed							
Hull Creek	native/wild			77-79	all unfed fry		192,000	192,000	Finch creek + unknown non-local stock plants have failed.
Grays River	native/wild	healthy							
Grays River			62-69	71	fed fry	1,218,705	638,493		Hood Canal
W F Grays River			73	72, 73, 75	fed fry	14,947	2,302,668		Hokkaido, Quilcene
Hamilton Creek		depressed							
Hamilton Sps	native/wild			79	all unfed fry		360,000	360,000	Plants of Quilcene stock failed.
Lower Columbia River									
Abernathy Creek	not in SASSI			84	12.6% eggs; 87.4% unfed fry		715,500	715,500	Hood Canal + Ellsworth
Clear Creek	not in SASSI			77	all unfed fry		50,000	50,000	Finch Creek
Chinook River	not in SASSI			84	all unfed fry	10,322		10,322	Chinook River
Elochoman River	not in SASSI			78,79	all unfed fry		851,000	851,000	Hood Canal
Crippen Creek	not in SASSI			77-79,82	all unfed fry		302,000	302,000	Finch creekX willapa
Germany Creek	not in SASSI			81,82	all unfed fry		125,000	125,000	Hood Canal X Ellsworth
Little Creek	not in SASSI			80	all unfed fry		69,691	69,691	Finch Creek
Skamokawa Creek	not in SASSI			80-82	all unfed fry		178,304	178,304	Hood Canal,Ellsworth
Lower Columbia River	not in SASSI								
Abernathy Creek			90		fed fry	157,798			

SASSI Stock	SASSI Designation	SASSI Status	Years Planted with Local Stocks	Years Planted with Non-Local Stocks	Life Stage @ Planting	# Released (All Years)		Total	Broodstock source/Comments
						Local	Non-Local		
Chinook River	not in SASSI		72, 79-85, 87-93	69, 71-73, 77, 78, 85, 86	fed fry	2,645,249	953,806		Naselle, Nemah, Bear River, unknown