NOAA Technical Memorandum NMFS-NWFSC-33

Status Review of Sockeye Salmon from Washington and Oregon

December 1997

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS Series

This document should be cited as follows:

Gustafson, R.G., T.C. Wainwright, G.A. Winans, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1997. Status review of sockeye salmon from Washington and Oregon. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-33, 282 p.

NOAA Technical Memorandum NMFS-NWFSC-33

Status Review of Sockeye Salmon from Washington and Oregon

Richard G. Gustafson, Thomas C. Wainwright,
Gary A. Winans, F. William Waknitz,
L. Ted Parker, and Robin S. Waples

National Marine Fisheries Service
Northwest Fisheries Science Center
Conservation Biology Division
2725 Montlake Blvd. E., Seattle, WA 98112-2097

December 1997

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Administrator

National Marine Fisheries Service
Rolland A. Schmitten, Assistant Administrator for Fisheries

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

Copies are also available from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone orders (1-800-553-6847)
e-mail orders (orders@ntis.fedworld.gov)

CONTENTS

EXECUTIVE SUMMARY

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

In September 1994, in response to a petition seeking protection for Baker Lake (Washington) sockeye salmon under the ESA, NMFS initiated a coastwide status review of sockeye salmon (*Oncorhynchus nerka*) (Walbaum, 1792) in Washington, Oregon, and California, and formed a Biological Review Team (BRT) to conduct the review. This report summarizes biological and environmental information gathered in that process.

West Coast Sockeye Salmon ESUs

The BRT examined genetic, life history, biogeographic, geologic, and environmental information in the process of identifying ESUs. In particular, genetic data; physical, chemical, and biological characteristics of nursery lakes; sockeye salmon river entry and spawn timing; and smolt outmigration timing were found to be most informative for this process. Based on this examination, the BRT identified six sockeye salmon ESUs and one provisional ESU in Washington, as follows:

1) Okanogan River

This ESU is named after the Okanogan River in the Columbia River drainage of Washington and includes all sockeye salmon that spawn in areas upstream from Lake Osoyoos, in Lake Osoyoos, or the downstream tributary Similkameen River (below Enloe Dam). The spawning and main rearing area for this ESU is in British Columbia, while the migration corridor for both juveniles and adults is through the Columbia River in Washington and Oregon. Important factors that differentiate this population as a separate ESU include: 1) the use of a very eutrophic lake-rearing environment (Lake Osoyoos), which is unusual for sockeye salmon, 2) the tendency for a relatively large percentage of the Okanogan River sockeye salmon population to return as 3-year-olds (age 1.1), 3) the juvenile outmigration-timing differences between Okanogan River and Lake Wenatchee-origin fish, 4) the adaptation of Okanogan River sockeye salmon to much higher temperatures during adult migration in the Okanogan River, and 5) protein electrophoretic data that indicate that this population is genetically distinct from other sockeye salmon currently in the Columbia River drainage. If “kokanee-sized” *O. nerka* observed spawning with sockeye salmon in the Okanogan River are identified as residual or resident sockeye salmon, then they are to be considered as part of the Okanogan River sockeye salmon ESU.

2) Lake Wenatchee

This ESU is named after Lake Wenatchee on the Wenatchee River in the Columbia River drainage of Washington and includes all sockeye salmon that spawn above or in Lake Wenatchee and rear in Lake Wenatchee. Important factors that distinguish this ESU include electrophoretic data that indicate this population is genetically the second most distinctive population (after Redfish Lake, ID) within the contiguous United States, and life history and environmental differences with sockeye salmon from the Okanogan River ESU (juvenile outmigration timing, environmental differences in lake-rearing habitat, and age composition). If “kokanee-sized” *O. nerka* observed spawning with sockeye salmon in Lake Wenatchee tributaries are identified as residual or resident sockeye salmon, then they are to be considered as part of the Lake Wenatchee sockeye salmon ESU.

3) Quinault Lake

This ESU is named after Quinault Lake on the Olympic Peninsula of Washington and includes all sockeye salmon that spawn in the Quinault River drainage and rear in Quinault Lake. Early river-entry timing, protracted adult run timing, extended lake residence prior to spawning, unusually lengthy spawn timing, unusual skin pigmentation of spawners, and genetic differences from other coastal Washington sockeye salmon are important factors in identifying this ESU.

4) Ozette Lake

This ESU is named after Ozette Lake on the Olympic Peninsula of Washington and includes all sockeye salmon that spawn in the Ozette River drainage and rear in Ozette Lake. Important factors that distinguish this ESU include electrophoretic data that indicate this population is genetically distinct from all other sockeye salmon stocks in the Northwest, early river-entry timing, and the relatively large adult body size and large average smolt size of sockeye salmon in Ozette Lake compared to other coastal Washington sockeye salmon populations. If “kokanee-sized” *O. nerka* observed spawning with sockeye salmon in Ozette Lake are identified as residual or resident sockeye salmon, then they are to be considered as part of the Ozette Lake sockeye salmon ESU.

5) Baker River

This ESU is named after the Baker River in the Skagit River drainage in northern Puget Sound, Washington and includes sockeye salmon that return to the Baker River. Important factors that distinguish this ESU include electrophoretic data that indicate that Baker River sockeye salmon are genetically distinct from sockeye salmon populations from the lower Fraser River and from other localities in Washington, the limnology of old Baker Lake (typically cold, oligotrophic, well-oxygenated, and influenced by glacial runoff, in contrast to other sockeye salmon systems under review with the exception of Lake Wenatchee), and the very large average smolt size of sockeye salmon in Baker Lake compared to other Washington sockeye salmon populations.

6) Lake Pleasant

This ESU is named after Lake Pleasant on the Olympic Peninsula of Washington and includes sockeye salmon that ascend the Quillayute and Sol Duc Rivers and Lake Creek to spawn in Lake Pleasant. Important factors that differentiate this population as a separate ESU include: 1) protein electrophoretic data that indicate that this population is genetically distinct from other Washington sockeye salmon populations, 2) the distinctive small body size of adult spawners, and 3) the unusual age structure of the population, with significant numbers of juveniles remaining for 2 years in freshwater and/or spending only 1 year at sea. If “kokanee-sized” *O. nerka* observed spawning with sockeye salmon in Lake Pleasant are identified as residual or resident sockeye salmon, then they are to be considered as part of the Lake Pleasant sockeye salmon ESU.

Big Bear Creek

The Big Bear Creek provisional ESU is named after a tributary of the Sammamish River in the Lake Washington/Lake Sammamish Basin and includes sockeye salmon that spawn in Big Bear Creek and its two tributaries, Cottage Lake Creek and Evans Creek. Genetically, sockeye salmon from Big Bear and Cottage Lake Creeks are distinct from other stocks of sockeye salmon in the Lake Washington/Lake Sammamish drainage. A great deal of uncertainty remains concerning the historical presence of sockeye salmon within the Lake Washington/Lake Sammamish drainage prior to sockeye salmon transplants, which occurred in the 1930s-1950s. The relationship of this stock to native and transplanted kokanee is also uncertain, although genetically it is unlike the current parent stock from which these kokanee transplants originated (Lake Whatcom). If “kokanee-sized” *O. nerka* observed spawning with sockeye salmon in Big Bear Creek are identified as residual or resident sockeye salmon they are to be considered as part of the provisional Big Bear Creek sockeye salmon ESU.

Other Population Units

Historical records, stocking history, and genetic data indicate that sockeye salmon that spawn in the Cedar River, Issaquah Creek, and on lakeshore beaches in Lake Washington in the Lake Washington Basin and in the Methow and Entiat Rivers in the Columbia River Basin originated from transplants from outside these basins. Therefore, the BRT concluded that these populations are not presently considered as ESUs or as part of any other ESUs and are therefore not an ESA issue. The ESU status of two other population units could not be determined due to a lack of biological and historical information. These units are classified as follows:

1) Riverine-spawning sockeye salmon

This population unit consists of multiple aggregations of small numbers of sockeye salmon that spawn in Washington rivers without lake-rearing habitat. Although genetic data were available for riverine spawners in the Nooksack, Skagit, and Sauk Rivers, the data were insufficient to eliminate the possibility that these sockeye salmon may be derived from recent or historical straying of British Columbia lake-type or sea/river-type sockeye salmon. Genetic data were unavailable for riverine spawners in other Washington rivers on the west side of the Cascade Mountains. The BRT concluded that insufficient information exists concerning riverine-spawning sockeye salmon to make a decision as to this group's ESU status.

2) Deschutes River, Oregon

This population unit consists of sockeye salmon that are observed at the base of Pelton Re-regulating Dam on Oregon's Deschutes River, a tributary of the lower Columbia River. The BRT concluded that sockeye salmon that historically migrated up the Deschutes River via the Columbia River to spawn in Suttle Lake were a separate ESU, but due to lack of genetic and life-history information, it is uncertain whether remnants of this ESU exist.

Assessment of Extinction Risk

The ESA (section 3) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the ESA, the determination 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, the BRT did not evaluate likely or possible effects of conservation measures, and therefore did not make recommendations as to whether identified ESUs should be listed as threatened or endangered species; rather, the BRT drew scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue.

The BRT concluded that five sockeye salmon ESUs (Okanogan River, Lake Wenatchee, Quinault Lake, Baker River, Lake Pleasant) and one provisional ESU (Big Bear Creek) are not in danger of extinction, nor are they likely to become so in the foreseeable future. The BRT also concluded that one sockeye salmon ESU (Ozette Lake), although not presently in danger of extinction, is likely to become so if present conditions continue into the foreseeable future. Information used by the BRT in coming to these conclusions follow for each ESU.

1) Okanogan River

Major concerns regarding health of this ESU were the channelization of spawning habitat in Canada, the summer high water-temperatures that periodically block migration in the lower Okanogan River, and effects of hydropower development in the Columbia River. The run-size for this ESU has been highly variable over time, with recent 5-year average annual escapement at about 11,000. Recent (1986-1995) abundance, as demonstrated by the abundance trend, has declined at about 2-20% per year. This is heavily influenced by high abundance in 1985 and low abundance in 1990, 1994, and 1995. Although the BRT concluded that sockeye salmon in this ESU are not in danger of extinction, nor are they likely to become so in the foreseeable future, they had several concerns about the overall health of this ESU and they concluded that the status of this ESU bears close monitoring.

2) Lake Wenatchee

There was unanimous agreement among the BRT that sockeye salmon in this ESU are not in danger of extinction and are not likely to become endangered in the foreseeable future if present trends continue. Despite this conclusion, the BRT had concerns about the overall health of this ESU, including the effects of hydropower development in the Columbia River and the effects of hatchery production and potential interbreeding with non-native kokanee on genetic integrity of the unit. Although production is apparently limited by the oligotrophic conditions in Lake Wenatchee, habitat conditions are generally considered good in this basin. The recent 5-year average annual escapement for this ESU was about 19,000 adult sockeye salmon, and recent (1986-1995) abundance has been declining by about 10% per year, with years of very low abundance in 1994 and 1995. The long-term (1961-1996) abundance trend for this ESU is flat.

3) Quinault Lake

The BRT concluded that sockeye salmon in this ESU are not in danger of extinction, nor are they likely to become endangered in the future if present trends continue. Despite this conclusion, the BRT was concerned that this ESU is presently near the lower end of its historical abundance range. This condition may be largely attributed to severe habitat degradation in the upper Quinault River that contributes to poor spawning habitat quality and possibly impacts juvenile rearing conditions in Quinault Lake. Recent (1991-1995) 5-year average annual escapement was about 32,000 sockeye salmon for this ESU. While abundance data from 1967-1995 show an increase of about 1% per year, the period from 1986-1995 shows a decrease in abundance of about 3% per year. Recent escapement is probably near the low end of historical abundance for this ESU; historical escapement estimates ranged from 20,000 to 250,000 in the 1920s, while run sizes in the early 1900s ranged from 50,000 to 500,000.

4) Ozette Lake

Major concerns that led the BRT to conclude that if present conditions continue into the future, Ozette Lake sockeye salmon are likely to become in danger of extinction in the foreseeable future include: siltation of beach spawning habitat, very low abundance compared to harvest in the 1950s, overall downward trend in abundance coupled with large fluctuations in abundance, and potential genetic effects of ongoing hatchery production and past practices of sockeye salmon being interbred with genetically dissimilar kokanee. Current escapements average below 1,000 adults per year, with little room for further declines before abundances would be critically low. The most recent (1992-1996) 5-year average annual escapement (based on weir counts) for this ESU was 700 adults, while historical run-size estimates range from a few thousand sockeye salmon in the mid-1920s to a peak recorded harvest of about 18,000 in the late 1940s. Abundance decreased by about 3% per year from 1977-1995 and by about 10% per year between 1986-1995.

5) Baker River

Despite the BRT's conclusion that the Baker River sockeye salmon ESU is not presently in danger of extinction, nor likely to become so in the foreseeable future, the BRT had several concerns about the overall health of this ESU that indicate that the ESU bears close monitoring. It is likely that this stock would become extinct if present human intervention (trap, haul, and spawning beach activities) were suspended. In addition, the BRT felt this ESU bears close monitoring due to proposed changes in management (confining spawners to a single artificial spawning beach) that could substantially increase risk to the population. Recent (1990-1994) average annual escapement for this ESU was about 2,700 adult sockeye salmon compared to historical pre-dam estimates of escapement averaging 20,000 fish near the turn of the century; however, other data indicates that this 20,000 figure is a peak value and that the average may have been substantially less than 20,000. Although sockeye salmon escapement in 1994 (about 16,000) was near the historic pre-dam maximum, recent average abundance is probably near the lower end of the historical abundance range for this ESU. Although stock abundance has fluctuated considerably over time, long-term abundance (1926-1995) has decreased by about 2% per year, while recent abundance (1986-1995) has increased at about 32% per year.

6) Lake Pleasant

At the time the BRT met, little information was available concerning recent escapement levels, and the majority of the BRT felt that there was insufficient information to adequately assess extinction risk for the Lake Pleasant ESU. However, a minority concluded that the ESU is not presently in danger of extinction nor likely to become so in the foreseeable future. Spawning ground peak counts from the late 1980s (and data received for the 1990s, subsequent to the BRT meeting) appear roughly comparable to habitat capacity for this small lake. Weir counts in the early 1960s ranged from 763 to 1,485 fish. Recently received spawner survey data (unavailable at the time of the BRT meeting) for the years 1987 to 1996 ranged from highs above 2,000 in 1987 and 1992 to a low of 90 in 1991 (a year with limited sampling). The BRT expressed concerns regarding potential urbanization of habitat and effects of sport harvest during the migration delay in the Sol Duc River.

Big Bear Creek

Relatively high recent average escapement levels between 10,000 and 20,000 spawners led a majority of the BRT to conclude that the Big Bear Creek sockeye salmon provisional ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future if present conditions continue. A minority of the BRT felt that information was insufficient to adequately assess extinction risk in this ESU. However, several factors led to a second minority opinion that this provisional ESU is likely to become endangered in the foreseeable future. These factors included extreme fluctuations in recent abundances and potential effects of urbanization in the watershed. Recent development of a county growth-management plan was seen by the BRT as a possible benefit to freshwater habitat for this population. The BRT felt that the status of this population bears close monitoring. Recent escapements have ranged from a high of 39,700 in 1994 to a low of 1,800 in 1989. The most recent (1991-1995) 5-year average annual escapement for this provisional ESU was 11,400 adults. Abundance decreased by about 7% per year from 1982-1995 and by about 4% per year between 1986-1995.

Consideration was also given to the condition of the two population units for which ESU status has not been determined. There was insufficient information available to assess the risk of extinction for riverine-spawning sockeye salmon. The BRT concluded that the final population unit (Deschutes River, Oregon sockeye salmon) is clearly in danger of extinction if not already extinct.

ACKNOWLEDGMENTS

The status review for west coast sockeye salmon was conducted by a team of researchers from the National Marine Fisheries Service’s (NMFS) Northwest Fisheries Science Center (NWFSC). This biological review team (BRT; technical terms and abbreviations such as “BRT” are defined in Appendix A) relied on the West Coast Sockeye Salmon Administrative Record, which was developed pursuant to this review and is comprised of comments and informational reports submitted by the public and by state, tribal, and federal agencies. The authors acknowledge the efforts of all who contributed to this record, especially the Washington Department of Fish and Wildlife, the Northwest Indian Fisheries Commission, the Quinault Indian Nation, the Makah Tribe, the Quileute Indian Tribe, Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service, and Olympic National Park.

Numerous fishery scientists and managers provided information that aided in preparation of this document and deserve special thanks. These include Jim Ames, Don Hendrick, Larrie LaVoy, Dr. James Shaklee, John Sneva, Gary Sprague, and Sewall Young of the Washington Department of Fish and Wildlife; Dr. Chris Wood and Dr. Kim Hyatt of the Canadian Department of Fisheries and Oceans; Kevin Craig, Dr. Chris Foote, Andrew Hendry, and Dr. Tom Quinn of the University of Washington; Dr. Ernest L. Brannon of the University of Idaho; Dr. Jeffrey K. Freyer of the Columbia River Inter-tribal Fish Commission; Gary Graves and Keith Lutz of the Northwest Indian Fisheries Commission; Eric Warner of the Muckleshoot Indian Tribe, Fisheries Department; Del Boyer Jr. and Scott Chitwood of the Quinault Fisheries Division; Jeff Haymes of Quileute Natural Resources; Ned Currence and Denise Dailey of Makah Fisheries Management; and Kathryn Kostow and John Leppink of Oregon Department of Fish and Wildlife.

The biological review team for this status review included: Thomas Flagg, Dr. Stephen Grabowski, Dr. Richard Gustafson, Dr. Robert Iwamoto, Dr. Conrad Mahnken, Gene Matthews, Dr. Michael Schiewe, Dr. Thomas Wainwright, Dr. Robin Waples, Laurie Weitkamp, Dr. John Williams, and Dr. Gary Winans, all from the NWFSC.

INTRODUCTION

Sockeye salmon, *Oncorhynchus nerka* (Walbaum, 1792) (locally called blueback salmon in the Columbia and Quinault Rivers, red salmon in Alaska, krasnaya ryba or nerka in Russia, and benimasu or benizake in Japan), occur in North America around the Pacific Rim from the Columbia River in the south to the Nome River (and perhaps the Noatak River), Alaska in the north. In Asia, this species ranges from Hokkaido, Japan, the Kuril and Komandorskiy Islands, and the northwest coast of the Sea of Okhotsk in the south to the Anadyr River in the north (Atkinson et al. 1967, Foerster 1968, Burgner 1991, Forrester 1987). Recent publications (Konkel and McIntyre 1987, Nehlsen et al. 1991, Wilderness Society 1993) reported that a number of local populations of sockeye salmon in Washington, Idaho, and Oregon have become extinct, and the abundance of many others is depressed. The U.S. Endangered Species Act (ESA) is intended to conserve threatened and endangered species in their native habitats. Under the ESA, the term “species” is defined rather broadly to include subspecies as “distinct population segments” of vertebrates (such as salmon) as well as taxonomic species.

On 14 March 1994, the National Marine Fisheries Service (NMFS) was petitioned by the Professional Resources Organization-Salmon (PRO-Salmon) to list Baker River sockeye salmon as a threatened or endangered species under the ESA (PRO-Salmon 1994). At about the same time, NMFS also received petitions for numerous other populations of Pacific salmon in the Puget Sound area. In response to these petitions, and to the more general concerns for 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 include 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 through a long series of reviews of individual populations.

Scope and Intent of the Present Document

This document reports results of the comprehensive ESA status review of sockeye salmon from Washington and Oregon (Fig. 1). Presently, there are no known sockeye salmon populations in California, and a previous review (Waples et al. 1991) considered the ESA status of sockeye salmon from Idaho. To provide a context for evaluating U.S. populations of sockeye salmon, biological and ecological information for populations of sockeye salmon in British Columbia was also considered (Fig. 2, Table 1). This review thus encompasses, but is not restricted to, the single population identified in the PRO-Salmon petition.

Because the ESA stipulates that listing determinations should be made on the basis of the best scientific information available, NMFS formed a team of scientists with diverse

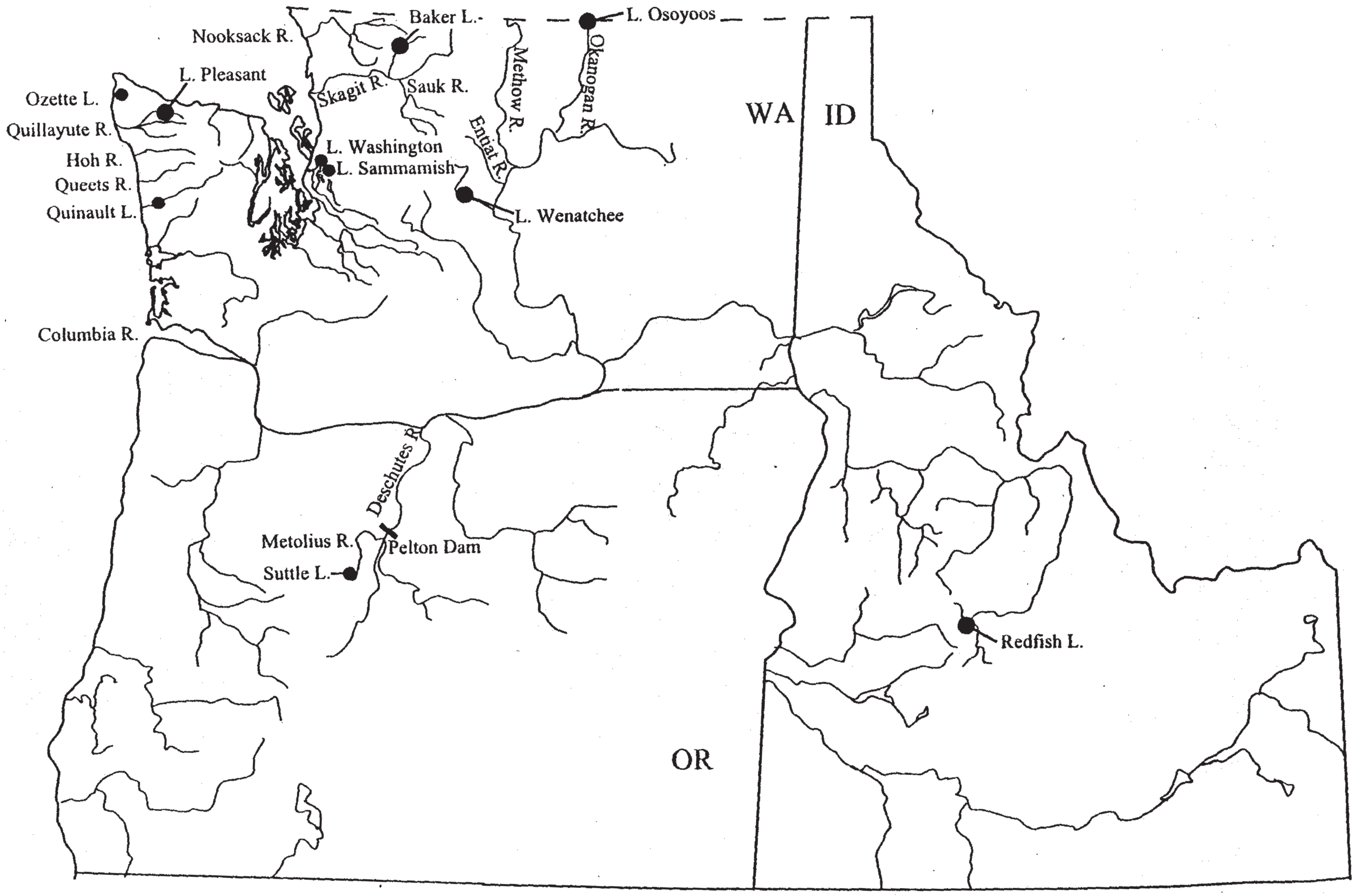


Figure 1. Locations of sockeye salmon nursery lakes and major river basins considered in this status review.

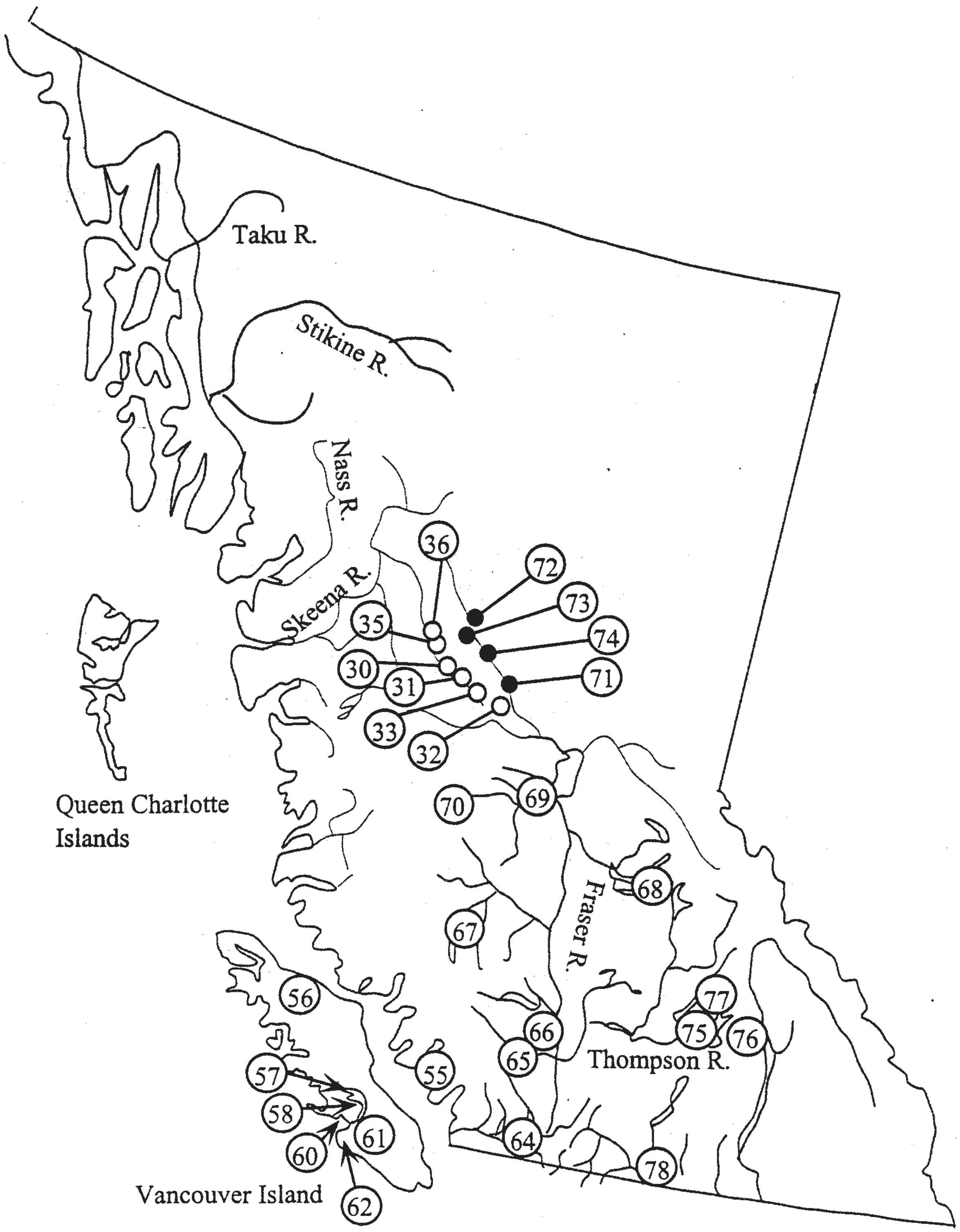


Figure 2. Location of sockeye salmon populations and major river basins in British Columbia considered in this status review. Site numbers correspond to locations listed in Table 1. Solid markers indicate sites on the Fraser River, hollow markers indicate sites on the Skeena River.

Table 1. Selected sockeye salmon nursery lakes and associated inlet streams in British Columbia. Locations correspond to site numbers in Figures 2, 10, and 12. Site numbers are identical to those used for collection sites in Wood et al. (1994).

River system	Major drainage	Lake or inlet stream	Site number
Skeena River	Babine River	Babine Lake	
		Pierre Creek	30
		Twain Creek	31
		Four Mile Creek	32
		Pinkut River	33
		Morrison River	35
		Tahlo Creek	36
Coastal B.C.	South mainland	Sakinaw Lake	55
	Vancouver Island	Woss Lake	56
		Great Central Lake	57
		Sproat Lake	58
		Kennedy Lake	60
		Hobiton Lake	61
		Cheewhat Lake	62
Fraser River	Lower Fraser River	Weaver Channel	64
		Birkenhead River	65
	Upper Fraser River	Gates Channel	66
		Chilko Lake	67
		Horsefly River	68
		Stellako River	69
		Nadina Channel	70
		Gluskie Creek/Takla Lake	71
		Dust Creek/Takla Lake	72
		Shale Creek/Takla Lake	73
		Narrows Creek/Takla Lake	74
	Thompson River	Lower Shuswap	
		Adams River	75
		Shuswap River	76
		Sinmax Creek/Adams Lake	77
Columbia River	Okanogan River	Okanogan River (Wells Dam)	78

backgrounds in salmon biology to conduct this review. This Biological Review Team (BRT)[1] discussed and evaluated scientific information presented at public meetings and also reviewed information submitted to the ESA administrative record for west coast sockeye salmon.

Key Questions in ESA Evaluations

An ESA status review involves answering two key questions: 1) Is the entity in question a "species" as defined by the ESA? and 2) If so, is the "species" in danger of extinction or likely to become so? These two questions are addressed in separate sections in the text that follows. 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) over-utilization 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.

The "Species" Question

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

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

---

[1] A list of the Biological Review Team members for west coast sockeye salmon is included in the acknowledgements section.

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

The key question with respect to the second 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 analysis 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.

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 in relation to historical abundance and carrying capacity of the habitat; 3) trends in abundance, based on indices such as dam or redd counts or on estimates of spawner-recruit ratios; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., selective fisheries and interactions between hatchery and natural fish); and 6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the ESU. Additional risk factors, such as disease prevalence or changes in life history traits, may also be considered in evaluating risk to populations.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. In this review, we 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 Office in making listing recommendations.

Artificial Propagation

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

Nevertheless, artificial propagation is important to consider in ESA evaluations of anadromous Pacific salmonids for several reasons. First, although natural fish are the focus of ESU determinations, possible effects of artificial propagation on natural populations must also be evaluated. For example, stock transfers might change the genetic 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 size 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 the "Assessment of Extinction Risk" section. 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 in this document.

Summary of Information Presented by the Petitioners

The single sockeye salmon population petitioned by PRO-Salmon (1994), Baker River, was characterized as "critical" by WDF et al. (1993). With respect to the two criteria established by NMFS to define a "species" of sockeye salmon in the context of the ESA, the petitioner argued that the Baker River population of sockeye salmon is the only significant remaining population of sockeye salmon in Puget Sound, with the exception of Lake Washington/Lake Sammamish populations. The petitioners argued that Lake Washington/ Lake Sammamish populations originated from transplants of Baker River stock. Reproductive isolation was inferred primarily on the basis of geographic separation from other sockeye salmon populations. Other observations of sockeye salmon spawning in the Skagit River drainage were postulated to represent Baker River strays or perhaps small river-type populations. The Washington State Salmon and Steelhead Stock Inventory (SASSI) cited NMFS unpublished genetic data, which is based on protein electrophoresis, and which shows that the Baker River stock is significantly different from all other Washington sockeye salmon stocks (WDF et al. 1993). In its petition, PRO-Salmon provided little information that addresses the criterion of "evolutionary significance." The petitioner argued that since there are few records of introductions of sockeye salmon into this population, and it is separated geographically from other populations, it should be considered an ESU.

The petitioner identified several threats to viability of Baker River sockeye salmon. Access to native spawning habitat is obstructed by two dams, Lower and Upper Baker Dams. Beginning in 1924, adult sockeye salmon returning to the Baker River were trapped and lifted over Lower Baker Dam and released in Lake Shannon to continue their migration to Baker Lake. Native beach-spawning habitat in Baker Lake was eliminated when Upper Baker Dam was constructed in 1959, inundating the original Baker Lake and forming Upper Baker Reservoir, which continues to be called Baker Lake. Since 1958, most adult sockeye salmon returning to the Baker River have been trapped at the barrier dam and fish trap below Lower Baker Dam and hauled by tanker truck to one of several artificial spawning beaches (ponds designed to simulate natural beach spawning habitat).

Major concerns of the petitioners included: 1) Puget Sound Power and Light Company's plans to curtail operation of artificial spawning beaches 2 and 3 and confine sockeye salmon spawning to a single beach (beach 4), 2) the potential for recurrence of the intrusion of silt and sand into the intake water source for spawning beach 4, which has caused siltation of spawning gravels, and 3) the potential for recurrence of the disease, infectious hematopoietic necrosis (IHN), in sockeye salmon confined to spawning beach 4. The water intake on Sulfur Creek for artificial spawning beach 4 is located at the base of a steep, unstable slope, and the petitioners were concerned that intrusion of fine sand present at the intake could trigger the turbidity meter (installed following intrusion of sand and mud into beach 4 in 1990-1991) to cut off the supply of fresh water to the spawning gravel. The petitioners were most concerned that a system to recirculate the water within spawning beach 4, in the event of an intake water shutdown, has not been installed.

The petitioners pointed out that mixed stock fisheries targeting early Fraser River stocks may harvest some Baker River sockeye salmon. The petitioners also suggested that juvenile sockeye salmon are likely taken in the spring recreational kokanee fishery that operates in this reservoir, since the range of fork lengths of 1-year-old sockeye salmon smolts in Baker Lake (up to 200 mm, average of 149 mm) overlaps the minimum retention size (152 mm) for kokanee. Two-year-old sockeye salmon smolts, though rare in Baker Lake, are all longer than 200 mm. In addition, the petitioners pointed out that in years when shore and lower tributary spawning of wild sockeye salmon is allowed to occur in Baker Lake (extensive wild spawning occurred in 1994), the late-fall and winter reservoir drawdowns leave many sockeye salmon redds dewatered (PRO-Salmon 1994).

INFORMATION RELATING TO THE SPECIES QUESTION

Environmental Features[2]

Spawning populations of west coast sockeye salmon that are the focus of this review are presently distributed over the northwest region of the contiguous United States, from the Washington-British Columbia border (49°N) south to the Deschutes River (44°N) in Oregon's interior. Climate and geological features vary markedly over this region, with diverse patterns of vegetation, weather, soils, land use, and water quality. This section summarizes environmental and biological information that may be relevant to determining the nature and extent of ESUs for sockeye salmon in Washington and Oregon.

Physical Features of the Freshwater Environment

The following discussion includes climate data from USDOC (1968) and Farley (1979), calculations of river flow patterns using U.S. Geological Survey (USGS) data from Hydrosphere Data Products, Inc. (1993), and information from Forstall (1969). Because some populations of sockeye salmon spawn and undergo early development in small tributaries, egg-alevin survival and, to a lesser degree, river- and lake-entry timing and spawn timing are sensitive to patterns in river flow. In this respect, river flow patterns and seasonal water temperature help define both early survival success and the temporal availability of access to lake habitat for these populations. Water temperatures in all regions of Washington and Oregon are generally highest in July and August (Hydrosphere Data Products, Inc., 1993). Run-timing and spawn-timing are sensitive to these factors.

---

[2] Much of the information in this section is excerpted from Weitkamp et al (1995) and Busby et al. (1996).

Along the west coast of North America, climate varies primarily with latitude; this coastal region exhibits south to north gradients of increasing average precipitation and declining average temperature. The coastal region has a mild climate, with warm, relatively dry summers and cool, wet winters. Climate in the interior basins, east of the Cascade Mountains, is greatly affected by topography and is influenced by continental air masses that bring much warmer, dryer summer conditions and colder winters than coastal areas influenced by maritime air to the west.

Columbia River Basin

Rivers draining into the Columbia River have their headwaters in increasingly dryer areas moving from west to east, as the Columbia River cuts through the 500-1,000-m-high Coast Range/Willapa Hills and the 1,000-2,000-m-high Cascade Mountains farther inland. Rivers draining into the lower Columbia River have a single peak in flow in December or January and relatively low flows in summer and fall. Rivers draining into the mid-upper Columbia River experience peak flow in spring associated with snow melt. Occasionally, rain-on-snow events in the fall give rise to widespread flooding.

Precipitation levels in the Willamette Valley in Oregon (100-120 cm/year) are much lower than those on the coast (120-240 cm/year) or in the Cascades (120-280 cm/year). Precipitation in the interior Columbia River Basin ranges from about 85 cm/year on the eastern slope of the Cascade Mountains, to between 25 and 36 cm/year in the dry central basin, and between 23 and 70 cm/year in the Snake River drainage. Water and air temperatures also reflect the more extreme climate east of the Coast Range. Maximum water temperatures in rivers draining into the Columbia River are slightly warmer (13-25^{o}C) and minimum temperatures are slightly cooler (3-6^{o}C) than those along the coast. Similarly, maximum (around 27^{o}C) and minimum (around -1^{o}C) air temperatures during the summer and winter are warmer and cooler, respectively, than along the coast. The Willamette Valley receives 2,000-2,200 hours/year sunshine, the lower Columbia River less than 2,000 hours/year, and the mid-Columbia River between 2,200-2,800 hours/year.

Olympic Peninsula

The Olympic Peninsula is much wetter (160-380 cm precipitation per year) than areas farther east and receives considerable snowfall (over 150 cm/year) at higher elevations (1,000-2,000 m). Currently, persistent spawning populations of sockeye salmon on the Olympic Peninsula are found only in watersheds draining the peninsula's western side. Many of the rivers draining the western Olympic Peninsula derive much of their water from snow and glacier melt that causes a second flow peak each year. These rivers have relatively high flows even in summer and have comparatively high annual flows. Maximum and minimum air and water temperatures are cooler in the Olympic Peninsula than farther south, reflecting effects of both latitude and elevation. Annual maximum and minimum water temperatures are 10-14^{o}C and 2-4^{o}C, respectively, while annual maximum and minimum air temperatures are approximately 21^{o}C and 2^{o}C, respectively. Annual sunshine along the Olympic Peninsula coast is the lowest of anywhere in the continental United States, averaging less than 1,800 hours/year.

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. 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, although glacial melt-water does not contribute as much to this flow on Vancouver Island as it does on the Olympic Peninsula and mainland coastal British Columbia. There is a general decrease in summer air temperatures with increasing north latitude; the Olympic Peninsula coast is 3-5^{o}C warmer than the southwest coast of Vancouver Island, which is 3-5^{o}C warmer than the northwest coast and the mainland north of Vancouver Island.

Inland waters

East of the Olympic Peninsula, precipitation rapidly decreases because of the rainshadow caused by the Olympic and Vancouver Island Mountains to the north, and Willapa Hills to the south. The rainshadow, which becomes apparent along the northern coastline of the Peninsula west of the Elwha River, continues through lowland Puget Sound, up the lowlands bordering the Strait of Georgia to the south end of Queen Charlotte Strait. Several Washington streams that support sockeye salmon are found in Puget Sound. This area receives rainfall of less than 120 cm/year, with some areas receiving as little as 50 cm/year. Mountains to the east and west of this rainshadow receive high precipitation (up to 280 cm/year) and have an annual snowfall of 500-1,020 cm/year. Due to snow, and in some cases glacier melt in their headwaters, rivers draining into Puget Sound, Hood Canal, and the southeastern Strait of Juan de Fuca have relatively high flows in summer and two annual high flow peaks. These flow patterns are similar to those of rivers on the western Olympic Peninsula, and limited data from western British Columbia rivers indicate similar flow patterns (Farley 1979). Occasionally, rain-on-snow events in the fall-winter give rise to widespread flooding. There appears to be a slight summer temperature cline within the northern rainshadow region; average maximum air temperatures in Puget Sound and Hood Canal (20-24^{o}C) are slightly higher than in the Strait of Georgia (16-20^{o}C), which in turn are higher than areas inside Vancouver Island farther north (14-16^{o}C). In contrast, winter air temperatures are more uniform and average 0-5^{o}C throughout the area. Stream temperatures in the area are fairly cold, with a maximum of 12-20^{o}C in summer and 0-4^{o}C in winter. The greater Puget Sound area receives 2,000-2,200 hours/year of sunshine.

Physiography and geology

Sockeye salmon inhabit areas in Washington, Oregon, Idaho, and southern British Columbia that are represented by several physiographic regions: 1) the Coast Range

Province, which extends in the U.S. from the Strait of Juan de Fuca south to the Klamath Mountains and from the Pacific Ocean east to Puget Sound; 2) the Puget-Willamette Lowland, which encompasses Puget Sound and the Willamette River Valley in the U.S.; 3) the Cascade Mountain Range of Washington and Oregon; 4) the Columbia Plateau, which incorporates the Columbia and Okanogan River valleys between the Cascade and Rocky Mountains in Washington; 5) the Northern Rocky Mountains in Idaho; 6) the Coast Mountains of British Columbia; 7) the Coastal Trough, which constitutes the area surrounding the Strait of Georgia and Johnstone Strait; and 8) the Vancouver Island Mountains of Vancouver Island. These regions are geologically diverse (Easterbrook and Rahm 1970, McKee 1972).

Glaciation events during the Pleistocene were instrumental in the formation of many lakes that were historically used or continue to be used as rearing habitat by sockeye salmon. Terminal moraines left behind by retreating glaciers created Quinault, Ozette, Wenatchee, Cle Elum, Kachess, Keechelus, and Wallowa Lakes; glacial scouring deepened existing river valleys that allowed formation of Okanagan[3], Osoyoos, Washington, Sammamish, and Upper and Lower Arrow Lakes (Easterbrook and Rahm 1970, McKee 1972).

Pleistocene Ice Age glaciation in the form of gigantic continental ice sheets and local alpine glaciers had a profound impact on the topography of the North Cascades, the Puget Lowland, the Olympic Peninsula section of the Coast Range Province, and the northern Columbia Plateau. Changes in climate during the Pleistocene caused several advances and retreats of the ice, and northern Washington was probably glaciated in every ice age. In the North Cascades, alpine glaciers were inundated by later advance of the continental ice sheet, whereas the South Cascades were not overwhelmed by large ice sheets, and the effects of alpine glaciers are more evident in this region than they are farther north (Easterbrook and Rahm 1970). During the last major continental glaciation event west of the Cascades, the Fraser Glaciation, the ice sheet split into two lobes; the Juan de Fuca Lobe, flowing westward, and the Puget Lobe, flowing south. This continental glaciation scoured out the deep troughs of Puget Sound and left behind extensive morainal deposits in the Puget Lowlands. The Juan de Fuca Lobe and Puget Lobe of the Fraser Glaciation heavily impacted the northern and eastern flanks of the Olympic Mountains, up to an altitude of about 915 m, but the southwestern side of the Olympics was beyond the continental glacier’s reach, and evidence of the extent of alpine glaciation in river valleys of the southwestern Olympics is much clearer there. The southwestern Olympics were glaciated at least four times during the Pleistocene. Valley glaciers extended to at least the mouth of the Hoh River, to near Taholah on the Quinault River, and to near Queets on the Queets River during the Pleistocene (Easterbrook and Rahm 1970, McKee 1972). During the last, or Late Wisconsin, glaciation on the east side of the Cascades, the Okanogan Lobe of the continental ice sheet extended down the Okanogan

---

[3] The accepted spelling in Canada is Okanagan, in the United States it is Okanogan. In this document Okanagan will be used when referring to geographic features in Cnada and Okanagon when referring to geographic features in the U.S.

and Columbia River Valleys to south of Lake Chelan (Easterbrook and Rahm 1970).

Physical and chemical characteristics of sockeye salmon nursery lakes

Juvenile sockeye salmon typically spend 1 or more years in the limnetic zone of a nursery lake prior to smoltification. Growth and survival while in the lacustrine environment depend on the morphological and limnological conditions of the nursery lake. Factors affecting a lake's productivity may be grouped into three major categories: morphometric, edaphic, and climatic (Rawson 1952, Northcote and Larkin 1956). Morphometric factors include lake area, volume, mean and maximum depth, and drainage area, while edaphic factors are defined by the abundance of dissolved nutrients, measured as concentrations of chlorophyll-*a*, total phosphorus, total nitrogen, and total dissolved solids. Climatic factors include effects of temperature, wind, and solar radiation. Values for a number of these parameters, together with distance from the sea, altitude, transparency (as measured by Secchi-disk depth), and dissolved oxygen from lakes in the Pacific Northwest are listed in Appendix Tables B-1 and B-2.

Lakes may be classified as oligo-, meso-, or eutrophic based on the relationships between nutrient concentrations, algal abundance, and water clarity (USEPA 1974). Lakes with a Secchi-disk depth greater than 3.7 m, and with less than 10 µg/L total phosphorus and less than 7 µg/L chlorophyll-*a* are classified as oligotrophic. Lakes with a Secchi-disk depth between 2.0 and 3.7 m, and concentrations of total phosphorus between 7-12 µg/L and chlorophyll-*a* between 10-20 µg/L, are classified as mesotrophic. Lakes with a Secchi-disk depth less than 2.0 m, and concentrations of chlorophyll-*a* and total phosphorus of greater than 12 and 20 µg/L, respectively, are classified as eutrophic (USEPA 1974). Oligotrophic lakes generally have greater diversity, but smaller populations of algal, zooplankton, and fish species, than eutrophic lakes (Brenner et al. 1990).

Lakes in the Pacific Northwest typically develop a summer thermocline resulting from solar heating, with water below the thermocline remaining colder and denser than the lighter water above it. Surface water in a thermally stratified lake is termed the epilimnion, whereas water below the thermocline is termed the hypolimnion. The hypolimnion may become depleted in oxygen as a result of natural decomposition of plant and animal matter on the lake bottom, if mixing is inhibited by thermocline formation. Lakes in the Pacific Northwest also undergo a single mixing event of the epi- and hypolimnion in the fall or winter in a process called turnover and are therefore referred to as monomictic (Brenner et al. 1990). Phosphorus is particularly important in limiting the abundance of phytoplankton, and thus zooplankton food for juvenile sockeye salmon, in Pacific Northwest lakes (Edmondson 1977b).

Several indices of fish production in lake environments have been developed, including the morphoedaphic index (MEI) (Ryder 1965, Henderson et al. 1973), the plankton-acre index (IPSFC 1972, Blum 1988), the mean-depth index (Rawson 1952), the bio-index (Northcote and Larkin 1956), the lake-surface-area index (Youngs and Heimbuch 1982), the chlorophyll-*a* index (Oglesby 1977), and indices based on phosphorus concentration or macrobenthos biomass divided by mean depth (Hanson and Leggett 1982). The morphoedaphic index is the most widely used index of potential fish production and is derived by dividing a lake's total dissolved solids (mg/L), or its conductivity, by its mean depth in meters to provide a metric expression of the MEI (Henderson et al. 1973). The mean depth of a lake is usually derived by dividing the lake's volume by its surface area. The level of total dissolved solids (TDS) is thought to be proportional to one of the limiting nutrients such as phosphorus or nitrogen, whereas mean depth depicts the extent of a lake's euphotic-littoral zone to some degree (Henderson et al. 1973). Relatively unproductive lakes have a low MEI, great depth, occupy U-shaped basins, and are located on firm igneous substrate, whereas productive north-temperate lakes have a high MEI, often have restricted depths, and are underlain by rich sedimentary deposits (Henderson et al. 1973). Available MEI values for selected Pacific Northwest lakes containing sockeye salmon are listed in Appendix Table B-2.

Ecoregions: Vegetation and Land Use

The U.S. Environmental Protection Agency has developed a system of ecoregions, based on the perceived pattern of factors such as climate, topography, natural vegetation, land use, and soils (Omernik and Gallant 1986, Omernik 1987). Under this system, the range of sockeye salmon in Washington, Oregon, and Idaho covers two ecoregions that border on salt water and three interior ecoregions. The Coast Range Ecoregion (containing the SASSI sockeye salmon stocks Ozette, Pleasant, and Quinault (WDF et al. 1993)) extends north and south from the Strait of Juan de Fuca to Monterey Bay, and east from the ocean to approximately the crest of the coastal mountains. The Puget Lowland Ecoregion (containing the three SASSI sockeye salmon stocks in the Lake Washington watershed (WDF et al. 1993)) 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 and up to the Cascade foothills. The Cascades Ecoregion (containing the SASSI stocks Baker River and Wenatchee (WDF et al. 1993) and the original lake habitat of Deschutes River, Oregon sockeye salmon) includes the high mountains and deeply dissected valleys of the Cascades Mountain Range in Washington and Oregon. The Columbia Basin Ecoregion (containing the SASSI sockeye salmon stock Okanogan (WDF et al. 1993)) is bordered on the west by the Cascade Mountains, on the east by the foothills of the Rocky Mountains, on the south by the Blue Mountains of Oregon, and extends north to the Canadian border through the Okanogan River valley. Finally, the Northern Rockies Ecoregion (containing Redfish Lake sockeye salmon) is comprised of the sharp ridges and steep slopes of the northern portion of the Rocky Mountains in Idaho and Montana between elevations of about 400 and 2400 m.

The Coast Range Ecoregion is forested with dense stands of Douglas fir, western hemlock, Sitka spruce, western red cedar, big-leaf maple, and red alder. Forest understories consist of herbaceous vegetation and shrubs such as rhododendron, vine maple, willow, salmonberry, and evergreen huckleberry (Omernik and Gallant 1986). Timber harvesting and logging road construction has occurred extensively throughout the northern section of the Coast Range Ecoregion, with consequent hill slope and stream bank erosion and increased stream sedimentation (Omernik and Gallant 1986).

The Puget Lowland Ecoregion is forested with Douglas fir, western hemlock, western white pine, lodgepole pine, ponderosa pine, western red cedar, big-leaf maple, and red alder. Localized habitats include prairie, oak woodland, northwestern paper birch, quaking aspen, and swamp and bog communities. Timber harvest, agriculture, and urban development are important land uses in this ecoregion. Stream water quality is affected by industrial and municipal wastes, increasing urbanization, and erosion resulting from timber harvest and road construction (Omernik and Gallant 1986).

The Cascades Ecoregion, located at an altitude between 600 and 2100 m, is densely forested with Douglas fir, noble fir, Pacific silver fir, western white pine, western hemlock, and western red cedar. Forest understories in this region consist of shrubs such as Oregon grape, salal, vine maple, rhododendron, oceanspray, huckleberry, and blackberry. At higher elevations, mountain hemlock, subalpine fir, whitebark pine and Englemann spruce predominate. Land uses are predominantly timber harvest, wildlife habitat, and recreation. Stream degradation is exacerbated by timber harvest, logging, and recreational road construction that, coupled with periods of heavy rainfall and rapid snowmelt, lead to scouring and disruption of stream habitat (Omernik and Gallant 1986).

Natural vegetation in the steppe and grassland habitat of the Columbia Basin Ecoregion consists of sagebrush, wheatgrass, and smaller amounts of bluegrass and fescue. Dryland wheat and irrigated vegetable, fruit, and pasture agriculture, together with cattle grazing, are the primary land uses in this ecoregion. Water withdrawals for irrigation and agricultural runoff, coupled with low annual precipitation, impact the quality and amount of water available to local streams (Omernik and Gallant 1986).

Natural vegetation in the Northern Rockies Ecoregion consists of stands of lodgepole pine, western white pine, western red cedar, western hemlock, western larch, Douglas fir, subalpine fir, Englemann spruce, and Ponderosa pine, with understory vegetation consisting of forbs and grasses. Wheatgrass, fescue, and needlegrass occur in localized prairie habitats. Major land uses include timber harvesting, recreation, wildlife habitat, mining, and livestock grazing on lower elevations. Stream water quality is affected by timber harvest, logging road construction, and mine waste runoff (Omernik and Gallant 1986).

Ocean Upwelling

Ocean upwelling (the movement of cold, nutrient-rich subsurface water to the surface) along the coasts of British Columbia, Washington, and Oregon is primarily wind driven (Bakun 1973, 1975). Upwelling in the area is both seasonal and episodic because winds that cause upwelling are more frequent in the spring and summer, but do not occur uniformly during those times (Smith 1983, Landry et al. 1989). Wind-driven upwelling also occurs within the Strait of Georgia, where it is similarly limited both spatially and temporally (Thompson 1981). One exception to this pattern has been observed off the southwest corner of Vancouver Island, where consistent and strong upwelling appears to occur throughout the year (Denman et al. 1981). Upwelling in this area is thought to be caused by current-driven as well as wind-driven events, leading to relative temporal and spatial stability.

Zoogeography

Patterns of marine and freshwater species' distributions indicate changes in the physical environment that are shared with sockeye salmon. These environmental differences may affect salmon habitat and provide different selective pressures in different areas to which salmon must adapt.

Marine fishes

Along the east coast of the North Pacific Ocean within the range considered in this status review, there is one distinct faunal boundary for marine fishes off the northern tip of Vancouver Island (approximately 50°N) (Allen and Smith 1988). Marine fishes north of 50°N are primarily cold-water, subarctic species, whereas those between 50°N and 34°30'N are primarily temperate species.

Marine invertebrates

The distribution of marine invertebrates shows transitions between major faunal communities similar to those of marine fishes (Hall 1964, Valentine 1966, Hayden and Dolan 1976, Brusca and Wallerstein 1979). Invertebrate faunal boundaries along the west coast of North America occur at approximately Dixon Entrance (between Prince of Wales Island, Alaska and the Queen Charlotte Islands, B. C.) and the Strait of Juan de Fuca (between Vancouver Island and the Olympic Peninsula). 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.

Freshwater fishes

Freshwater fishes in south/central British Columbia, Washington and most of coastal Oregon are of Columbia River origin (McPhail and Lindsey 1986, Minckley et al. 1986). Variations in the makeup of freshwater fish communities in these areas reflect the varied dispersal patterns of fishes between river basins. The Stikine River in northern British Columbia is the point at which freshwater fishes from the north displace the Columbia River fish fauna (McPhail and Lindsay 1986). Thus, there is no evident pattern of variation in freshwater fishes associated with sockeye salmon in Washington and southern British Columbia.

Estuarine fishes

Estuarine fishes also show regional differences based on presence or absence of species and can be roughly divided into four groups in Washington and Oregon (Monaco et al. 1992). Two groups were identified in Washington: the Fjord Group, which is restricted to Puget Sound and Hood Canal, and a second group, which is found in Grays Harbor, Willapa Bay, and the Columbia River estuary. Two other large groups, with considerable geographic overlap, extend from Willapa Bay in Washington to the Eel River estuary in California. Other estuary groupings are less evident and seem to depend more on characteristics of individual estuaries rather than geographic location.

Freshwater mollusks

Freshwater mollusks and anadromous salmonids share similar freshwater habitat and water quality requirements, while the distributions of salmonids, large prosobranch snails, and freshwater mussels are similarly constrained by the requirement for continuous waterways for dispersal (Clarke 1981). Small sphaeriacean clams and small freshwater snails are not good indicators of zoogeographic regions, as they may be dispersed when attached to bird feathers, or imbedded in mud attached to the feet of water birds. The distribution of freshwater mussels, whose larvae (glochidia) parasitize the gills or fins of fish and require fish hosts to complete their life cycle, may be particularly dependent on the distribution of host fish. Certain bivalve glochidia rely on specific species of fish as hosts, whereas others tolerate a wide range of fish hosts. Within the range of west coast sockeye salmon, glochidia of the Yukon floater mussel *Anodonta beringiana* parasitize the gills of sockeye and chinook salmon, while glochidia of the western pearlshell *Margaritifera falcata* parasitize the gills of chinook salmon and other fishes (Clarke 1981). The host fishes for other species of freshwater mussels in this region are unknown, but likely include juvenile sockeye salmon.

Five recognized species of freshwater mussels occur within the range of west coast sockeye salmon: *Anodonta beringiana* (Yukon floater), *A. nuttalliana* (winged floater), *A. kennerlyi* (western floater), *Margaritifera falcata* (western pearlshell), and G*onidea angulata* (western ridgemussel). Dall (1905), Zhadin (1965), and Clarke (1981) record *A. beringiana* from Kamchatka to central Alaska and into the upper Yukon drainage, whereas Henderson (1929) and Ingram (1948) extend this species' range south into Oregon and include several western Washington lakes in this species' distribution including Whatcom, Samish, Washington, and Crescent. *Anodonta nuttalliana* (which has been synonymized with *A. oregonensis* and *A. wahlamatensis*) occurs in the Fraser and Columbia Rivers south into central California (Clarke 1981) and east into Idaho in the Snake and Spokane Rivers (Henderson 1929). It has been recorded from Shuswap, Nicola, Sumas, and Chilliwack Lakes on the Fraser River; Okanagan Lake, The Dalles, and Astoria in the Columbia River Basin; Nootka Sound on Vancouver Island; Lakes Whatcom, Sammamish, Union, and Washington in the Puget Sound lowlands; Upper Klamath Lake in Oregon; and the Sacramento and San Joaquin Rivers in California (Dall 1905; Henderson 1929, 1936; Ingram 1948; Clarke 1981). *Anodonta kennerlyi* occurs on the Queen Charlotte Islands south through the Skeena and

Fraser Rivers, Vancouver Island, and into the Pacific drainage of Oregon. It has been seen in Quinault and Samish Lakes in western Washington, at Spokane and Yakima on the Columbia River, and in Eugene and just north of Coos Bay, Oregon (Henderson 1929, 1936; Ingram 1948; Clarke 1981). *Margaritifera falcata* ranges from California to the southern interior of British Columbia, to the Queen Charlotte Islands, and to Revillagigedo Island in Southeast Alaska (Clarke 1981). It has been recorded north to Naha Bay, Alaska (at 55^0N); in the Fraser River; the Snake River in Idaho (Stanford 1942); at Spokane, Yakima, Walla Walla, The Dalles, and Portland on the Columbia River; in Lake Crescent and the Chehalis River on the Olympic Peninsula; in North Creek (Sammamish River drainage), Whatcom Creek, Samish River, and Snoqualmie River in the Puget Sound lowlands; in the Deschutes River (at Bend, Oregon); in the Umpqua and Coos Rivers in Oregon; and in the Sacramento River, California (Dall 1905; Henderson 1929, 1936; Ingram 1948; Clarke 1981). *Gonidea angulata* occurs from the upper Columbia River in British Columbia (Okanagan and Kootenai Rivers) south to southern California in rivers that drain into the Pacific. It has been recorded from Vaseux Lake on the Okanagan River; from Spokane, The Dalles, the Willamette River, and the Snake River (at Weiser, Idaho) all in the Columbia River drainage; and in California from the Klamath River south to Los Angeles (Dall 1905; Henderson 1929, 1936; Ingram 1948; Clarke 1981).

The combined range of *A. beringiana*, *A. nuttalliana*, and *A. kennerlyi* encompasses the range of sockeye salmon, as well as other Pacific salmon species, and may indicate either a close link in habitat requirements between this species complex of freshwater mussels and anadromous salmonids or a direct reliance by these mussels on Pacific salmonid juveniles as hosts for the larval glochidial stage. The range of *M. falcata* is likewise coincident with the range of sockeye salmon south of Alaska.

Three large freshwater prosobranch snails also occur within the range of west coast sockeye salmon: *Juga plicifera*, *J. bulbosa*, and *J. hemphilli.* The latter two species appear confined to the lower Columbia River (Burch 1989), whereas *J. plicifera* occupies the lower Columbia River and the Willamette and Santiam Rivers, as well as drainages on the southern Olympic Peninsula and south into northern California (Henderson 1929, 1936; Millimann and Knapp 1970; Clarke 1981; Burch 1989). *Juga plicifera* is the first intermediate host for the trematode *Nanophyetus salminicola*, which is the vector for the rickettsia-like organism *Neorickettsia helminthoeca* that causes “salmon poisoning disease” in dogs and other canids (Millimann and Knapp 1970).

Amphibians

Although most amphibians are not restricted to aquatic habitats, and therefore have little direct habitat overlap with sockeye salmon, many amphibian species have very restricted distributions, suggesting preferences for specific habitat types and environmental conditions. Because of this sensitivity, patterns of amphibian distributions may serve as indicators of subtle differences in environmental conditions.

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

Life History of *Oncorhynchus nerka*

With the exception of certain river-type and sea-type populations, the vast majority of sockeye salmon spawn in or near lakes, where the juveniles rear for 1 to 3 years prior to migrating to sea. For this reason, the major distribution and abundance of large sockeye salmon stocks is closely related to the location of rivers that have accessible lakes in their watersheds for juvenile rearing (Burgner 1991). Although there are no commercially exploited sockeye salmon populations north of the Kuskokwim River in Alaska, small populations occur in the Yukon River and rivers flowing into Norton Sound (L. Buklis[4]), and perhaps in the Noatak River in Kotzebue Sound (Atkinson et al. 1967). In North America, the two dominant areas of sockeye salmon production occur in areas with extensive lake-rearing habitat: the Bristol Bay watershed in Alaska (Kvichak, Naknek, Ugashik, Egegik, Wood, and Nushagak Rivers) and the Fraser River in British Columbia. Other watersheds with major sockeye salmon stocks include the Chignik, Karluk, and Copper Rivers, and rivers draining into Cook Inlet in Alaska; and the Skeena, Nass, and Somass Rivers, and Rivers and Smith Inlets of British Columbia (Ricker 1966, Aro and Shepard 1967, Atkinson et al. 1967, Poe and Mathisen 1981, Burgner 1991). In Asia, the major sockeye salmon producing systems are on the Kamchatka Peninsula: the Kamchatka River, draining east through central Kamchatka; the Paratunka River in south-eastern Kamchatka; and the Ozernaya and Bolshaya Rivers in southwestern Kamchatka (Hanamura 1967, Burgner 1991). Kuril Lake in the Ozernaya River Basin on the Kamchatka Peninsula produces nearly 90% of all Asian sockeye salmon. Approximately 8% of sockeye salmon production in Asia comes from the Kamchatka River, while all other systems account for only about 2% (N. V. Varnavskaya[5]).

Sockeye salmon exhibit a greater variety of life history patterns than either chum, coho, chinook, or pink salmon. The vast majority of sockeye salmon spawn in either inlet or

---

4 Larry Buklis, Regional Research Biologist, AYK Region, Alaska Department of Fish and Game, Anchorage, AK (Pers. commun. to M.L. Dahlberg, NOAA, NMFS, AFSC, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801-8626).

5 Dr. N.V. Varnavskaya, Kamchatka Institute of Fisheries and Oceanography (KamchatNIRO), Petropavlosk-Kamchatsky, 683602, Russia (Pers. commun. to M.L. Dahlberg, NOAA, NMFS, AFSC, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801-8626).

outlet streams of lakes or in lakes themselves. The offspring of these “lake-type” sockeye salmon utilize the lake environment for juvenile rearing for 1, 2, or 3 years and then migrate to sea, returning to the natal lake system to spawn after spending 1, 2, 3, or 4 years in the ocean. However, some populations of sockeye salmon spawn in rivers without juvenile lake rearing habitat. The offspring of these riverine spawners utilize the lower slow-velocity sections of rivers as the juvenile rearing environment for 1 or 2 years (“river-type” sockeye salmon), or migrate to sea as underyearlings after spending only a few months in the natal river and therefore rear primarily in saltwater (“sea-type” sockeye salmon) (Gilbert 1918, Foerster 1968, Wood 1995). In common with lake-type sockeye salmon, river/sea-type sockeye salmon return to the natal spawning habitat following 1 to 4 years in the ocean.

Certain populations of *O. nerka* that become resident in the lake environment over long periods of time are called kokanee, silver trout, or little redfish in North America and himemasu in Japan (Burgner 1991). Occasionally, a proportion of the juveniles in an anadromous sockeye salmon population will remain in the rearing lake environment throughout life and will be observed on the spawning grounds together with their anadromous siblings. Ricker (1938) defined the terms “residual sockeye” and “residuals” to identify these resident, non-migratory progeny of anadromous sockeye salmon parents. Kokanee and residual or resident sockeye salmon are further discussed in the “Nonanadromous forms” section below.

Sockeye salmon exhibit the greatest diversity in selection of spawning habitat among the Pacific salmon. Sockeye salmon also exhibit great variation in river entry timing and the duration of holding in lakes prior to spawning. Although sockeye salmon typically spawn in inlet or outlet tributaries of a nursery lake, they may also spawn in 1) suitable habitat between lakes, 2) along the nursery lakeshore on outwash fans of tributaries or where upwelling occurs along submerged beaches, 3) along beaches where the gravel or rocky substrate is free of fine sediment and the eggs can be oxygenated by wind-driven circulation, or 4) in mainstem rivers without juvenile lake-rearing habitat (Foerster 1968, Burgner 1991).

Adaptation to a greater degree of utilization of lacustrine environments for both adult spawning and juvenile rearing has resulted in the evolution of complex timing for incubation, fry emergence, spawning, and adult lake entry that often involves intricate patterns of adult and juvenile migration and orientation not seen in other *Oncorhynchus* species (Burgner 1991). Adult sockeye salmon home precisely to the natal stream or lake habitat (Hanamura 1966, Quinn 1985, Quinn et al. 1987). Stream fidelity in sockeye salmon is thought to be adaptive, since this ensures that juveniles will encounter a suitable nursery lake. Wood (1995) inferred from protein electrophoresis data that river/sea-type sockeye salmon have higher straying rates within river systems than lake-type sockeye salmon.

Velsen (1980) reported that, at a constant temperature of 10^{o}C, sockeye salmon had the longest incubation period to 50% hatch of five salmon species tested. Benefits of intergravel incubation include protection from predation, freezing, fluctuating flows, and desiccation. Survival during incubation is influenced by environmental conditions, the degree of crowding during spawning (Foerster 1968, Burgner 1991), the type of gravel in which eggs are laid, and the gravel’s permeability to water (Foerster 1968). Little is known about predation during incubation. Desiccation, freezing (in northern latitudes), low oxygen due to siltation, and dislodgement by later spawning fish are important mortality factors (Burgner 1991). In addition, severe water-flow changes (floods or drought) can lead to heavy losses during incubation (Foerster 1968).

Upon emerging from the substrate, sockeye salmon alevins exhibit varied behavior: 1) Inlet spawners may proceed downstream to the nursery lake or remain in the stream and show substantial growth before migrating downstream; 2) lakeshore beach spawners take up residence directly in the lake; 3) outlet spawners may require a period of growth before migrating upstream to the nursery lake; and 4) riverine spawners without lake access travel downstream to backwater sections of the lower river, where they may rear for a short period before going to sea as underyearlings (sea-type sockeye salmon) or they may rear for longer periods prior to going to sea in their second or third year of life (river-type sockeye salmon). Predation on migrating sockeye salmon fry varies considerably with spawning location (lakeshore beach, creek, river, or spring area). Sockeye salmon fry mortality, due to predation by other fish species and birds, can be extensive during downstream and upstream migration to nursery lake habitat and is only partially reduced by the nocturnal migratory movement of some fry populations (Burgner 1991). Predation losses during fry migration to Lakelse Lake, British Columbia down Scully Creek were estimated at 63-84% over 4 years (Foerster 1968). In Karymaisky Spring (Bolshaya River, Kamchatka) predation losses ranged from 13% to 91% over 8 years (Semko 1954). In the Cedar River, predation losses of sockeye salmon fry migrating to Lake Washington were 25% and 69% in two separate tests (Stober and Hämäläinen 1980), while 15% of the migrating sockeye salmon fry in the Cedar River in 1985 were eaten by wild steelhead smolts (Beauchamp 1995).

Juvenile sockeye salmon in lakes are visual predators, feeding on zooplankton and insect larvae (Foerster 1968, Burgner 1991). In certain lakes (Wood River lakes in Alaska, Lake Dalnee in Kamchatka, and Babine Lake in British Columbia), sockeye salmon fry feed initially in the littoral zone and subsequently migrate offshore to the limnetic zone (various references in Burgner 1991). In other lakes (Cultus Lake beach spawners and fry migrating from the Cedar River to Lake Washington), fry move directly into the limnetic zone upon reaching the nursery lake (Brannon 1972b, Woodey 1972, Dawson 1972). Although previous studies have not found sockeye salmon fry in the littoral zone of Lake Washington or other lakes in Washington (WDFW 1996), Martz et al. (1996) reported that

> The majority of the sockeye fry were found in the limnetic zone; however, a smaller but significant number of sockeye fry also utilize the littoral zone for up to one month after emigrating from the Cedar River.

Juvenile sockeye salmon in lakes commonly undergo diel vertical migrations such that they are present in deeper water by day than by night (Levy 1987). In Lake Washington, juvenile sockeye salmon were reported to undergo diel vertical migrations at all times of year and to occupy certain depths in direct relation to water temperature (Woodey 1972). The surface area and productivity of a nursery lake limit population size of sockeye salmon, and offspring of large return years may show reduced growth due to intraspecific competition. Increased growth in freshwater may lead to higher marine survival and decreased ocean age at return.

Smolt migration typically occurs between sunset and sunrise, beginning in late April and extending through early July, with southern stocks migrating earliest. Some sockeye salmon smolts undergo a complicated migration to reach the lake system outlet (Johnson and Groot 1963). Once in the ocean, sockeye salmon feed on copepods, euphausiids, amphipods, crustacean larvae, fish larvae, squid, and pteropods. Increase in length is typically greatest in the first year of ocean life, whereas increase in weight is greater during the second year. Northward migration of juveniles to the Gulf of Alaska occurs in a band relatively close to shore, and offshore movement of juveniles occurs in late autumn or winter. Sockeye salmon prefer cooler ocean conditions than other Pacific salmon (Burgner 1991).

Lake-Type Sockeye Salmon

The vast majority of sockeye salmon typically spawn in inlet or outlet tributaries of lakes or along the shoreline of lakes where upwelling of oxygenated water through gravel or sand occurs. Growth influences the duration of stay in the nursery lake and is influenced by intra- and interspecific competition, food supply, water temperature, thermal stratification, migratory movements to avoid predation, lake turbidity, and length of the growing season. Lake residence time is usually greater the farther north a nursery lake is located. In Washington and British Columbia, lake residence is normally 1 or 2 years, whereas in Alaska some fish may remain 3, or rarely 4 years in the nursery lake, prior to smoltification (Burgner 1991, Halupka et al. 1993).

While in the lacustrine environment, fry and yearlings feed as visual predators, primarily on copepods (*Cyclops*, *Epischura*, and *Diaptomus*), cladocerans (*Bosmia, Daphnia*, and *Diaphanosoma*), and insect larvae. In some lakes, sockeye salmon fry initially feed near the lake shoreline in the littoral zone, subsequently shifting to the deeper waters of the limnetic zone. In other lakes, sockeye salmon fry enter the limnetic zone directly. In many lakes, juveniles feed in the limnetic zone at dusk and dawn to avoid day-time visual predators, and this feeding pattern may be tied to diel vertical migrations (Eggers 1978, Pauley et al. 1989, Burgner 1991). In summer and fall 1972, juvenile Lake Washington sockeye salmon fed intensively during the afternoon through dusk. In winter 1972-1973, a high percentage of the population did not feed on a daily basis. No feeding occurred at night during any season of the year (Doble and Eggers 1978).

Competitors for common food of sockeye salmon during lake residence may include threespine and ninespine sticklebacks (*Gasterosteus aculeatus* and *Pungitius pungitius*), red sided shiner (*Richardsonius balteatus*), pond smelt (*Hypomesus olidus*), pygmy whitefish (*Prosopium coulteri*), lake whitefish (*Coregonus clupeaformis*), northern squawfish

(*Ptychocheilus oregonensis*), yellow perch (*Perca flavescens*), peamouth (*Mylocheilus caurinus*), and kokanee (Foerster 1968, Dlugokenski et al. 1981, Burgner 1991). Longfin smelt (*Spirinchus thaleichthyes*) are reportedly an important competitor with sockeye salmon in Lake Washington (WDFW 1996). Nursery lake area and productivity coupled with inter- and intra-specific competition can exert a limiting effect on smolt size, and ultimately population size, of sockeye salmon (Kyle et al. 1988).

Potential predators on lake resident sockeye salmon fry throughout their North American range include: lake trout (*Salvelinus namaycush*), rainbow trout (*O. mykiss*), Dolly Varden charr (*Salvelinus malma*), Arctic charr (*Salvelinus alpinus*), cutthroat trout (*O. clarki*), juvenile coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*), lake whitefish (*Prosopium clupeaformis*), mountain whitefish (*Prosopium williamsoni*), northern squawfish (*Ptychocheilus oregonensis*), burbot (*Lota lota*), northern pike (*Esox lucius*), prickly sculpin (*Cottus asper*), and bird predators (Foerster 1968, Hartman and Burgner 1972, Burgner 1991, Emmett et al. 1991, Beauchamp et al. 1995). Principle bird predators include: common loon (*Gavia immer*), red-necked grebe (*Podiceps grisegna*), common merganser (*Mergus merganser*), belted kingfisher (*Megaceryle alcyon*), osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), terns, and gulls (Emmett et al. 1991).

River-Type and Sea-Type Sockeye Salmon

In areas where lake-rearing habitat is unavailable or inaccessible, sockeye salmon may utilize river and estuarine habitat for rearing or may forgo an extended freshwater rearing period (Birtwell et al. 1987; Wood et al. 1987a, Heifitz et al. 1989; Murphy et al. 1988, 1989, 1991; Lorenz and Eiler 1989; Eiler et al. 1992; Levings et al. 1995; Wood 1995). Riverine spawners that rear in rivers for 1 or 2 years are termed “river-type” sockeye salmon. Riverine spawners that migrate as fry to sea or to lower river estuaries in the same year emergence occurs, following a brief freshwater rearing period of only a few months, are referred to as “sea-type” sockeye salmon.

River-type and sea-type sockeye salmon are common in northern areas and may predominate over lake-type sockeye salmon in some river systems (Wood et al. 1987a, Eiler et al. 1988, Halupka et al. 1993, Wood 1995) (see Table 2). River/sea-type sockeye salmon have been rarely reported in rivers south of the Stikine River, although those that spawn in the Harrison River rapids and rear in the lower Fraser River system of southern British Columbia are the exception (Gilbert 1918, 1919; Schaefer 1950, 1951; Birtwell et al. 1987; Levings et al. 1995). Halupka et al. (1993) suggested that the lack of reported river/sea-type sockeye salmon stocks south of the Stikine River, with the exception of the Fraser River population, may be due to any of three factors: 1) the lack of sufficient colonists with the genetic capacity for developing this life-history pattern, 2) the lack of suitable habitat for development of a river/sea-type life history pattern, or 3) small river/sea-type stocks exist in southern rivers but their presence has been overlooked. Eiler et al. (1992) indicated that riverine spawning has been reported (if only sometimes anecdotically) throughout the range of sockeye salmon.

Known self-sustaining populations of river/sea-type sockeye salmon throughout the Pacific Rim are listed in Table 2.

Many populations of river/sea-type sockeye salmon spawn and rear in close proximity to glaciers or in glacially influenced drainages. Milner and Bailey (1989) observed that sockeye salmon were one of the first salmonids to colonize clearwater streams in Glacier Bay National Park, Alaska following glacial retreat. Lorenz and Eiler (1989) noted that river/sea-type sockeye salmon in the glacial Taku River, Alaska preferred main channel or off-channel areas for spawning, where upwelling groundwater occurs. Fish spawning in these areas had, on average, two times more fine sediment in their redds than had been previously measured in other sockeye salmon redds.

Several studies have indicated that sea-type sockeye salmon possess heritable physiological adaptations for successful migration to sea as underyearlings (Rice et al. 1994, Wood 1995). Underyearling sea-type sockeye salmon from the East Alsek River, Alaska (Rice et al. 1994) and river/sea-type sockeye salmon from the Scud River in the Stikine River basin (Wood 1995) showed superior seawater adaptability over lake-type fry when exposed to similar seawater challenge. When reared in 30 ppt seawater, sea-type sockeye salmon fry from the East Alsek River grew significantly faster than river-type sockeye salmon, which in turn grew faster than lake-type sockeye salmon (Rice et al. 1994). Underyearling sockeye salmon in the Situk River, Alaska and Fraser River estuaries grow unusually fast in nature, obtaining a size similar to that of age 1+ lake-type smolts by the middle to end of their first summer (Birtwell et al. 1987, Rice et al. 1994). Juvenile sea-type sockeye salmon in the Situk River estuary in southeast Alaska rear in the estuary for 3-4 months in 0-30 ppt salinity until they are large enough to tolerate full-strength ocean salinity as underyearlings greater than 50 mm in length (Heifitz et al. 1989). Both Craig (1985) and Wood (1995) have reported that egg size in river/sea-type sockeye salmon is significantly larger than in lake-type sockeye salmon within the Stikine River Basin, and this may provide a size advantage to river/sea-type sockeye salmon fry over lake-type fry. At present, it is unknown whether these egg size differences are heritable (Wood 1995).

In studies of genetic variation of sockeye salmon in the Stikine River drainage, widely separated spawning populations of river/sea-type sockeye salmon showed much less genetic differentiation than did widely separated spawning populations of lake-type sockeye salmon (Wood 1995). This apparent lack of reproductive isolation among spawning populations of river/sea-type sockeye salmon in the Stikine River (some populations separated by over 180 km) was interpreted by Wood (1995) to indicate that precise homing may be relaxed in river/sea type sockeye salmon in systems where river/sea-type fry from throughout the watershed rear together in the lower river or estuary.

Wood (1995) speculated further that the combined traits of living in glacially influenced drainages and having higher straying rates than lake-type sockeye salmon give river/sea-type sockeye salmon the role of primary colonists of new habitat following glacial retreat.

Table 2. List of known spawning populations of river/sea-type sockeye salmon. Column labeled percent zero freshwater age, includes sea-type sockeye salmon only; river-type sockeye salmon showing 1 or 2 years freshwater growth may not be recognizable as riverine-rearing in scale or otolith analyses. Dashes indicate data were unavailable.

Location River System Stream name	Glacially influenced drainage	Percent zero freshwater age	Estimated total escapement of river/sea-type	Percent of total as river/ sea-type	Reference
British Columbia					
Fraser River					
Harrison River	yes	--	--	--	Schaefer (1951)
Pitt River (Widgeon Slough)	yes	--	--	--	Birtwell et al. (1987)
Nass River Basin					
Gingut Creek	no	97-100	1,500-21,000	100	Rutherford et al. (1994)
British Columbia/Southeast Alaska					
Stikine River Basin			41,000-109,000	43-53	Wood et al. (1987a, b)
Julian Slough	?	76	--	100	Halupka et al. (1993)
Chutine River	yes	2-6	--	100	Wood et al. (1987a, b)
Scud River	yes	20-23	--	100	Wood et al. (1987a, b)
Stikine mainstem	yes	21-55	--	100	Wood et al. (1987a, b)
Iskut River	yes	2-21	--	100	Wood et al. (1987a, b)
Taku River Basin		48			Eiler et al. (1992)
Mainstem					
Chum Salmon Slough	yes	51	--	--	Halupka et al. (1993)
Chuunk Mountain Slough	yes	44	--	--	Halupka et al. (1993)
Coffee Slough	yes	59-79	--	--	Eiler et al. (1988), Halupka et al. (1993)
Fish Creek	yes	42	--	--	Eiler et al. (1988)
Honatka Slough	no	62	--	--	Eiler et al. (1988)
South Fork Slough	yes	35-65	--	--	Eiler et al. (1988), Halupka et al. (1993)
Shustahini Slough	yes	43-52	--	--	Eiler et al. (1988), Halupka et al. (1993)
Tuskwa Slough	yes	56-69	--	--	Eiler et al. (1988), Halupka et al. (1993)
Yonakina Slough	yes	27	--	--	Halupka et al. (1993)

Table 2. Continued.

Location River System Stream name	Glacially influenced drainage	Percent zero freshwater age	Estimated escapement of river/sea-type	Percent river/sea-type	Reference
British Columbia/Southeast Alaska					
Taku River Basin (continued)					
Hackett River	yes	39-54	--	--	Eiler et al. (1988), Halupka et al. (1993)
Nahlin River	no	18	--	--	Halupka et al. (1993)
Nakina River	yes	38	--	--	Eiler et al. (1988)
Tatsamenie River	yes	26	--	--	Halupka et al. (1993)
Yehring Creek	yes	9	--	--	Eiler et al. (1988)
Southeast Alaska					
Admiralty Island					
Hasselborg River	no	84	--	--	Halupka et al. (1993)
Lynn Canal					
Lace River	yes	19	--	--	Halupka et al. (1993)
Chilkat River	yes	50	--	--	Halupka et al. (1993)
Yakutat Forelands					
East Alsek River	no	93	--	--	Halupka et al. (1993)
Akwe River	yes	83	--	--	Halupka et al. (1993)
Ahrnklin River	yes	99	--	--	Halupka et al. (1993)
Lost River	no	31	--	--	Halupka et al. (1993)
Old Situk River	no	92	2,775 (sea-type)	--	Pahlke and Riffe (1988)
Central Alaska					
Bering River Basin					
Bering Lake	no	33	4,300 (sea-type)	--	Sharr et al. (1988)
Shepard Creek	yes	54	1,955 (sea-type)	--	Sharr et al. (1988)
Kushtaka Lake	yes	22	178 (sea-type)	--	Sharr et al. (1988)

Table 2. Continued.

Location River System Stream name	Glacially influenced drainage	Percent zero freshwater age	Estimated escapement of river/sea-type	Percent river/sea-type	Reference
Central Alaska					
Copper River Delta					
Eyak Lake	yes	17	614 (sea-type)	--	Sharr et al. (1988)
McKinley Lake	?	24	3,122 (sea-type)	--	Sharr et al. (1988)
27-Mile Slough	yes	74	1,506 (sea-type)	--	Sharr et al. (1988)
Ragged Point Lake	yes	57	2,219 (sea-type)	--	Sharr et al. (1988)
Martin Lake	?	10	1,165 (sea-type)	--	Sharr et al. (1988)
Martin River Slough	yes	81	6,504 (sea-type)	--	Sharr et al. (1988)
Pleasant Creek	?	17	165 (sea-type)	--	Wilcock (1993)
Kenai River	yes	2	14,642 (sea-type)	--	Waltemyer (1994)
Susitna River Basin					
Yentna River	yes	13	14,000 (sea-type)	--	Waltemyer (1994)
Karluk River	no		16,534 (sea-type)	--	Rounesfell (1958b)
Nushagak River	no	38	260,316 (sea-type)	--	Miller et al. (1994)
Mulchatna River	no	--	--	--	Russell et al. (1989)
Western Kamchatka Peninsula					
Tigil' River	no	8	--	--	Bugaev (1992)
Khairyuzova River	no	4	--	--	Bugaev (1992)
Krutogorova River	no	6	--	--	Bugaev (1992)
Vorovskaya River	no	4	--	--	Bugaev (1992)
Kikhchik River	no	17	--	--	Bugaev (1992)
Utka River	no	28	--	--	Bugaev (1992)
Bol'shaya River	no	8	--	--	Semko (1954)

Table 2. Continued.

Location River System Stream name	Glacially influenced drainage	Percent zero freshwater age	Estimated escapement of river/sea-type	Percent river/sea-type	Reference
Eastern Kamchatka Peninsula					
Paratunka River	no	--	--	--	Krogius (1958)
Tikhaya River	no	25	--	--	Bugaev (1992)
Kamchatka River	no	4-58	--	--	Bugaev (1984, 1987)
Stolbovaya River	no	7	--	--	Bugaev (1992)
Malamvayam River	no	5	--	--	Bugaev (1992)
Khailyulya River	no	10	--	--	Bugaev (1992)
Ivashka River	no	43	--	--	Bugaev (1992)
Karaga River	no	4	--	--	Bugaev (1992)
Tymlat River	no	12	--	--	Bugaev (1992)
Kichiga River	no	12	--	--	Bugaev (1992)
Av'yavayam River	no	2-7	--	--	Bugaev (1992)
Apuka River	no	3	--	--	Bugaev (1992)
Ukoloyat River	no	6	--	--	Bugaev (1992)
Tumanskaya River	no	2	--	--	Bugaev (1992)

Nonanadromous Forms

"Kokanee," for the purposes of this review, are defined as the self-perpetuating, nonanadromous form of *O. nerka* that occurs in balanced sex-ratio populations and whose parents, for several generations back, have spent their whole lives in fresh water. Commonly, kokanee occur in land-locked lakes, where access from the ocean has become difficult or impossible (such as Lake Whatcom, Washington). Kokanee and sockeye salmon also co-occur in many interior lakes of the Skeena, Fraser, and Columbia River Basins, where access from the sea is possible, although energetically costly. Kokanee are rarely found in easily accessible coastal lakes that contain sockeye populations and where the energetic costs of migration are minimal.

The terms "residual sockeye" and "residuals" have been used to identify resident, non-migratory progeny of anadromous sockeye salmon (Ricker 1938). Ricker (1938) was of the opinion that it would be unusual if residual sockeye salmon were not found in most lakes which have an anadromous sockeye population, although Burgner (1991) stated that residual sockeye salmon are rare or absent in most northern sockeye salmon lakes. For the purposes of this review, we have defined the term "resident sockeye salmon" to indicate those fish that are the progeny of anadromous parents, yet spend their adult life in freshwater and are observed together with their anadromous siblings on the spawning grounds. The degree to which resident sockeye salmon produce anadromous offspring is generally unknown.

Both kokanee and resident sockeye salmon are normally smaller at maturity than anadromous sockeye salmon, primarily because of productivity differences between their respective freshwater and oceanic post-juvenile rearing environments. According to Ricker (1938, 1940, 1959), Burgner (1991), and Wood (1995), "residual" or resident sockeye salmon 1) mature earlier (males earlier than females) and at a smaller size than anadromous sockeye salmon, 2) have a sex ratio biased toward males, 3) spawn in the vicinity of anadromous individuals, and 4) develop a dull olive-green spawning coloration, although this later character may not be expressed in all resident sockeye salmon populations (Ricker 1959). According to Ricker (1938, 1940, 1959), Burgner (1991), and Wood (1995), kokanee have a balanced sex ratio, spawn earlier in the year, mature at a smaller size, have more gill rakers, and absorb their scale margins to a greater degree upon maturity than anadromous sockeye salmon. These same authors stated that kokanee typically display a bright red body coloration at spawning, although this trait is not expressed in all populations of kokanee. On the other hand, Brannon (1996) argued that exceptions to the above differences in spawn timing, size at maturity, and spawning coloration between kokanee and resident sockeye salmon invalidate these criteria as characters that can be used to define the types.

All three forms (sockeye salmon, resident sockeye salmon, and kokanee) typically spawn in the vicinity of a nursery lake, die after spawning a single time, and as juveniles rear in the pelagic zone of a nursery lake. Kokanee and resident sockeye salmon remain in fresh water for their entire life cycle, whereas sockeye salmon migrate to sea following 1 to 4 years in freshwater, grow to maturity in the ocean, and return to the natal freshwater habitat to spawn following an additional 1 to 4 years at sea.

Genetic differentiation among sockeye salmon and kokanee populations indicates that kokanee are polyphyletic, having arisen from sockeye salmon on multiple independent occasions, and that kokanee may occur sympatrically or allopatrically in relation to sockeye salmon (Foote et al. 1989, Wood and Foote 1990, Foote et al. 1992, Taylor et al. 1996, Wood and Foote 1996, Winans et al. 1996). In some cases, both forms may spawn at the same time and place (Hanson and Smith 1967, McCart 1970, Foote and Larkin 1988, Foote et al. 1994), although typically kokanee spawn earlier than sockeye salmon. According to Brannon (1996), early spawning is not a universal kokanee trait, as some populations spawn at the same time or later than sympatric sockeye salmon. In the locations that have been studied where sockeye salmon and kokanee remain sympatric and spawn in the same place and time, there is a high degree of size-based assortative mating (Foote and Larkin 1988). Assortative mating by body size usually leads to assortative mating by type; kokanee with kokanee and sockeye salmon with sockeye salmon. Even where sneak-spawning by small satellite kokanee males occurs, and results in successful fertilization of sockeye salmon eggs, substantial post-zygotic isolating mechanisms between kokanee and sockeye salmon may reduce gene flow (Wood and Foote 1996).

In relation to co-occurring sockeye salmon and kokanee-sized *O. nerka*, McCart (1970) asked the question, “Do they constitute distinct, non-interbreeding populations or are they simply alternative life-history types arising within single populations?” McCart (1970) showed that spawning sockeye salmon and kokanee in shallow streams tributary to Babine Lake, British Columbia, overlap almost completely in their spawning season and in their distribution on the spawning grounds. He suggested that hybridization between the forms probably occurs under natural conditions. Foote et al. (1989) studied genetic relatedness of sockeye salmon and kokanee from these same streams in Babine Lake and stated that “there were significant differences between sockeye and kokanee in all systems where they spawn sympatrically.” In relation to the Babine Lake tributaries, Foote et al. (1989) stated that “Despite apparent interbreeding, there is an effective restriction in gene flow between sockeye and kokanee that indicates that they do not constitute a single panmictic population.”

Foote et al. (1989) further showed that sympatric kokanee and sockeye salmon in each of three different lake systems in British Columbia were genetically distinct from each other, but were more similar to each other within a lake system than either was to the same morph in another lake system. Likewise, Taylor et al. (1996) showed that, based on allelic variation in mitochondrial DNA *Bgl II* endonuclease restriction sites and two minisatellite nuclear DNA repeat loci, genetic affinities among sockeye salmon and kokanee throughout their range in the North Pacific were organized more by geographic proximity than by life-history type. Within Takla Lake, British Columbia, Wood and Foote (1996) showed that genetic differences between kokanee and sockeye salmon in the same stream were much greater than within morph differences among either sockeye salmon or kokanee spawning in different streams in the same lake system.

However, there are exceptions to the above pattern of sockeye salmon and kokanee genetic relatedness. Winans et al. (1996) investigated the genetic similarity of sympatric populations of kokanee and sockeye salmon in the Lower Shuswap River (in the Fraser River drainage of British Columbia) and Ozette Lake on the Olympic Peninsula and found significant genetic differences between sympatric morphs in both cases. In addition, kokanee from the Lower Shuswap River were genetically more similar to kokanee from Okanagan Lake in the Columbia River drainage than they were to sympatric sockeye salmon from the Lower Shuswap River. Robison (1995) also found genetic similarity between Lower Shuswap River kokanee and Okanagan Lake kokanee, which he interpreted as suggestive of transplantation of Shuswap Lake kokanee into Okanagan Lake. Winans et al. (1996) showed that kokanee from Ozette Lake were divergent from sympatric sockeye salmon, as well as from all other contiguous U.S. stocks of *O. nerka* investigated.

Craig (1995) has shown that although both sockeye salmon and kokanee from Takla Lake, British Columbia exhibit similar red spawning coloration, they are genetically divergent in the ability to utilize the carotenoid pigments in the diet that, when mobilized from the muscle tissue and deposited in the skin, produce the red coloration. Carotenoids are more abundant in the marine diet of sockeye salmon than in the freshwater diet of kokanee, and apparently, kokanee in the Takla Lake population are able to compensate for this difference by being more efficient at extracting carotenoids. Craig (1995) demonstrated that when reared under identical conditions in the hatchery, Takla Lake kokanee turned red at maturity, Takla Lake sockeye salmon were olive-green, and hybrid forms were intermediate in coloration. In addition, Craig (1995, p. 25) stated that “residuals do not turn red at maturity, presumably because they lack the genetic adaptations for increased carotenoid absorption needed to turn red in freshwater.”

Taylor and Foote (1991) compared sustained swimming performance and morphology of sockeye salmon, kokanee, and hybrid juveniles obtained from sympatrically spawning populations in Babine Lake, British Columbia and showed that juvenile sockeye salmon are stronger swimmers than kokanee or sockeye salmon x kokanee hybrids. Similar comparisons of developmental rate (Wood and Foote 1990), ontogeny of seawater adaptability (Foote et al. 1992), and growth and onset of maturity (Wood and Foote 1996) between juvenile sockeye salmon, kokanee, and sockeye salmon × kokanee, indicated that progeny of hybrid crosses may be less successful than progeny of pure crosses of either type in their respective environments.

Danner (1994) studied behavioral, physiological, and genetic differences among sockeye salmon, sockeye salmon x kokanee hybrids, and kokanee. Danner (1994) showed that sockeye salmon were able to adapt to a 24-hour saltwater challenge 3 to 6 weeks before either sockeye x kokanee hybrids or pure kokanee, although he suggested that this earlier onset of saltwater adaptability may be a function of the larger size of sockeye versus sockeye × kokanee hybrids or pure kokanee of the same age. Growth rates of the three types exposed to identical conditions were greatest for sockeye salmon, intermediate for the hybrids, and slowest for kokanee (Danner 1994), although survival was not significantly different among types. Pure sockeye salmon also had significantly higher interlamellar chloride cell density than sockeye × kokanee hybrids or pure kokanee. Danner (1994) also measured migratory tendency of sockeye salmon, kokanee, and their hybrids by their ability to exit rearing tanks through a modified central standpipe. Migration tendency was similar for all three forms. According to Danner (1994), mixed DNA fingerprints of seven *O. nerka* populations differentiated stocks by origin but failed to reveal a marker separating migratory and non-migratory *O. nerka* stocks. Danner (1994) concluded that kokanee stocks with “smoltification characteristics similar to anadromous stocks have not likely separated far from anadromous ancestors” and that “characteristics necessary to become anadromous are maintained” in kokanee populations.

Robison (1995) examined mtDNA genetic divergence between sockeye salmon and freshwater resident *O. nerka*, in four systems where these life history forms spawn sympatrically: 1) Pierre Creek in the Babine Lake Basin, British Columbia, 2) Eagle River, British Columbia, 3) the Middle Shuswap River, British Columbia, and 4) a beach spawning site in Redfish Lake, Idaho. Freshwater residents and sockeye salmon were genetically indistinguishable in the Eagle River and on beach sites in Redfish Lake, but sympatric populations of the two forms were divergent in Pierre Creek and the Middle Shuswap River (Robison 1995). Robison (1995) interpreted these data to indicate that in the Eagle River and Redfish Lake populations, either sockeye salmon or the freshwater residents have been established recently from their counterpart form.

The above studies indicate that both sockeye salmon and kokanee exhibit a suite of heritable differences in morphology, rate of early development, seawater adaptability, growth, and maturation that appear to be divergent adaptations that have arisen from different selective regimes associated with anadromous vs. non-anadromous life histories. Although these heritable differences are strongly expressed in many populations, both indirect and direct evidence exists showing that kokanee are capable of producing anadromous offspring that return from the ocean with the sockeye salmon morphology (Chapman 1941, Foerster 1947, Rounsefell 1958a, Fulton and Pearson 1981, Chapman et al. 1995) and that sockeye salmon are capable of producing freshwater resident offspring (Ward 1932; Ricker 1938, 1959; Scott 1984; Graynoth 1995).

Based on indirect evidence, Chapman (1941) and Rounsefell (1958a) postulated that sockeye salmon observed at the base of Enloe Falls on the Similkameen River, and those below falls that are a natural barrier to fish passage downstream from Lake Chelan, may have been derived from downstream passage of kokanee from up-river lakes. Similarly, sockeye salmon that have been observed at the Whatcom Creek Hatchery of the Bellingham Technical School (Bellingham, Washington) (from 6 to 8 in most years, although none were observed in 1994 and only 2 in 1995), and below natural upstream passage barriers in Whatcom Creek itself, are presumed to be derived from returns of outmigrating Lake Whatcom kokanee (E. Steele[6]).

Several other researchers have provided more direct evidence that kokanee may at times go to sea, survive ocean life, and then return to spawn in freshwater. Foerster (1947) released almost 64,000 marked Kootenay Lake yearling kokanee in the outlet stream of Cultus Lake in 1934 and observed 5-year-old adult sockeye salmon with these markings that returned in 1937, with a calculated survival rate of 0.14% (Chapman et al. 1995). For comparison, survival rates for sockeye smolts returning as sockeye salmon to Cultus Lake were in the range of 1.9-2.6% during this time period (Foerster 1947). According to Foerster (1947) and Ricker (1972), since Kootenay Lake kokanee were known to mature at age-3, with a few at age-2 and age-4, surviving anadromous kokanee were expected to return at age-3 or age-4, not as age-5 sockeye salmon in 1937. Marked Kootenay Lake kokanee returning to Cultus Lake exhibited spawn-timing concurrent with Cultus Lake sockeye salmon (October-November) (Foerster 1947) rather than with the spawn-timing of Kootenay Lake kokanee (August-September) (Vernon 1957). The results of this study "indicated that, when liberated in a stream below a lake and barred from ascending into the lake, some of the kokanee proceeded to sea and returned" (Foerster 1947).

Similar kokanee-marking experiments were conducted in the Columbia River Basin in the 1940s (Fulton and Pearson 1981). Fin-clipped yearling Lake Chelan kokanee released in the Entiat River and Lake Wenatchee kokanee released in Lake Wenatchee and Icicle Creek returned as adults at rates of 0.004%, 0.50%, and 0.27%, respectively. Kokanee in Lake Chelan had been introduced from Lake Whatcom kokanee transplants. In the case of Lake Wenatchee kokanee, Fulton and Pearson (1981) stated that "there was a question as to whether [these] fish were far enough removed from seaward migratory behavior to be classified as kokanee." Also in reference to Lake Wenatchee, Ricker (1972) stated that "there may still be a very incomplete separation of kokanee from sockeye at this lake" and that Lake Wenatchee kokanee may have diverged from sockeye salmon only within the past 90 years, as difficulties in migrating up the Wenatchee River have increased due to water diversions, dams, and high water temperatures. Fulton and Pearson (1981) concluded that in these experiments "adult sockeye salmon that had kokanee parents were slightly smaller than adult sockeye salmon that had anadromous parents."

Kaeriyama et al. (1992) documented returns of sockeye salmon derived from marked kokanee plants in Lake Toro, Japan. Of the 60,000 smolt-sized *O. nerka* released in 1988-1989 in Lake Toro, a total of 20 adult sockeye returned (0.03% of those released). According to Kaeriyama et al. (1992), the parent kokanee population from Lake Shikotsu, Japan that was used in this experiment had been derived from sockeye salmon in Lake Urumbetsu on Iturup Island that were introduced into Lake Shikotsu between 1925 and 1940

---

[6] E. Steele, Hatchery Manager, Whatcom Creek Hatchery, Bellingham Technical College, Maritime Heritage Center, Bellingham, WA. Pers. commun., 20 October 1995.

and were subsequently landlocked for 15 generations. As such they may have retained more capability for anadromy than is typical of kokanee in general. Kaeriyama et al. (1992) concluded that "both anadromous and nonanadromous types of *Oncorhynchus nerka* can be produced from both sockeye and kokanee salmon."

Not only may kokanee occasionally give rise to anadromous individuals, but in several documented instances sockeye salmon stocked in lakes without ocean access have developed into self-sustaining resident "kokanee" or "residual sockeye salmon" populations (Scott 1984, Kaeriyama et al. 1992). For the sake of completeness, it should also be noted that in at least two instances (Ozette Lake, Washington and Lake Cowichan, Vancouver Island), large viable kokanee populations with no documented anadromous members exist in lake basins where access to and from the sea is relatively easy (Dlugokenski et al. 1981, Rutherford et al. 1988).

Historical Distribution

Most modern sockeye salmon populations in Alaska, Canada, and northern Washington arose within the last 10,000 years following retreat of the Cordilleran ice sheet at the close of the last ice age (Wood 1995). Sockeye salmon are thought to have survived the ice ages in refugia in the Bering Sea region of Alaska, south of the ice sheet in the Columbia River, on coastal islands in British Columbia, in Kamchatka, and perhaps on Kodiak Island in Alaska (Wood 1995).

Spawning populations of sockeye salmon do not presently occur in California, and it is uncertain whether they existed there historically. Jordan and Evermann (1896) stated that sockeye salmon occurred in the Klamath River, and Scofield (1916) relates the unsubstantiated claim that 20 sockeye salmon were taken in the commercial fishery in the Klamath River in the summer of 1916. Klamath Lake was accessible to migrating salmon prior to the construction of Copco Dam on the Klamath River in 1917. However, early reports of sockeye salmon in the Klamath River may be explained by Wilcox's (1898) statement that "silver salmon are locally known as blueback" and that "blueback" is the common name for sockeye salmon on the Columbia and Quinault Rivers. Taft (1937) reported the taking of a single sockeye salmon in the Klamath River in August 1936.

Cobb (1911, p. 8) reported that "small runs [of sockeye salmon] are said to occur in Mad and Eel Rivers" in Humboldt County, whereas Jordan and Gilbert (1881a) indicated that sockeye salmon were unknown in the Eel and Sacramento Rivers. Jordan and Gilbert (1881b) did not observe sockeye salmon in the Sacramento River. Rutter (1904) reported the occurrence of a single sockeye salmon in the Sacramento River in 1899. Hallock and Fry (1967) described the recovery of 22 sockeye salmon from the Sacramento River between 1949 and 1958 and speculated as to whether these fish may have been strays, part of a remnant run, or partially derived from kokanee planted in Shasta Lake. Currently, there are no recognized runs of sockeye salmon in California, although introduced kokanee populations have been established in numerous reservoirs and lakes.

Jordan and Gilbert (1881a) indicated that sockeye salmon were unknown in the Rogue River, Oregon, whereas Jordan and Evermann (1896) stated that sockeye salmon occurred in the Rogue River. Oakley and Kruse (1963) reported the occurrence of a stray female sockeye salmon in 1961 in the Kilchis River, a tributary of Tillamook Bay. Currently, there are no recognized populations of sockeye salmon in coastal Oregon streams.

Only about 5% of the pre-1900 nursery lake habitat in the Columbia River drainage remains accessible today to sockeye salmon (Mullan 1986). Historically, two Oregon lakes within the Columbia River Basin supported populations of sockeye salmon: Suttle Lake in the Deschutes River Basin (Nielson 1950, Nehlsen 1995), and Wallowa Lake in the Snake/ Grande Ronde River Basin (Mullan 1986).

Suttle Lake, at the head of the Metolius River, has a surface area of 0.1 km^2 (250 acres) and probably never supported a large population of sockeye salmon. A small dam and screen installed at the outlet of Suttle Lake in 1930 (Fulton 1970, Nehlsen 1995) blocked fish passage both into and out of the lake, while a swimming pool dam, built sometime between 1925 and 1938 at Lake Creek Lodge, impeded fish passage in Lake Creek below Suttle Lake (Nehlsen 1995). Three further dams were subsequently constructed downstream of Suttle Lake, on the Deschutes River: Pelton Dam and Pelton Re-regulating Dam were constructed in 1958, and Round Butte Dam was constructed in 1964. A small number of sockeye salmon are currently observed at the base of the Pelton Re-regulating Dam each summer; however, neither their origin nor whether they spawn below the dams, is known (ODFW 1995a).

Wallowa Lake, near the head of the Wallowa River in northeastern Oregon, once supported a substantial sockeye salmon population. Bartlett (1967) indicated that following the forced removal of members of the Nez Perce Tribe in 1877 and elimination of their ceremonial and subsistence fishery based on sockeye salmon from the Wallowa Valley, seining by horse and rowboat at the head of Wallowa Lake became a small industry that produced an annual catch of about 27,216 kg (60,000 pounds) of sockeye salmon by 1881. Bendire (1881) reported the taking of several *O. nerka* specimens in Wallowa Lake on 31 August and 1 September 1880. A rough dam to supply water to a small shingle mill was built across the lake outlet in 1884, and a more substantial dam and irrigation ditch were constructed in 1890 (Bartlett 1967). Bartlett (1967) indicated that this latter dam blocked the migration corridor for the Wallowa Lake population and resulted in land-locked sockeye salmon, locally termed “yanks,” that spawned in tributary creeks in the fall. Evermann and Meek (1898) reported that both “large and small redfish” occurred in Wallowa Lake and spawned together. The small redfish or “yanks” or “grayling” were likely residual sockeye salmon, as they were overwhelmingly males and more silvery in color than larger fish (Evermann and Meek 1898).

Several authors (CBFWA 1990, ODFW 1995a) have reported that prior to increasing the height of the dam at Wallowa Lake in 1916, sockeye salmon continued to return and spawn above the lake. The last reported sockeye salmon were apparently observed in

Wallowa Lake in 1916 (Toner 1960) or 1917 (CBFWA 1990). However, Cramer (1990) stated that "sockeye were extinct from the lake by 1904." ODFW (1995a) reported that sockeye salmon were observed until the early 1930s in the Wallowa River below the lake, while Parkhurst (1950a) and Fulton (1970) reported that construction of a 12-m high concrete dam at the lake outlet in 1929 finished off the population. Cramer (1990) stated that a 4-m tall dam that existed between 1906 and 1924 at the Wallowa River Hatchery, 43 miles below Wallowa Lake, completely blocked upstream fish passage. Considerable numbers of non-native sockeye salmon were stocked in the Wallowa River below Wallowa Lake in the 1920s and 1930s (Cramer 1990; his Appendix 8), perhaps contributing to reports of sockeye salmon returning to the Wallowa River up until the early 1930s (see Appendix Table D-2).

Historically, sockeye salmon spawned and reared in the Snake River in several high mountain lakes in Idaho. In the Salmon River Basin, sockeye salmon occurred in Alturas, Redfish, Pettit, and Stanley Lakes (Evermann 1895, 1896; Evermann and Scovell 1896; Evermann and Meek 1898), and perhaps in Yellowbelly Lake (Bjornn et al. 1968, Mullan 1986, Chapman et al. 1990). Mullan (1986) stated that the presence of kokanee indicated that sockeye salmon once used Little Redfish Lake and Hell Roaring Lake in the Stanley Basin and Warm Lake on the South Fork Salmon River. In the Payette River Basin, sockeye salmon reportedly occurred in Big Payette, Upper Payette (Evermann 1895, 1896; Evermann and Scovell 1896; Fulton 1970), and Little Payette Lakes (Mullan 1986). Currently, a genetically distinct sockeye salmon population exists in Redfish Lake, Idaho and is listed as endangered under the federal Endangered Species Act. Other anadromous *O. nerka* populations in Idaho are thought to be extinct, although *O. nerka* in Alturas Lake have been known to produce outmigrating individuals. In addition, kokanee stocks in Redfish, Alturas, and Stanley Lakes are genetically more similar to sockeye salmon from Redfish Lake than they are to other *O. nerka* stocks investigated from outside the Stanley Basin (Winans et al. 1996, Waples et al. in press).

The history of the decline of sockeye salmon in the Stanley Basin lakes on the Salmon River was reviewed in Bjornn et al. (1968), Chapman et al. (1990), and Waples et al. (1991). Evermann (1895) observed sockeye salmon spawning in the inlet to Big Payette Lake and related that local residents informed him that between 1870 and 1880 two fisheries operated on this lake and in some years took up to 75,000 fish (or 13,600 to 18,140 kg) and that a few sockeye salmon may have gone as far as Upper Payette Lake. A diversion dam built about 1914 near Horseshoe Bend on the Payette River, and Black Canyon Dam constructed in 1923, blocked access by sockeye salmon to the Payette Lakes (Parkhurst 1950b, Fulton 1970, Mullan 1986). Current accessible lake-rearing habitat for sockeye salmon in Idaho, based on lake area, represents about 25% of historically available habitat (Hassemer et al. 1996).

Within the Columbia River Basin in Washington, historical populations of sockeye salmon existed in the Yakima, Wenatchee, and Okanogan Rivers. Sockeye salmon populations reportedly existed in two small lakes at the head of the Yakima River on the present site of Lake Keechelus, as well as in Cle Elum Lake in the Yakima/Cle Elum River Basin, in Kachess Lake in the Yakima/Kachess River Basin, and in Bumping Lake in the

Yakima/Naches/Bumping River Basin (Davidson 1953, Fulton 1970, Mullan 1986). The historical total run size of Yakima River sockeye salmon has been estimated at either 100,000 (Davidson 1953) or 200,000 (CBFWA 1990). Construction of crib dams without fish passage facilities at Lakes Keechelus and Kachess in 1904 and at Lake Cle Elum in 1905 eliminated sockeye salmon populations in these lakes (Bryant and Parkhurst 1950, Davidson 1953, Fulton 1970, Mullan 1986). Construction of an impassable storage dam at Bumping Lake in 1910 likewise eliminated a sockeye salmon population in that lake, with an estimated annual run of 1,000 fish (Davidson 1953, Fulton 1970).

The native population of sockeye salmon in Lake Wenatchee was severely depleted during the early 1900s (Bryant and Parkhurst 1950, Davidson 1966, Fulton 1970), with returns counted over Tumwater Dam on the Wenatchee River in 1935, 1936, and 1937 amounting to 889, 29, and 65 fish, respectively (WDF et al. 1938). Small dams and unscreened irrigation diversions on the Wenatchee River contributed to the decline of this population (Bryant and Parkhurst 1950).

Historically, sockeye salmon are thought to have utilized Lakes Okanagan, Skaha, and Osoyoos in the Okanogan River Basin for juvenile rearing (Bryant and Parkhurst 1950, Fulton 1970, Mullan 1986). Sockeye salmon access to Lakes Okanagan and Skaha in British Columbia was blocked by dams in 1915 and 1921, respectively. Access to Lake Osoyoos remained open, but the population was severely depleted in the early 1900s (Davidson 1966, Fulton 1970), with returns to the Okanogan River in 1935, 1936, and 1937, amounting to 264, 895, and 2,162 sockeye salmon, respectively (WDF et al. 1938).

In order to preserve a portion of the sockeye salmon stocks denied access to the Upper Columbia River in 1939 by Grand Coulee Dam, the Grand Coulee Fish-Maintenance Project (GCFMP) trapped all sockeye salmon at Rock Island Dam between 1939 and 1943 and relocated them to Lakes Wenatchee or Osoyoos or to one of three national fish hatcheries (Leavenworth, Entiat, and Winthrop) for artificial propagation. Numerous descendants of artificially propagated sockeye salmon trapped at Rock Island and Bonneville Dams, together with progeny of Quinault Lake sockeye salmon, were stocked into Lakes Wenatchee and Osoyoos between 1940 and 1968 (Mullan 1986, see Appendix Table D-2). Consequently, the current populations of sockeye salmon that return to Lake Wenatchee and the Okanogan River may consist of some mixture of native and non-native fish (see “Artificial Propagation” section below).

Fulton (1970) listed Palmer Lake on the Similkameen River, a tributary of the Okanogan River, as originally supporting native sockeye salmon, although some authors (Craig and Suomela 1941) suggested that salmon could not have ascended Enloe Falls. The current Enloe Dam blocks access to all but the lower six miles of the Similkameen River. Sockeye salmon have been observed on numerous occasions since 1936 in the Similkameen River below the dam, during the Okanogan River sockeye salmon migration (Chapman 1941, Bryant and Parkhurst 1950, Chapman et al. 1995). Sockeye salmon (see Appendix Table D-

2) and kokanee (see Appendix Table D-5) have been released above Enloe Dam at various times.

In reference to sockeye salmon, WDF et al. (1938) stated that “it is certain that none go into the Entiat, and none have ever been seen in the Methow.” During operation of the GCFMP, sockeye salmon fry and fingerlings were released in the Methow and Entiat Rivers (Mullan, 1986, see Appendix Table D-2), and currently small numbers of sockeye salmon are consistently seen each year in these rivers (Langness 1991, Chapman et al. 1995; see section below on “Information Specific to Sockeye Salmon Populations Under Review”).

Historically, it is likely that Upper Arrow, Lower Arrow, Whatshan, and Slocan Lakes in the Upper Columbia River drainage in British Columbia were utilized by sockeye salmon, as nursery lake habitat (Mullan 1986). In addition, Fulton (1970) stated that sockeye salmon probably ascended to Kinbasket, Windermere, and Columbia Lakes in the Canadian portion of the Columbia River, and Mullan (1986) suggested that the presence of kokanee indicated the past use of these lakes by sockeye salmon. WDF et al. (1938) and Chapman (1943) reported observations of sockeye salmon at Kettle Falls on the Columbia River and at Upper and Lower Arrow Lakes on the Upper Columbia River in British Columbia prior to Grand Coulee Dam construction. Comparison of sockeye salmon counts at Rock Island Dam, Tumwater Dam on the Wenatchee River, and Zosel Dam at Oroville on the Okanogan River between 1935 and 1937 indicated that more than 85% of the sockeye salmon passing Rock Island Dam were bound for spawning areas above the Grand Coulee Dam site (WDF et al. 1938). Chapman et al. (1995) indicated that this value was likely overestimated by the amount of pre-spawning mortality that might have occurred between Rock Island Dam and both Tumwater Dam on the Wenatchee River and the mill dam at Oroville on the Okanogan River. Recent escapement data on Okanogan River sockeye salmon indicate that pre-spawning mortality between Wells Dam and spawning grounds on the Okanogan River is about 30%. If similar pre-spawning mortality occurred upstream of the Grand Coulee Dam site in the years 1935 through 1937, the percentage of sockeye salmon passing Rock Island Dam that spawned upstream of Grand Coulee Dam would have been 60-64% (Chapman et al. 1995).

Historically, sockeye salmon were known to occur in Puget Sound at Baker Lake on the Baker River, a tributary of the Skagit River, and probably in Mason Lake at the base of the Kitsap Peninsula (Nehlsen et al. 1991). It is uncertain whether sockeye salmon were present historically in the Skokomish River, which drains into Hood Canal, or in the Lake Washington/Lake Sammamish Basin, which drains into Puget Sound (see following discussion). A sockeye salmon population may have spawned in Mason Lake but was reportedly eliminated in 1852 when a dam was placed on Sherwood Creek, the outlet creek of Mason Lake (Nehlsen et al. 1991). It should be noted, however, that the information cited in Nehlsen et al. (1991) concerning Mason Lake was attributed to a Twana Indian born 13 years after this stock reportedly went extinct, and as such is second-hand information at best. Baker River sockeye salmon continue to return to the lower Baker River, where they are trapped and transported above one or both dams on the Baker River to spawn in artificial beaches provided with gravel substrate and upwelling water.

Historical information indicates that sockeye salmon may once have ascended the North Fork of the Skokomish River, located at the southern end of Hood Canal (Wampler 1980, N. Lampsakis[7]). The original Lake Cushman had a surface area of 500 acres (Henshaw et al. 1913) and had the potential to support sockeye salmon, prior to a dam being placed at its outlet.

Numerous introductions of Baker Lake, Cultus Lake, and an unknown stock of sockeye salmon have occurred in the Lake Washington/Lake Sammamish Basin (see Appendix Table D-2), and presently the largest population of sockeye salmon in the contiguous U.S. spawns in the Cedar River, the main tributary of Lake Washington (Royal and Seymour 1940, Kolb 1971, WDF et al. 1993). Historical accounts concerning the presence and distribution of sockeye salmon within the Lake Washington/Lake Sammamish drainage are equivocal (see discussion in "Information Specific to Sockeye Salmon Populations Under Review" section below). Kokanee were present within this drainage historically and are known to be native (Crawford 1979).

Construction of Elwha Dam in 1910 on the Elwha River on Washington's Olympic Peninsula reportedly eliminated a native sockeye salmon population that spawned and reared in Lake Sutherland (Brown 1982, Wunderlich et al. 1994, Hiss and Wunderlich 1994, NPS 1995). However, Gilbert (1914), in reference to Lake Sutherland, stated that

> we are acquainted with certain colonies of dwarf redfish which have been inaccessible to the sea-run form for a very long period. Such are the colonies which inhabit Lakes Crescent and Sutherland, on the northern slopes of the Olympic Mountains in Washington. The outlets of these lakes open on the southern shore of the Straits of Fuca [sic]. No run of sockeyes occurs along this shore nor into any of the streams tributary to it.

Hiss and Wunderlich (1994) recorded that 7,128,000 kokanee from outside the Elwha Basin were released in Lake Sutherland between 1933 and 1964. In 1993, an estimated 3,174 kokanee of unknown heritage spawned in Lake Sutherland (Hiss and Wunderlich 1994).

Native sockeye salmon populations exist in Ozette and Quinault Lakes on the outer coast of the Olympic Peninsula in Washington (Evermann and Goldsborough 1907, Cobb 1911, Kemmerich 1945, Atkinson et al. 1967, WDF et al. 1993). Sockeye salmon currently exist in Lake Pleasant on the Olympic Peninsula of Washington, but whether this population is native or the result of introductions is uncertain (Kemmerich 1945, WDF et al. 1993). Numerous sources indicate that Ozette and Quinault Lake sockeye salmon were of great importance for subsistence and in ceremonies of the Makah and Quinault Indian cultures, respectively (Willoughby 1889, Lestelle and Workman 1990, Storm et al. 1990). Although

---

[7] N. Lampsakis, Point No Point Treaty Council, 7999 W. Salish Lane, Kingston, WA 98346. Pers. commun. 14 June 1995.

sockeye salmon may not currently run up the Dickey River to Dickey Lake (a tributary system of the Quillayute River on the Olympic Peninsula), a sockeye salmon population existed in the lake historically (according to E. L. Brannon[8]).

Age Composition

Overall age of maturity in sockeye salmon ranges from 3 to 8 years. Male sockeye salmon are capable of maturing at any of 22 different combinations of freshwater and ocean ages, while female sockeye salmon may mature at any of 14 different age compositions (Healey 1986, 1987). Kokanee generally mature after either 2, 3, or 4 years in fresh water. Formulas for designating freshwater and ocean age in sockeye salmon have been reviewed by Koo (1962) and Foerster (1968). In this report, the European method of age designation will be used, in which a decimal point separates the number of winters spent in freshwater (minus the incubation period) from the number of winters spent in saltwater (Burgner 1991). Total age is calculated by adding 1 year to the total of freshwater and saltwater age. This is the method adopted by the Fisheries Research Institute (University of Washington) and the Pacific Salmon Commission to designate age of sockeye salmon. For example, an age 1.2 fish would have spent one winter in fresh water and 2 winters in the sea for a total age of 4 years.

A combination of both environmental and genetic factors is thought to influence age composition and age at maturity. Rogers (1987) reported that among sockeye salmon from Wood River, Alaska, ocean age was most often determined by parental ocean age, whereas environmental factors most often determined freshwater age. Godfrey (1958) and Ricker (1972) thought that hereditary factors were more important than environmental factors in determining age at maturity in sockeye salmon, whereas Peterman (1985) thought that environmental conditions during early marine life were of primary importance in determining age at maturity.

While age composition and total age at maturity among sockeye salmon populations may vary year-to-year within a population, due to environmental variation and maternal influences (Bilton 1970), age composition also varies between populations, both in different river systems and within river systems (Ricker 1972, Smirnov 1975, Peterman 1985, Healey 1987, Rogers 1987, Burgner 1991, Rutherford et al. 1992, Blair et al. 1993). Further complicating analyses of age structure comparisons between populations is the fact that for some populations the percent age composition is known to change over the course of a single year's run, and selective harvests can alter the age structure of escapements (Halupka et al. 1993). Available data on age composition (see Appendix Table C-1) or total age at maturity (see Appendix Table C-2) for sockeye salmon in Washington and selected British Columbia populations reveals temporal variability within populations, as well as geographical differences among populations.

---

[8] E.L. Brannon, University of Idaho, Moscow, Idaho 83843. Pers. commun., 22 May 1995.

With the exceptions of Quinault Lake, Lake Washington Basin, Lake Wenatchee, and Okanogan River, multiple-year freshwater/saltwater age composition data on populations of sockeye salmon in Washington and Oregon were extremely limited (see Appendix Table C-1). Figure 3 compares the overall mean percentage of returning sockeye salmon in each age category among eleven localities in Washington. Since these data were collected over different years and have been derived from both long-term (30 years, Quinault Lake) and short-term (1 year-Ozette Lake, 2 years-Lake Pleasant) data sets, they should be interpreted in light of the above-mentioned potential for temporal variation in population age structure. Figure 4 compares age composition of adult sockeye salmon in the Quinault River tribal fishery for the years 1912 to 1924 and 1974 to 1993.

In general, there has been a shift in sockeye salmon age at return to the Lake Washington Basin over the past 25 years, with adults appearing to return at an older age than they did in the 1970s (J. Ames[9]). Although return-year data for sockeye salmon in Lake Washington show large fluctuations, comparison of data from 1970 to 1994 indicates that in early years less than about 5% of returning sockeye salmon were 5-year-olds; presently, an average of 19.5% (range 8-63% between 1989 and 1994) are 5-year-olds (J. Ames[10]) (see Appendix Table C-1). Hendry (1995) and Hendry and Quinn (1997) concluded that in 1992 and 1993, a greater proportion of sockeye salmon of age 1.1 (3-year-olds) occurred in Big Bear and Cottage Lake Creeks than in the Cedar River or Issaquah Creek, within the Lake Washington Basin. However, the sampling methods used on the Cedar River could easily have missed the jacks because of their smaller size or potentially different migration timing. The weir on the Cedar River where sockeye salmon were caught was less than 100% “jack-tight” (J. Ames[11]). Therefore, Hendry’s (1995) data may not characterize the normal sockeye salmon jack composition of Lake Washington stocks. Ricker (1972, p. 65) reports that a “large number” of 0-age or underyearling sockeye salmon smolt were observed leaving Lake Washington in summer 1966. About 4% of the sockeye salmon smolts leaving Lake Washington in 1996 were thought to be underyearlings (see Appendix Table C-4).

In both Lake Wenatchee and on the Okanogan River, adult sockeye salmon spawners are typically 4-year-olds; however, in some years fish of age 1.1 (3-year-olds) may be more abundant than 4-year-olds in the Okanogan River population (Mullan 1986, Chapman et al. 1995) (see Appendix Tables C-1 and C-2). Three-year-old sockeye salmon in the Okanogan River population are predominately males, however limited sex-ratio data of carcasses on the spawning grounds extracted from Allen and Meekin’s (1980) Table 15, indicated that

---

[9] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 24 April 1995.

[10] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091.

[11] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 13 March 1996.

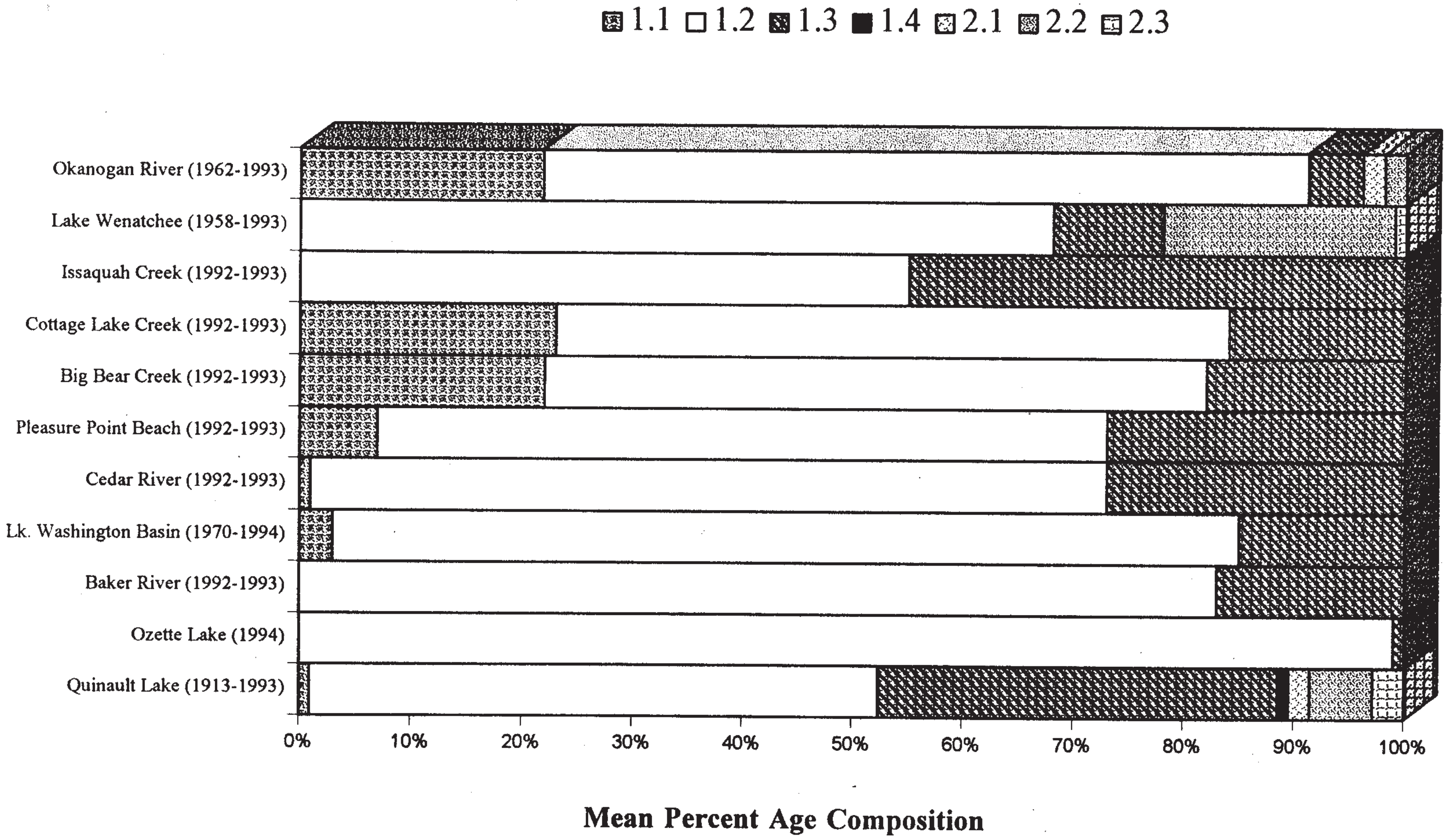


Figure 3. Mean percent age composition of sockeye salmon returns to eleven localities in Washington (see Appendix Table C-1). Age is designated by the European method (see "Age Composition" section).

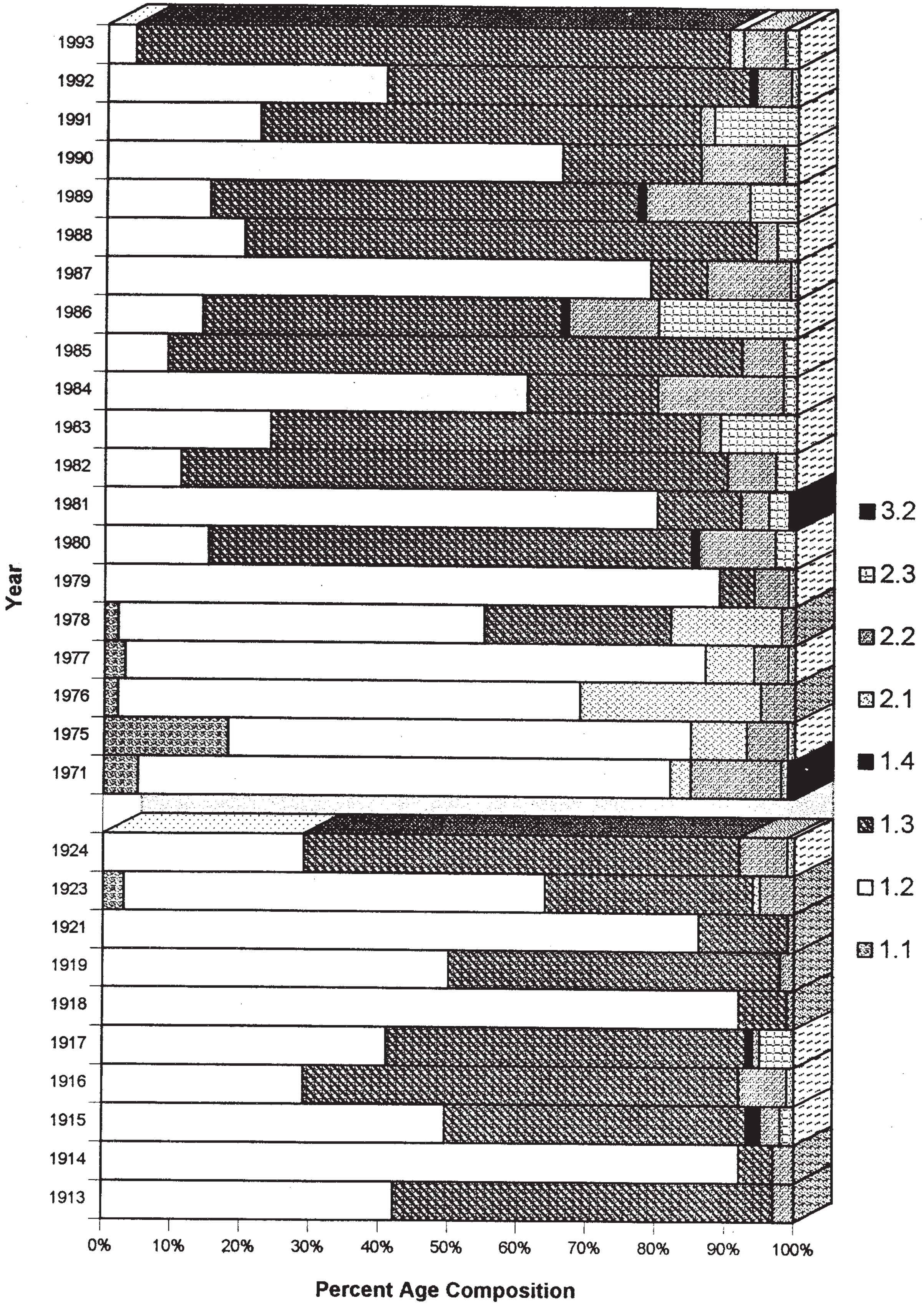


Figure 4. Age composition of adult sockeye salmon in Quinault River fishery from 1913-1994 (Davidson and Barnaby 1936, QIN 1995a). Age is designated by the European method (see "Age Composition" section).

3-year-old returns in 1971, 1972, and 1973 consisted of 20%, 28%, and 22% females, respectively. The population age structure of Lake Pleasant sockeye salmon is highly unusual, with both a high number of 3-year-old spawners (36-40%) and of smolts that have spent 2 years in freshwater (40-50%) (Fig. 3 and Appendix Table C-1).

Rutherford et al. (1992) found that among coastal British Columbia sockeye salmon lakes, Mikado and Mercer Lakes had greater than 50% freshwater age-2 spawners, and this freshwater age was more common in the northern mainland and Queen Charlotte Island populations than in populations from Vancouver Island or the southern mainland. Some small coastal lakes on Vancouver Island, like Cheewhat Lake and Muriel Lake, reportedly have a high proportion of both male (jacks) and female (jills) 3-year-old returns (K. Hyatt[12]).

Halupka et al. (1993) identified 14 populations out of 230 in southeast Alaska with substantial proportions of zero freshwater age (= sea-type sockeye salmon) individuals (Table 2). In addition, they found 4 populations dominated by fish having spent 2 years in freshwater prior to smoltification, including those from Benzeman Lake on Baranof Island, which had the shortest length of any sockeye salmon population investigated and were listed as unique. The Hasselborg River stock on Admiralty Island was listed as unique; it is dominated by sea-type individuals and spawns in a clearwater stream, whereas other sea-type stocks listed by Halupka et al. (1993) were restricted to glacial drainages.

Fecundity and Egg Size

For a given fish size, female sockeye salmon have the highest fecundity and the smallest egg size among the Pacific salmon (Burgner 1991). Average fecundity across the range of sockeye salmon is from 2,000 to 5,200, and from about 300 to slightly less than 2,000 for kokanee (Burgner 1991, Manzer and Miki 1985). Because larger females have higher fecundity than smaller females, any comparison of fecundity between populations is confounded by differences in female age and size (Rounsefell 1957, Bagenal 1978). However, studies have shown that once the size of females has been taken into account, differences between age classes are not significant (Beacham 1982, Manzer and Miki 1985). Consequently, comparisons of fecundity should be adjusted for size (Beacham 1982), which requires measurements of both size and fecundity from the same individuals. Available information that provides these measurements for naturally spawning sockeye salmon populations was insufficient to adequately evaluate patterns of relative fecundity among sockeye salmon populations in the Pacific Northwest (see Appendix Table C-3). Data on average fecundity were available for Okanogan River, Lake Wenatchee, Cedar River, and Quinault Lake sockeye salmon stocks in Washington (see Appendix Table C-3). Chapman et al. (1995) pointed out that sockeye salmon from Okanogan River and Lake Wenatchee in the mid-Columbia River have some of the lowest fecundity estimates reported in the literature,

---

[12] K. Hyatt, Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological STation, Nanaimo, B.C., Canada V9R 5K6. Pers. commun., 5 June 1995.

and that this low fecundity may be related to the long migration distance inherent to these populations. Quinault Lake sockeye salmon also have a relatively low average fecundity (see Appendix Table C-3).

In other areas, researchers have reported that fecundity can be effectively used to differentiate between sockeye salmon populations in different river systems (Hartman and Conkle 1960, Foerster 1968, Ivankov and Andreyev 1969, Manzer and Miki 1985, Burgner 1991) and between spawning locations within the same river system (Aro and Broadhead 1950, Gard et al. 1987, Beacham and Murray 1993, Blair et al. 1993). Manzer and Miki (1985) found that within British Columbia, coastal sockeye salmon stocks were about 18% more fecund than interior stocks. Beacham and Murray (1993) also found that fecundity was less in upper river stocks of sockeye salmon than lower river stocks in both the Skeena and Fraser Rivers, although the relationship was statistically significant only in the former.

With the exception of the Lake Washington Basin, no information on egg size was found for sockeye salmon populations in Washington and Oregon. Mean egg weight differed among sockeye salmon populations in the Lake Washington Basin (Cedar River, Issaquah Creek, Big Bear Creek, Cottage Lake Creek, and Lake Washington beach spawners) in both 1992 and 1993, although large inter-annual variation was evident in all populations except the Cedar River, which had larger sample sizes than the other populations (Hendry 1995). In the Cedar River, Quinn et al. (1995) found body length of females to be positively correlated with gonad weight, egg number, and egg weight. In other locations the size of sockeye salmon eggs has been used to differentiate populations (Robertson 1922, Brannon 1987, Beacham and Murray 1993). Within Fraser River sockeye salmon, upper river populations had smaller diameter and lighter eggs than did lower river populations (Beacham and Murray 1993), whereas sea-type sockeye salmon in Harrison Rapids (on the Fraser River) had larger eggs than did nearby lake-type populations (Robertson 1922, Beacham and Murray 1993). Quinn et al. (1995) reported very high correlations between egg weight and size composition of incubation gravels, whereas neither body length nor snout length were well correlated with egg weight among 18 Alaskan sockeye salmon populations.

Fry Emergence Timing and Fry Migration

Sockeye salmon populations may differ in spawn timing and rates of development and fry emergence as adaptations to different thermal regimes (Brannon 1987, Beacham and Murray 1989). Beacham and Murray (1989) observed that development rate (based on hatching and emergence timing) was faster for interior-spawning sockeye salmon in the Fraser River, which experienced colder temperatures, than for lower Fraser River sockeye salmon. Sockeye salmon eggs spawned in lake outlet tributaries or on lakeshore beaches are typically exposed to warmer temperatures than eggs spawned in inlet tributaries, since lakes cool more slowly in the fall. It has been postulated that in order to synchronize fry emergence in these three spawning habitats with optimal feeding and survival conditions in common lake environments, differences in egg size, incubation period, and spawn timing have arisen (Godin 1982, Brannon 1987, Burgner 1991). This has been suggested to explain the observation that inlet spawners typically spawn earlier than lakeshore beach and lake outlet spawners, which experience higher incubation temperatures (Burgner 1991).

Sockeye salmon fry emerge in the Cedar River from January through early June, with peak emergence occurring from early March to mid-May (Stober and Hämäläinen 1979, 1980; Seiler and Kishimoto 1996). Within Lake Washington/Lake Sammamish populations, Hendry (1995) observed different hatching and emergence timing among Cedar River, Big Bear Creek, Cottage Lake Creek, Issaquah Creek, and Lake Washington beach spawners.

Emerging fry possess heritable rheotactic and directional responses that allow fry from outlet tributaries to move upstream and fry from inlet tributaries to move downstream, in order to reach the nursery lake habitat (Raleigh 1967, Brannon 1972a, Burgner 1991). Fry of some populations that spawn in side tributaries connected to lake outlet streams must first travel downstream and then reverse orientation and travel upstream to the nursery lake (Egorova 1970, Brannon 1972a). Fry spawned in rivers without nursery-lake habitat rear in spring areas, side channels, and sloughs or travel to the lower estuary to rear (Birtwell et al. 1987, Eiler et al. 1992). Raleigh (1967), Brannon (1972a, b), and Miller and Brannon (1982) indicated that fry migration patterns of sockeye salmon are under genetic control.

Quinn (1980, 1981) showed that sockeye salmon fry have innate directional preferences, with Cedar River fry displaying a northerly direction preference, corresponding to the direction they take in migrating into Lake Washington. Fry emigrating from the Cedar River do so primarily at night (less than 1% were seen to migrate in daylight) (Hämäläinen 1978; Stober and Hämäläinen 1979, 1980) and in normal flows from 24% to 98% of marked released fry migrated to Lake Washington in one night (Seiler and Kishimoto 1996). Hendry (1995) observed no difference between migration patterns of sockeye salmon fry from the Cedar River and those from Lake Washington beach spawners (both populations were positively rheotactic), although beach spawners were predicted to lack a particular rheotactic response based on studies of beach fry from Cultus Lake (Brannon 1972b).

Smolt Size and Outmigration Timing

Summaries of available data on sockeye salmon smolt size (see Appendix Table C-4) and smolt migration timing (see Appendix Table C-5) reveal differences between populations that are related to lake productivity, thermal regime, and altitude (Burgner 1991). Sockeye salmon smolt size is influenced by length of stay in the lake habitat and lake productivity. Smolts migrating earlier in the season tend to be larger than later migrants, and both survival at sea and age and size at maturity are dependent on smolt size (Burgner 1991). Unfertilized coastal lakes of British Columbia reportedly produce smaller smolts than more productive interior lakes (Pauley et al. 1989). Freshwater age-1 smolts from Lake Washington, Ozette Lake, Baker Lake, and Lake Osoyoos tend to be relatively large, whereas the smallest lake-type sockeye salmon smolts are found in glacial Owikeno Lake in coastal British Columbia (see Appendix Table C-4). Although large smolt size in the Lake Osoyoos population apparently results in a large proportion of small 3-year-old returns, large smolt size in the

Baker River, Ozette Lake, and Lake Washington populations has not resulted in large numbers of 3-year-old returning adults in those systems (see Appendix Table C-1).

Since most sockeye salmon lakes in the north are ice-covered in the winter, and sockeye salmon migration begins soon after ice break-up, there is both a south-to-north cline and an altitude-dependent factor in sockeye salmon smolt outmigration timing (Hartman et al. 1967, Burgner 1991). Besides time of ice breakup, variations in outmigration timing can be affected by water temperatures; wind direction and its effects on the lake surface; and age, size, and physiological condition of the smolts (Burgner 1991).

Because of their responses to lake productivity, smolt size and outmigration timing have been influenced by anthropogenic activities that affect lake productivity, including artificial fertilization (Hyatt and Stockner 1985) and agricultural (Allen and Meekin 1980, Chapman et al. 1995) and municipal pollution (Edmondson and Lehman 1981). Density-dependent processes may also lead to smolts leaving overcrowded lakes at a smaller than normal size (Hartman and Burgner 1972, Goodlad et al. 1974, Hyatt and Stockner 1985). These factors thoroughly complicate the assessment of any regional pattern that may exist for either smolt size or outmigration timing, since these activities have occurred throughout the range of sockeye salmon. Sampling design may also influence reported smolt sizes and outmigration timing.

Sockeye salmon smolts migrate from most nursery lake systems at night, with greatest numbers leaving between sunset and early morning (Burgner 1991). However, this migration pattern is reversed in Lake Washington, with most sockeye salmon smolts exiting the system during daylight hours (Warner 1997).

Adult Run-Timing

In general, river entry[13] and spawn timing[14] of sockeye salmon show considerable spatial and temporal variability. Sockeye salmon enter Puget Sound rivers from mid-June through August, while Columbia River populations begin river entry in May, passing Bonneville Dam from very late May to late August (see Appendix Table C-6). Sockeye salmon spawn in Puget Sound from late September to late December and occasionally into January, and in the Columbia River from late September to early November (see Appendix Table C-6). Small numbers of spawners are present in the Cedar River into February

---

[13] River entry was taken from reports which specifically listed it, or was based on the timing of peak in-river catches of sockeye salmon.

[14] Spawn timing was compiled from reports listing spawn timing, or was based on dates when peaks in spawning occurred, as reported in spawning ground surveys.

(WDFW 1996). Sockeye salmon on the western Olympic Peninsula of Washington and on Vancouver Island, British Columbia begin entering rivers much earlier than the above stocks, in April and May, and in the case of Quinault Lake as early as January. Sockeye salmon begin entering Cheewhat Lake on Vancouver Island in late February or early March, and the migration continues into September with a peak in mid-June to mid-July (K. Hyatt[15]). Sockeye salmon on the Olympic Peninsula may spend 3 to 6 months in fresh water before spawning, and in the extreme case of Quinault Lake from 3 to 10 months. Spawning on the Olympic Peninsula begins later in the fall and extends further into the new year than in Puget Sound or on the Columbia River (see Appendix Table C-6).

Fraser River sockeye salmon exhibit remarkably consistent chronological separation of river entry and spawn timing among individual spawning populations (Killick 1955; Gilhousen 1960, 1990). Two Fraser River sockeye salmon stocks, early Stuart and early Nadina, overlap in run-timing with Puget Sound stocks from Baker River and Lake Washington. Other Fraser River stocks overlap the run-timing of Okanogan River and Lake Wenatchee sockeye salmon (see Appendix Table C-6). Adaptation of round-the-clock video technology to sockeye salmon escapement counts at Tumwater Dam on the Wenatchee River revealed that up to 5% of the sockeye salmon were passing up-river at night and would not normally have been counted (Hatch et al. 1992).

Halupka et al. (1993) found no latitudinal pattern in run-timing in an analysis of 230 sockeye salmon stocks in southeast Alaska, although interior stocks had later mean migration dates and more compact run-timing than coastal mainland or island stocks. Five sockeye salmon populations in southeast Alaska were identified as having protracted run-timing, including two that may have had separate population segments and one interior stock that was identified as having run-timing lasting more than twice as long as any other interior stock (Halupka et al. 1993).

Egorova (1970) reported that in comparison with other Kamchatka sockeye salmon stocks, both river-entry timing and spawning duration are unusually protracted in sockeye salmon from the Ozernaya River on the southwestern coast of Kamchatka. River entry begins at the end of May, peaks in August, and is not over until the beginning of October. Spawning in this system lasts from the end of July to the beginning of February.

Burgner (1991) stated that since there is an optimum time for fry emergence that coincides with maximum conditions for juvenile survival, accurate spawn timing is crucial to allow these events to coincide. Spawn timing depends to some degree on spawning gravel temperature (Brannon 1987, Burgner 1991). Sockeye salmon river- and lake-entry timing is also influenced by other factors including river flow, as in Lake Pleasant (WDF et al. 1993), and river temperature, as in the Okanogan River (Major and Mighell 1966, Allen and Meekin

---

[15] K. Hyatt, Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, B.C., Canada V9R 5K6. Pers. commun., 5 June 1995.

1980, Mullan 1986, Swan et al. 1994). Blackbourne (1987) reported that Fraser River and Quinault River sockeye salmon run-timing is closely correlated with winter-to-spring sea-surface temperatures in the Gulf of Alaska; presumably these stocks tend not to travel so far north in a cold year and thus reverse direction earlier, approaching their natal rivers earlier than usual. All these factors make determinations and comparisons of “average” or “peak” river entry and spawn timing difficult because of the high spatial and temporal variability exhibited within basins.

Available information on dates of occurrence and spawn timing for sockeye salmon observed in rivers without accessible lake rearing habitat in Washington is summarized in Appendix Table C-7.

Spawner Size

Like the other life history traits discussed above, adult spawner size[16] in naturally spawning populations shows considerable spatial and temporal variability, which may obscure regional patterns of variation. Based on fishery catch data, which tends to select for larger fish than are present in the total run, Columbia River sockeye salmon average about 1.58 kg after two winters at sea; Fraser River sockeye salmon average 2.73 kg after a similar time at sea; Bristol Bay, Alaska sockeye salmon average 2.56 kg after two years at sea; and Chignik River, Alaska sockeye salmon average 3.16 kg after three winters at sea (Burgner 1991). At the same age, males are generally larger than females after two and three winters at sea (Burgner 1991). Halupka et al. (1993) found that within populations in southeast Alaska, age-1.3 and 2.3 males were larger than females, whereas age-1.2 females were larger than males of the same age.

Adult body size may also be affected by variations in stock abundance. McKinnell (1995) found that from 1912 to the late 1960s, the mean lengths of age-1.3 sockeye salmon from northern and central British Columbia stocks (Rivers Inlet, Nass, and Skeena Rivers) were significantly smaller ($P = 0.05$) in years when Bristol Bay sockeye salmon abundance was high. Density-dependent effects during ocean life on sockeye salmon growth and adult body length have also been reported by Rogers (1980), Peterman (1984), and Rogers and Ruggerone (1993).

Although the size at maturity of pink, coho, and chinook salmon caught in coastal British Columbia (Ricker 1982, 1995) and chum salmon caught in Asia and Alaska (Ogura et al. 1991, Helle and Hoffman 1995) has declined in recent decades, Ricker (1995) did not detect similar declines in length or weight at maturity in mixed-stock commercial catch data

---

[16] The data presented come from measurements of naturally spawning sockeye salmon and fish landed in in-river fisheries. This latter source of data is included because of the scarcity of direct data for naturally spawning populations.

for Canadian sockeye salmon. However, Cox and Hinch (1997), using stock-specific data for 10 Fraser River sockeye salmon stocks, showed that size at maturity for females in all 10 stocks and for males in 8 of the 10 stocks has generally declined over the past 4 decades. These declines are similar to those documented for other Pacific salmon stocks. In general, growth and subsequent size at maturity for Fraser River sockeye salmon were reduced when sea surface temperatures were relatively warm (Hinch et al. 1995a,b; Cox and Hinch 1997).

Various methods are used to measure body lengths of adult sockeye salmon: the Alaska Department of Fish and Game uses the mid-eye to the tail fork (MEF), the Canadian Department of Fisheries and Oceans uses the post-orbit of the eye to the hypural plate (POH), the Quinault Indian Nation and Columbia River Intertribal Fisheries Commission use the snout to the tail fork (SNF), investigators reporting on Fraser River sockeye salmon have used the tip of the snout to the base of the caudal peduncle (“standard length,” similar to POH) (STD), and other investigators (Woodey 1966, Hendry 1995) use the mid-eye to the hypural plate (MEH). Because SNF includes the length of the snout, which displays great sexual dimorphism in spawning sockeye salmon, and SNF and MEF lengths include a portion of the caudal fin, which erodes on the spawning grounds, direct conversions between these different measurements should be considered as gross approximations.

Since the majority of length data available for west coast sockeye salmon exist in the form of SNF, all adult body lengths in this report were converted to SNF length using generalized equations for converting sockeye salmon lengths (Ricker 1982, Pahlke 1989, Linley 1993) (see Appendix Table C-8). Although some of these conversion equations were developed from ocean-caught sockeye salmon in British Columbia (Ricker 1982) and Southeast Alaska (Pahlke 1989), they remain the best available conversions. Linear regression equations to convert MEH, MEF, and STD to SNF were not available, nor were separate sex-specific linear regression equations available to convert MEH or MEF to POH. The equations relating MEH and MEF to POH and POH to SNF and their correlation coefficients and sample sizes, where available, are these:

POH = 0.891(MEF) - 9.064; r^2 = 0.977 (n = 820) (Pahlke 1989)
POH = 0.982(MEH) + 0.606; r^2 = 0.986 (n = 820) (Pahlke 1989)
POH = 0.857 (STD) + 20.29 (Linley 1993)
males: SNF = 1.2605(POH) - 28.47 (Ricker 1982)
females: SNF = 1.191(POH) + 0.24 (Ricker 1982).

Among coastal British Columbia sockeye salmon populations, Rutherford et al. (1992) showed that Skidegate Lake in the Queen Charlotte Islands and Cheewhat Lake on Vancouver Island had the smallest spawners at age 1.2, while the smallest average lengths were recorded for sockeye salmon in the Queen Charlotte Islands, and the largest tended to occur in the northern mainland populations (Rutherford et al. 1992). Lowe Lake, where adults have to ascend a 3-m-high falls, had the longest fish at both age 1.2 and 1.3 (Rutherford et al. 1992) (see Appendix Table C-8).

Halupka et al. (1993) found no significant differences in length between lake-type and river/sea-type sockeye salmon. In general, Halupka et al. (1993) determined that body length was a poor trait for identifying unique stocks due to high within-population variability, and they were unable to detect geographic or temporal trends in body length or weight. However, Blair et al. (1993) showed that six populations of sockeye salmon, from various spawning sites within the Iliamna Lake system, Alaska, varied significantly in size at age.

One population of sockeye salmon in southeast Alaska, out of 230 investigated, consisted of unusually small individuals (Halupka et al. 1993). Individuals in this population, which rears in Benzeman Lake in Necker Bay on Baranof Island, weigh on average about 1 kg (Moser 1899), have an average length of 460 mm at age 1.2, and 457 mm at age 2.2. Age 2.2 sockeye salmon predominate in this population (McPherson and McGregor 1986, Halupka et al. 1993). Similarly, Britton et al. (1982) reported that a "race of small sockeye averaging about 1.5 kg accounts for 60% of the escapement" in some years in Cridge Inlet Creek on the south coast of Pitt Island in coastal British Columbia.

In 1992 and 1993, average length of same-age male and female Baker River sockeye salmon was greater than that of Lake Washington fish (Hendry 1995). However, sockeye salmon of similar age did not differ significantly in length among these populations within the Lake Washington Basin: Big Bear Creek, Cottage Lake Creek, Cedar River, Issaquah Creek, and Lake Washington beach spawners (Hendry 1995). Likewise, within a common age-class and sex, length at maturity differs little between sockeye salmon from Lake Wenatchee and Okanogan River, although these populations reportedly have the smallest body size of any major stock of sockeye salmon (Chapman et al. 1995). In fact, in some years, average length of sockeye salmon from Quinault Lake is smaller than the length of fish of the same age from the mid-Columbia populations (see Appendix Table C-8).

Adult spawner lengths of sockeye salmon in the Lake Pleasant population are very small. In 1996, age-1.2 sockeye salmon from Lake Pleasant averaged approximately 464 mm in fork length for males and 456 mm for females (see Appendix Table C-8). The small body size of Lake Pleasant sockeye salmon is comparable to that noted above for the Benzeman Lake population in Southeast Alaska.

After noting differences in sample size and number of sampling years between stocks, as well as potential for interannual variations in lengths, Shaklee et al. (1996) classified age-1.2 sockeye salmon from populations in Washington into three size groups based on SNF length: large (males >520 mm and females >510 mm), small (males <515 mm and females <500 mm, but both sexes >460 mm), and very small (males and females <460 mm). Using these criteria, Shaklee et al. (1996) classified sockeye salmon adults from Ozette Lake, Baker River, Cedar River, and Lake Washington and Lake Sammamish tributaries as "large size"; Quinault Lake, Lake Wenatchee, Okanogan River, and Lake Washington beach locations as "small size"; and Lake Pleasant as "very small size."

Appendix Table C-9 summarizes data on kokanee adult spawner lengths in selected lakes in Washington, Oregon, Idaho, and British Columbia. With the exception of kokanee in Odell Lake, Oregon; Donner Lake, California; and Issaquah Creek, Washington, average size of kokanee at maturity is typically <300 mm fork length. Odell and Donner Lake kokanee are reportedly the remnants of transplanted populations, whereas early entry Issaquah Creek kokanee are native. Comparison of body length of native kokanee in Issaquah Creek between the early 1980s and 1993 indicates a recent decline in size for both males and females (Appendix Table C-9). Kimsey (1951) reported finding spawning kokanee in Donner Lake, California with an average length of 470 mm fork length, which is greater than the average length of sockeye salmon from Lake Pleasant, Washington and from Benzeman Lake, Alaska (see above).

Ocean Life and Migration

Populations of sockeye salmon have a genetic disposition to specific migratory patterns in the ocean (Burgner 1991). Ocean distribution of sockeye salmon has been studied using tagging, morphological, parasitological, serological, and scale pattern analyses (Margolis et al. 1966, French et al. 1976, Forrester 1987). Season, temperature, salinity, age, size, and prey distribution also affect sockeye salmon movements in the open ocean. Initially, sockeye salmon juveniles travel northward from Washington and British Columbia to the Gulf of Alaska staying in a migratory band relatively close to the coast (Hartt 1980). Fraser River sockeye salmon smolts migrate north through the Gulf of Georgia, either staying close to the mainland coast or crossing the Gulf and traveling north along the Gulf Islands, where they later rejoin the north migrating mainland coast smolts (Groot and Cooke 1987). The rate of travel for northward migrating Fraser River sockeye salmon juveniles was estimated at 18.5 km/day (Hartt and Dell 1986). Once in the Gulf of Alaska, offshore movement of juveniles is conjectured to occur in late autumn or winter.

Burgner (1991) reported that Blackbourn’s (1987) study implies, although indirectly, that sockeye salmon have stock-specific winter distributions in the Gulf of Alaska. French et al. (1976) provided separate models of migration for Asian stocks, western Alaskan stocks, and northeastern Pacific stocks of sockeye salmon, but not for finer-scale stock separation. The ocean distribution of Asian and North American sockeye salmon appears to overlap a broad area of the Bering Sea and North Pacific Ocean, although in general the center of North American fish abundance is east of 175°E, and the center of Asian fish abundance is west of this longitude (French et al. 1976, Burgner 1991). Although there is also considerable overlap in distribution among sockeye salmon originating all the way from the Alaska Peninsula to the Columbia River, scale pattern analyses indicate that sockeye salmon from central Alaska are distributed much further to the west than populations from southeast Alaska, British Columbia, and Washington (French et al. 1976, Burgner 1991). British Columbian and Washington populations of sockeye salmon utilize the area east and south of Kodiak Island in concert with Alaskan stocks, but tend to be distributed further to the south than the Alaskan stocks (down to 46°N) (French et al. 1976, Burgner 1991). We found no data that could be used to distinguish between the general ocean distribution of Washington, Oregon, and British Columbia sockeye salmon or of individual stocks from these regions.

Parasitism

The occurrence of parasites and parasite resistance in sockeye salmon phenotypes are additional traits to consider when determining the ecological/genetic importance of salmon populations under the ESA (Waples 1991a, p. 14). Extensive work has been done in Russia and Canada utilizing prevalence of parasites acquired by juveniles in freshwater to differentiate local sockeye salmon populations (Margolis 1963, Margolis et al. 1966, Konovalov 1975). As a consequence of their long freshwater life as juveniles, sockeye salmon as a species host as many as 36 freshwater parasite species, and the occurrence of parasites specific to Bristol Bay and Kamchatkan-origin sockeye salmon, respectively, have been used to differentiate the continent of origin of fish samples on the high seas (Burgner 1991).

Bower and Margolis (1984) reported that populations of sockeye salmon (from the Fraser and Skeena Rivers) exhibit a genetic difference in susceptibility to infection by the hemoflagellate *Cryptobia salmositica*. In British Columbia, occurrence of the myxosporeans *Myxobolus arcticus* and *Henneguya salminicola*, parasites of the brain and musculature, respectively, have been utilized to differentiate stocks of sockeye salmon (Quinn et al. 1987; Wood et al. 1987a,b, 1988, 1989; Moles et al. 1990; Rutherford et al. 1992). Among British Columbia coastal lakes, Awun, Yakoun, Kitlope, Kimsquit, Skidegate, and Long Lakes were free of *M. arcticus*, while other populations had levels of infection varying up to 100%. Geographical patterns in prevalence of infection were not observed (Rutherford et al. 1992).

Information relative to parasite or disease prevalence in sockeye salmon stocks from Washington and Oregon was largely unavailable. However, Bailey and Margolis (1987) compared parasite fauna of juvenile sockeye salmon from Lake Washington with sockeye salmon populations from several British Columbia lakes. Populations from Lakes Washington, Nimpkish (on Vancouver Island), and Cultus (lower Fraser River) clustered together based on their particular parasite faunas. Based on this study, Bailey and Margolis (1987) stated that although “geography influences the characteristics of the parasite fauna . . . the trophic status of the lake and many biotic variables clearly have strong influences on the parasite faunas studied.”

Information Specific to Sockeye Salmon Populations Under Review

Oregon

The only river systems in Oregon, besides the mainstem Columbia, where anadromous *O. nerka* are consistently seen each year are the Deschutes and Willamette Rivers.

Deschutes River, Oregon

Small numbers of sockeye salmon are consistently seen each year and trapped at the base of the re-regulating dam below Pelton Dam (which forms Lake Simtustus) on the Deschutes River. These fish are subsequently released at the same location and it is unknown whether they spawn below the Pelton/Round Butte Dam complex (ODFW 1995a, Kostow 1996b). Historically, sockeye salmon occurred in the Deschutes River sub-basin, migrating up the Columbia River to the Deschutes River and then up the Metolius River to Suttle Lake.

Fulton (1970) reported that a 1.2-m-tall power dam and upright screen were installed at the outlet of Suttle Lake in 1930 (Mullan 1986). Nielson (1950) reported that "Blueback salmon formerly ascended to Suttle Lake, but none have been seen for a number of years." Nielson (1950) also reported that a fish passage survey of the Deschutes River in 1942 revealed that

> There is a concrete power dam, 4 feet high, at the outlet of the stream from Suttle Lake. This dam . . . may have been responsible for the disappearance of the blueback salmon run. The spillway has a 15 inch flashboard at the upper end of a sloping concrete apron 11 feet long that would be impassable except under very favorable circumstances. The 3-step fishway is too small for large fish and is blocked at the upper end by a stationary screen. Two rotary screens prevent the escapement of fish from the lake to the creek. The diversion to the small power plant is screened.

Nehlsen (1995) also reported on this dam at Suttle Lake, and added that a swimming pool dam (built between 1925 and 1938) and power dam (built between 1925 and 1942) were installed at Lake Creek Lodge on Lake Creek, the outlet stream of Suttle Lake, and both likely hindered or blocked upstream and downstream fish passage.

Several subsequent authors (CBFWA 1990, Olsen et al. 1994, ODFW 1995a) indicated that sockeye salmon continued to return to the Metolius River and spawned below Suttle Lake after fish passage to Suttle Lake was blocked. ODFW (1995a) suggested that sockeye salmon persisted in the Metolius River after construction of the Suttle Lake barrier, until construction of Pelton Re-regulating Dam and Pelton Dam in 1958 and Round Butte Dam (which formed Lake Billy Chinook) in 1964. Sockeye salmon may have persisted by continued spawning in the Metolius River, with juvenile rearing occurring in the Deschutes River or Columbia River, or by return of outmigrants of residual sockeye salmon or kokanee that had escaped over the Suttle Lake barrier. However, Gunsolus and Eicher (1962) stated that, "The spawning of blueback salmon is confined to the Suttle Lake area of the Metolius River and the run is composed, for all practical purposes, of hatchery fish which the Oregon Fish Commission has planted in an attempt to generate a run."

Presently, two kokanee populations occur above the dams: one population resides in Suttle Lake and spawns in the lake inlet stream (Link Creek), and a second population resides in Lake Billy Chinook and spawns in the upper Metolius River (ODFW 1995a). Both kokanee populations have a distinctive blue-black body coloration and are distinguished from hatchery kokanee reared in Lake Simtustus and Deschutes River basin hatcheries by their color pattern (ODFW 1995a). The Lake Billy Chinook/Metolius kokanee reportedly spawn about the same time that Deschutes River sockeye salmon arrive at the Pelton Dam hatchery trap, whereas the Suttle Lake/Link Creek kokanee spawn 2 to 3 weeks later (ODFW 1995a). Sockeye salmon enter the Deschutes River from July to September.

ODFW (1995a) and Kostow (1996b) suggested that sockeye salmon that are consistently trapped in the Deschutes River may derive from 1) a self-sustaining sockeye salmon population that spawns below the Pelton/Round Butte Dam complex and rears in mainstem Columbia River reservoirs, 2) strays from elsewhere on the Columbia River, or 3) outmigrating smolts of “kokanee-sized” fish that escape over the Pelton/Round Butte Dam complex and return as sockeye salmon.

Artificial propagation data (see Appendix Table D-2) indicate that over 740,000 sockeye salmon fry and fingerlings from the Leavenworth National Fish Hatchery and 15,000 smolt from the Bonneville Hatchery were released into Suttle Lake between 1937 and 1958. Additionally over 478,000 sockeye salmon fry, fingerlings, and smolts of mixed Metolius, Leavenworth, and unknown parentage were released in the Metolius River or its tributaries between 1948 and 1961 (see Appendix Table D-2). Many of the reported returns of sockeye salmon to the Deschutes River prior to the 1960s may have been derived from these juvenile sockeye salmon releases.

Willamette and Santiam Rivers

Foy et al. (1995a) and Chapman et al. (1995) reported that small numbers of adult sockeye salmon currently return to the Willamette, Middle Santiam, and South Santiam Rivers. Juvenile sockeye salmon were introduced into several reservoirs in the upper reaches of the Willamette and Santiam Rivers in the 1950s (see Appendix Table D-2), and presumably the downstream migration of some individuals derived from these transplants led to returns of anadromous sockeye salmon (Foy et al. 1995a, Chapman et al. 1995, p. 21).

Washington

The following nine spawning populations of sockeye salmon have been identified in Washington by WDF et al. (1993): 1) Baker River, 2) Ozette Lake, 3) Lake Pleasant, 4) Quinault Lake, and 5) Okanogan River, classified as native stocks; 6) Cedar River classified as a non-native stock; 7) Lake Wenatchee classified as having mixed stock origin; and 8) Lake Washington/Lake Sammamish tributaries, and 9) Lake Washington beach spawners, classified as having unknown stock origin. Chapman et al. (1995) listed four additional spawning aggregations of sockeye salmon that appear consistently in Columbia River tributaries: the Methow, Entiat, and Similkameen Rivers and Icicle Creek in the Wenatchee River drainage.

Sockeye salmon have been periodically observed in other Washington rivers that lack accessible lake habitat, including the Nooksack, Samish, mainstem Skagit, Sauk, Stillaguamish, Green, Skokomish, Dungeness, Calawah, Hoh, Queets and North Fork Lewis Rivers. Reportedly, several sockeye salmon are observed yearly during spawner surveys in almost every river in Puget Sound; this phenomenon is more common, and numbers of sockeye salmon are higher, in north Puget Sound rivers than in south Puget Sound rivers (J. Ames[17]).

Okanogan River

Okanogan River sockeye salmon rear in Lake Osoyoos, which is composed of three connected basins: north, middle, and south. WDF et al. (1993) reported that Okanogan River sockeye salmon bound for Lake Osoyoos begin migrating up the Columbia River in mid- to late-June and peak in early July. In contrast, Chapman et al. (1995) reported that sockeye salmon bound for the mid-Columbia River begin entering the Columbia River in April and May, peaking at Bonneville Dam in the third week of June and at Rock Island Dam in the third week of July. Chapman et al. (1995) compared sockeye salmon run-timing data from dam counts in 1933-1947 to similar counts in 1988-1992 and found that current run-timing is about a week earlier than it used to be. This change in timing was believed to be due to reduced water velocities in mainstem reservoir reaches of the Columbia River, with later velocities allowing for more rapid upriver fish migration (Chapman et al. 1995). Quinn and Adams (1996) also reported that sockeye salmon upriver migration timing is about 6 days earlier now than it was in 1949. Based on scale pattern analysis, Fryer and Schwartzberg (1994) suggested that Okanogan River sockeye salmon migrate past Bonneville Dam later than the population bound for Lake Wenatchee. Major and Mighell (1966) reported that most adult sockeye salmon begin migrating up the Okanogan River in mid- to late-July and enter Lake Osoyoos in August, although in some years sockeye salmon may reach Lake Osoyoos as early as mid- to late-July. WDFW (1996) stated that

> Okanogan sockeye begin migrating slightly later than the Wenatchee stock, based on scale analysis at Bonneville Dam which shows Wenatchee fish dominating the early portion and shifting to Okanogan stock later. Okanogan sockeye probably begin their entry in early to mid-June and peak at Bonneville Dam in early July.

Migration may be impeded by as much as 3 weeks in some years by high water temperatures during mid-summer in the Okanogan River (Major and Mighell 1966, Allen and Meekin 1980, Mullan 1986, Swan et al. 1994, Chapman et al. 1995). Sockeye salmon congregate at the confluence of the Okanogan and Columbia Rivers when water temperatures exceed 21.1°C and only migrate up the Okanogan River when temperatures fall below this level (Major and Mighell 1966, Allen and Meekin 1980, Chapman et al. 1995).

---

[17] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., April 1995 and 13 March 1996.

Swan et al. (1994) reported that upon reaching Lake Osoyoos, sockeye salmon stay in the lake from less than 1 day to 46 days, with a median of 28 days, prior to moving upstream to the spawning grounds. WDF et al. (1993) indicated that this population spawns upstream from Lake Osoyoos in the Okanogan River but below the Southern Okanagan Lands Project Dam (=Oliver Diversion Dam = Vaseux Dam) during late September through October. According to Chapman et al. (1995), spawning occurs primarily from about 1 to 23 October, with a peak about the third week in October.

Burner (1951) observed a few sockeye salmon redds on the shoreline of Lake Osoyoos. Allen and Meekin (1980) observed about 1,200 sockeye salmon spawning on the shoreline of Lake Osoyoos in October of 1971, whereas only a “few” to none were observed in 1972-1974.

Lake Osoyoos has been variously characterized as eutrophic (Mullan 1986) and as displaying the range of conditions known as mesotrophic (see Appendix Table B-2) (Rensel 1995, cited in Chapman et al. 1995). Lake Osoyoos is atypical of sockeye salmon rearing lakes, which are typically oligo- or ultra-oligotrophic (Mullan 1986, Chapman et al. 1995). From data provided in Mullan (1986), the morphoedaphic indices for the northern, middle, and southern basins of Lake Osoyoos were estimated as 10.91, 4.69, and 14.74 respectively; these values are at the high end of the scale for sockeye salmon nursery lakes and indicate the potential for high primary production (see Appendix Table B-2). Lake Osoyoos has been ranked as one of the most productive of all sockeye salmon rearing lakes, based on phytoplankton and zooplankton abundance (Foerster 1968, Allen and Meekin 1980, Chapman et al. 1995). A strong thermocline develops in Lake Osoyoos during the summer, when surface temperatures can reach 25^{o}C and the hypolimnion becomes anoxic, leaving only a narrow 1- to 2-m sub-surface layer of water in the south basin with conditions suitable to sockeye salmon survival. These conditions indicate that sockeye salmon juveniles may be limited to the north and middle basins of Lake Osoyoos during summer months (Rensel 1995, cited in Chapman et al. 1995).

High plankton productivity has led to the production in Lake Osoyoos of “some of the largest sockeye salmon smolts reported in the literature” (Mullan 1986). The average length of known age-1+ sockeye salmon smolts from Lake Osoyoos has ranged over a number of years from 94 to 114 mm with a median of about 110 mm (Allen and Meekin 1980, Chapman et al. 1995), a length exceeded only by sockeye salmon smolts from Lake Washington, Baker Lake, and Ozette Lake (see Appendix Table C-4). Age composition data presented in Allen and Meekin (1980) and Chapman et al. (1995) show that in some years an unusually large percentage of adult spawners in the Okanogan River sockeye salmon population are 3-year-old fish, whereas 3-year-olds are extremely rare in the Lake Wenatchee population (see Appendix Tables C-1 and C-2). Okanogan River sockeye salmon are thought to have the youngest average age at maturity for sockeye salmon throughout their range (Chapman et al. 1995).

Fry emergence and migration downstream to Lake Osoyoos has been reported to occur mostly at night, beginning in early March (prior to the Lake Wenatchee migration), peaking in mid-April, and concluding by the third week in May (Allen and Meekin 1980, Shepherd and Inkster 1995 as cited in Chapman et al. 1995). Data presented in Chapman et al. (1995) indicate that currently sockeye salmon smolts leave Lake Osoyoos in mid- to late May and migrate past Rock Island Dam in May (Peven 1987). In contrast, Wenatchee-origin sockeye salmon smolts typically arrive at Rock Island Dam in April (Peven 1987). Chapman et al. (1995) pointed out that currently, sockeye salmon smolts appear to arrive at downstream dams on the Columbia River earlier than they did in the 1940s through 1960s, although the reasons for this earlier run-timing are not clear.

Between 1939 and 1943, all adult sockeye salmon returning to the Columbia River above the confluence with the Snake River were trapped at Rock Island Dam on the Columbia River as part of the Grand Coulee Fish Maintenance Project. A total of 19,795 of these trapped adult sockeye salmon of mixed Okanogan River, Lake Wenatchee, and Upper Columbia River heritage were transported to and released in Lake Osoyoos. Appendix Table D-2 shows that between 1940 and 1968, about 395,000 fry resulting from a mixed-stock spawning of Rock Island Dam and Quinault Lake stock, and over 4.2 million fish descended from original spawners collected at Rock Island and Bonneville Dams, were released into Lake Osoyoos (Mullan 1986). In the brood years 1992 and 1993, 73,000 and 110,500 pen-reared juvenile sockeye salmon (adults captured at Wells Dam) were released in Lake Osoyoos (Chapman et al. 1995). No adult returns from the releases in 1992 and 1993 have been noted (Chapman et al. 1995).

Sockeye salmon and kokanee-sized *O. nerka* are reported to spawn at the same time and place in the Okanogan River, often with overlapping redds, although it is unknown whether peak spawn timing of these two groups of fish are the same. Kokanee-sized fish reportedly acquire a drab-olive spawning coloration, whereas sockeye salmon in this population have the typical spawning color pattern (L. LaVoy[18]). Dark colored residual *O. nerka* presumably occur to some degree in all years on the sockeye salmon spawning grounds of the Okanogan River (Chapman et al. 1995, p. 21).

Kokanee stocking history in Lake Osoyoos includes the release of 195,550 kokanee fry from an unnamed source into Lake Osoyoos between 1919 and 1920 (WDFG 1921a) (see Appendix Table D-5). Further kokanee stocking information was not obtained from either U.S. or Canadian sources.

---

[18] L. LaVoy, Washington Department of Fish and Wildlife, 3860 Chelan Highway North, Wenatchee, WA 98801-0452. Pers. commun., 31 May 1995.

Lake Wenatchee

WDF et al. (1993) reported that sockeye salmon bound for Lake Wenatchee begin migrating up the Columbia River in mid-June, peaking in early July, and enter Lake Wenatchee in late July to early August. It was stated in WDFW (1996) that "Wenatchee sockeye enter the Columbia in May and peak at Bonneville Dam in late June or early July." Based on scale pattern analysis, Lake Wenatchee sockeye salmon appear to migrate past Bonneville Dam earlier than the population bound for the Okanogan River (Fryer and Schwartzberg 1994). As mentioned above for Okanogan River, Chapman et al. (1995) reported that sockeye salmon bound for the mid-Columbia River begin entering the Columbia River in April and May, peaking at Bonneville Dam in the third week of June and at Rock Island Dam in the third week of July. Chapman et al. (1995) reported that comparison of run-timing data from dam counts in 1933-1947 and 1988-1992 indicate that current sockeye salmon run-timing is about a week earlier than it used to be. Quinn and Adams (1996) also reported that sockeye salmon upriver migration timing is about 6 days earlier now than it was in 1949. Run-timing of sockeye salmon in the Wenatchee River, as measured at Tumwater Dam, appears to be as much as a month earlier at the present time than it was in the 1930s (Chapman et al. 1995). Factors contributing to this run-timing change may include improvements to fish ladders at Tumwater and Dryden Dams on the Wenatchee River, lower river flows in recent years, and faster within-reservoir migration in the Columbia River since modern dam construction (Allen and Meekin 1980, Mullan 1986, Chapman et al. 1995).

The Wenatchee population spawns from mid-September through October in the Little Wenatchee, White, and Napeequa Rivers above Lake Wenatchee (WDF et al. 1993). According to Chapman et al. (1995), main spawning activity currently occurs from mid-September to about the beginning of October, with a peak in the third week of September. Gangmark and Fulton (1952) reported two lakeshore seepage areas in Lake Wenatchee that were used by spawning sockeye salmon. Mullan (1986) indicated that only limited shore spawning occurs in Lake Wenatchee. Although no active surveys targeting beach-spawning sockeye salmon have been undertaken, shoreline spawning has not been observed in recent years in Lake Wenatchee (L. LaVoy[19]).

Lake Wenatchee has been characterized as a typical oligotrophic or ultra-oligotrophic sockeye salmon nursery lake: clear, cold, well-oxygenated, and with low productivity (Allen and Meekin 1980, Mullan 1986, Chapman et al. 1995). Lake Wenatchee has an estimated metric morphoedaphic index of 0.51, which is within the range of MEI typical for sockeye salmon nursery lakes (see Appendix Table B-2) and is considerably lower than the MEI for Lake Osoyoos (Mullan 1986). Water residence time in Lake Wenatchee was estimated at the relatively rapid rate of 2.2 exchanges per year (Mullan 1986). A strong thermocline does not apparently develop in Lake Wenatchee in the summer, and dissolved oxygen and temperature

---

[19] L. LaVoy, Washington Department of Fish and Wildlife, 3860 Chelan Highway North, Wenatchee, WA 98801-0452. Pers. commun., 31 May 1995.

conditions allow sockeye salmon to use all depths of the lake (Chapman et al. 1995, p. 83). Thompson and Tufts (1967) identified Dolly Varden and northern squawfish as predators of sockeye salmon juveniles in Lake Wenatchee, although only 12% of Dolly Varden and 1% of northern squawfish collected had consumed wild sockeye salmon fingerlings.

The average size of known age-1+ sockeye salmon smolts from Lake Wenatchee have ranged from 65 to 124 mm fork length, with a median of about 88 mm (Allen and Meekin 1980, Chapman et al. 1995) (see Appendix Table C-4). Peven (1987) indicated that sockeye salmon smolts from Lake Wenatchee are generally smaller than 100 mm, whereas Okanogan River smolts are generally larger than 100 mm. Age composition data show (see Appendix Tables C-1 and C-2) that although an unusually large percentage of adult spawners in the Okanogan River sockeye salmon population are 3-year-old fish, very few Lake Wenatchee sockeye salmon exhibit this age pattern. Chapman et al. (1995) pointed out that sockeye salmon from Wenatchee show a stronger tendency to spend 2 years in freshwater prior to smoltification than do members of the Okanogan River population.

Dawson et al. (1973) found that sockeye salmon fry were entering Lake Wenatchee between March and May, while Chapman et al. (1995) deduced from data in Gangmark and Fulton (1952) that fry emerge from redds in the Wenatchee River by mid-March. Peven (1987) showed that Wenatchee-origin sockeye salmon smolts typically arrive at Rock Island Dam in April. As mentioned above for Okanogan River sockeye salmon, Chapman et al. (1995) pointed out that currently, sockeye salmon smolts appear to arrive at downstream dams on the Columbia River earlier than they did from the 1940s through 1960s, although the reasons for this earlier run-timing are not clear.

Between 1939 and 1943, all sockeye salmon entering the mid-Columbia River were trapped at Rock Island Dam, and over 32,000 mixed Lake Wenatchee, Okanogan River, and Arrow Lakes adult sockeye salmon were released into Lake Wenatchee as part of the Grand Coulee Fish Maintenance Project. Between 1940 and 1968, over 2.4 million fry derived from original Quinault Lake stock, and over 52.8 million fry descended from original spawners collected at Rock Island and Bonneville Dams, were released into Lake Wenatchee (see Appendix Table D-2). Starting with the 1989 brood year, between 167,500 and 372,100 pen-reared Lake Wenatchee-origin juvenile sockeye salmon have been released yearly into Lake Wenatchee. From the 1990 release, an estimated 4,133 sockeye salmon returned in 1994, for a fry-to-adult survival rate of 1.6% (survival estimate based on scale pattern analysis) (Chapman et al. 1995).

Kokanee are reportedly native to Lake Wenatchee (Crawford 1979). Sockeye salmon and kokanee have been seen to spawn at the same time and place in tributaries of Lake Wenatchee (the forms may have overlapping redds in the White, Napeequa, and lower end of the Little Wenatchee Rivers), and the kokanee reportedly acquire a drab olive spawning coloration, whereas Wenatchee sockeye salmon have the typical spawning color pattern

(L. LaVoy[20]). Residual *O. nerka* reportedly occur on the spawning grounds with Lake Wenatchee sockeye salmon (Chapman et al. 1995). Between 1934 and 1966, 22.5 million Lake Whatcom kokanee were released in Lake Wenatchee (Mullan 1986) and approximately 0.5 million kokanee of the same broodstock origin were released in 1983 (Knutzen 1995) (see Appendix Table D-5).

Quinault Lake

This sockeye salmon population is the most southerly coastal population of this species in North America. WDF et al. (1993) indicated that sockeye salmon, or blueback salmon as they are known locally, begin entering the lower Quinault River in small numbers in January and continue to the end of July, peaking in late May to early July. Sockeye salmon have been known to enter the Quinault River as early as December and as late as August (QIN 1981). The duration of this run is unusually long for sockeye salmon, lasting over 7-9 months (Burgner 1991, p. 9). Johnson (1977) stated that it takes sockeye salmon approximately 3 days to migrate between the mouth of the Quinault River and Quinault Lake. Sockeye salmon adults may remain in Quinault Lake for 3-10 months without feeding (QIN 1981) prior to moving upstream to spawn from November through February, primarily in the upper Quinault River and its tributaries (WDF et al. 1993). Sockeye salmon spawn timing for the Quinault stock is unusually protracted; observed duration has been 7 months, from August through March, although peak spawning occurs from November through January (QIN 1981).

The majority of sockeye salmon in the Quinault system take on a drab gray-green (D. Boyer, Jr.[21]) or olive (Storm et al. 1990) spawning coloration, in contrast to the typical red body coloration of sockeye salmon, but are very red-fleshed with high oil content when they enter the river (D. Boyer Jr.[22]). Storm et al. (1990) stated that a small segment of early spawners take on the more typical coloration of spawning sockeye salmon, and these may represent a unique strain. Due to carotenoid metabolism, spawning sockeye salmon may contain up to 65% less carotenoid than pre-spawning sockeye salmon taken at sea (Crozier 1969). The loss of tissue carotenoids in Quinault Lake sockeye salmon may result from the prolonged non-feeding adult lake-residence period prior to maturation and spawning. Although a green coloration at spawning is not common for sockeye salmon, spawning individuals of two sockeye salmon stocks in British Columbia (Weaver Creek (lower Fraser

---

[20] L. LaVoy, Washington Department of Fish and Wildlife, 3860 Chelan Highway North, Wenatchee, WA 98801-0452. Pers. commun., 31 May 1995.

[21] Del Boyer, Jr., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., 24 April 1995.

[22] Del Boyer, Jr., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., 24 April 1995.

River) and Alastair Lake (Skeena River)) also reportedly appear more green than red (C. C. Wood[23]).

Smolt outmigration occurs in May and June (Davidson and Barnaby 1936) or April and May (Tyler and Wright 1974), and takes place during the hours of darkness (Tyler and Wright 1974) (see Appendix Table C-5). The percentage in each age group, and length and weight of sockeye salmon captured in the fishery for various years, are presented in Appendix Tables C-1 and C-8. Figure 4 illustrates temporal changes in freshwater and saltwater age composition of Quinault Lake sockeye salmon by return year.

The Quinault sockeye salmon or blueback has always been culturally and economically important to the Quinault Indians, and its flavor has often been remarked upon. Lestelle and Workman (1990) stated that

> Culturally, this salmon run links Quinault people to their rich heritage as nothing else does. The salmon was always the very lifeblood of Quinault society, and the blueback was the most sacred of the various fish runs.

Brown (1982, p. 32) related that

> The Chinook tribe . . . esteemed the Quinault sockeye so highly that they used it as an all-purpose term of excellence. Whites . . . picked this up and mistakenly applied the name to the most prized of the Columbia’s runs, the salmon known as the Chinook. For half a century Chinook salmon were known as “Quinnat” . . .

Numerous early references to the superior quality of Quinault Lake sockeye salmon exist (Willoughby 1889, Curtright 1979), and the unusual quality of the flesh has often been attributed to the stored energy reserves necessary to maintain these fish through the long lake residence period prior to maturation (QIN 1981, Lestelle and Workman 1990). This population of sockeye salmon has long supported a commercial set-net fishery operated by the Quinault Indian Nation near Taholah on the lower Quinault River.

The U.S. Bureau of Fisheries operated a fish hatchery from 1914 to 1947 at Falls Creek on Quinault Lake (this hatchery was referred to as the “Quinault, Washington Station,” and should not be confused with the present-day Quinault National Fish Hatchery). This hatchery program utilized native broodstock for the most part; however, out-of-basin transplant history includes the transfer from Alaska of about 20 million sockeye salmon eggs from 1916 to 1921 and 260,000 kokanee eggs from Lake Whatcom in 1925 to the Quinault, Washington Station on Falls Creek (see Appendix Tables D-1 and D-5). Kokanee do not currently inhabit Quinault Lake, although over 300,000 kokanee fry from unnamed sources

[23] C.C. Wood, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C., Canada V9T 5K6. Pers. commun., August 1996.

were released in Quinault Lake between 1917 and 1922 (WDFG 1919, 1921a, 1923) (see Appendix Table D-5).

A portion of the lower watershed above Quinault Lake was logged in association with early homesteading and Sitka spruce harvest for war plane construction during the First World War. Around this period of time, severe erosion of the banks of the upper Quinault River occurred, although it is unknown whether logging caused this accelerated erosion, or whether the erosion was part of a natural process (D. Boyer, Jr[24]). Today, much of the upper Quinault River below the North Fork, where most sockeye salmon spawning occurs, is a braided stream subject to severe meander (Davidson and Barnaby 1936, Brown 1982, WDF et al. 1993). Davidson and Barnaby (1936) reported that

> The early settlers and inhabitants of this region describe the upper Quinault River as a large stream that flowed between two rather narrow heavily wooded banks. . . . the logging off of the watersheds of the river has caused excessive washing to the extent that there is no definite river bed but a wide river valley through which the stream frequently changes its course with the winter and spring freshets.

Severe storm runoff problems in the upper Quinault River in the fall of 1990 and winter of 1990-1991 led to a prolonged period of lake turbidity (S. A. Chitwood and D. Boyer, Jr.[25]).

Ozette Lake

Migration of adult sockeye salmon up the Ozette River and into Ozette Lake occurs between dusk to dawn from April to early August (WDF et al. 1993) (see Appendix Table C-6) or May to August (Dlugokenski et al. 1981). Kemmerich (1945) counted sockeye salmon past a weir constructed in the Ozette River in 1924, 1925, and 1926 between 27 May and 8 August, 8 June and 15 September, and 28 May and 8 September, respectively. Jacobs et al. (1996) noted that the tribal sockeye salmon fishery in the lower Ozette River that operated between 1948 and 1957, began in mid-April and peaked from 2 to 15 June. Fifty sockeye salmon were seen moving up the Ozette River on 20 October 1989 following a rise in the lake level (LaRiviere 1991).

High water temperatures in Ozette Lake and River and low water flows in the summer may create a thermal block to migration and influence timing of the sockeye salmon migration (LaRiviere 1991). Recorded water temperatures in late-July and August in the Ozette River

---

[24] Del Boyer, Jr., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., 13 March 1996.

[25] S.A. Chitwood and Del Boyer, Jr., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., 24 April 1995.

near the lake outlet have exceeded the temperature range over which sockeye salmon are known to migrate (J. Meyer[26]).

Currently, spawning is restricted to submerged beaches where upwelling occurs along the lakeshore or to tributary outwash fans (Dlugokenski et al. 1981, WDF et al. 1993). Spawning has been variously reported to occur from mid- to late November through early February (WDF et al. 1993) and from late November to early April (Dlugokenski et al. 1981) (see Appendix Table C-6). Dlugokenski et al. (1981) suggested that discreet sub-populations may be present in the lake, as evidenced by disjunct spawning times between beach spawners in different parts of the lake.

The two principle shoreline spawning beaches for sockeye salmon in Ozette Lake are Olsen’s Beach (or Olsen’s Landing) (north of Siwash Creek on the lake’s eastern shore) and the beach area north of Allen’s Bay on the lake’s western shore (WDF et al. 1993, Jacobs et al. 1996). Reportedly, some spawning has also been seen recently on the south shore of Baby Island at the southern end of Lake Ozette (Jacobs et al. 1996). Historically, sockeye salmon reportedly spawned in tributary creeks of Ozette Lake, on the shoreline north of Umbrella Point, and in Ericson’s Bay (Dlugokenski et al. 1981, WDF et al. 1993, Jacobs et al. 1996). A small degree of outlet spawning may occur in the Ozette River or in Coal Creek, a tributary of Ozette River below Ozette Lake (WDF et al. 1993, Jacobs et al. 1996, E. Currence and D. Dailey [27]). A number of sockeye salmon fry were inadvertently released in Umbrella Creek near the tribal hatchery in 1987, and 13 adult sockeye salmon were noted spawning in this creek 4 years later, in 1991. Over 8,000 sockeye salmon fry of the 1991 brood year were released in Umbrella Creek in 1992 and approximately 30-50 sockeye salmon redds were counted in Umbrella Creek in the fall of 1995 (Jacobs et al. 1996, E. Currence[28]).

Kemmerich (1945) reported that during his work with sockeye salmon at Ozette Lake in the years 1923-1926, “there was no evidence that they ascended any of the tributaries of the lake to spawn.” In reference to Ozette Lake sockeye salmon, Kemmerich (1939) in a letter to R. E. Foerster stated that

> We made no special investigations of spawning beds during the years covered . . . but merely observed from time to time that most of the spawning seemed to be along the lake shore in suitable places and especially at the mouths of the several creeks. I do

---

[26] J.H. Meyer, Olympic National Park, 600 E. Park Ave., Port Angeles, WA 98362. Pers. commun., 19 march 1996.

[27] E. Currence and D. Dailey, Makah Fisheries Management, Makah Tribe, P.O. Box 115, Neah Bay, WA 98357. Pers. commun., 22 March 1995.

[28] E. Currence, Makah Fisheries Management, Makah Tribe, P.O. Box 115, Neah Bay, WA 98357. Pers. commun., 19 March 1996.

> not recall that any sockeyes ascended any of the creeks to spawn but it seems to me that spawning took place during the latter part of September and October.

Abundance of sockeye salmon outmigrant smolts from Ozette Lake was estimated in 1977 at 9,600 (Dlugokenski et al. 1981), in 1990 at 7,942, and in 1992 at 2,752 (Jacobs et al. 1996). Based on these numbers and adult returns 2 years later (see Jacobs et al. 1996, their table 3), ocean survival of broodyears 1975, 1990, and 1991 were 5.6%, 18%, and 27%, respectively (Jacobs et al. 1996).

A total of 13 species of fish occur in Ozette Lake (see Appendix Table B-4). Dlugokenski et al. (1981) and Blum (1984) listed potential competitors with sockeye salmon juveniles in Ozette Lake, including kokanee, red sided shiner (*Richardsonius balteatus*), northern squawfish (*Ptychocheilus oregonensis*), yellow perch (*Perca flavescens*), and peamouth (*Mylocheilus caurinus*). Potential predators listed by these same authors included cutthroat trout (*Salmo clarki*), northern squawfish (*Ptychocheilus oregonensis*), and prickly sculpin (*Cottus asper*). Beauchamp et al. (1995) showed that competition is unlikely to limit the sockeye salmon population in Ozette Lake; however, predation on juvenile sockeye salmon, which was 25 times greater by individual cutthroat trout than by individual squawfish, may be limiting, although total predator abundance has yet to be assessed.

Harbor seals (*Phoca vitulina*) migrate up the Ozette River into Ozette Lake and have been seen feeding on adult sockeye salmon off the spawning beaches in Ozette Lake. The numbers of seals and the number of salmon taken by each seal is unknown. Seal predation on sockeye salmon at the river mouth and during the salmon's migration up the Ozette River may also be occurring. The upriver migration of harbor seals to feed on adult sockeye salmon is common in British Columbia, occurring 100 miles upriver on the Fraser River at Harrison Lake and up to 200 miles inland on the Skeena River (Foerster 1968). Sockeye salmon migrate up to Ozette Lake in less than 48 hours and the majority of adults travel at night (Jacobs et al. 1996).

Chamberlain (1907, p. 40) reported that "dwarf sockeye" were present in Ozette Lake around the turn of the century, and it is likely that kokanee were present prehistorically in Ozette Lake. Between 5,000 and 10,000 kokanee spawn in small tributaries to Ozette Lake, and Dlugokenski et al. (1981) and Beauchamp et al. (1995) thought that these numbers of kokanee were insufficient to deplete food resources for sockeye salmon. Dlugokenski et al. (1981, p. 34) reported that kokanee spawn not only in tributaries, but also spawn interspersed with sockeye salmon on the lakeshore in mid-November to early December. Over 108,000 kokanee fry from the Lake Crescent Trout hatchery were planted in Ozette Lake in 1940 (Kloempken 1996, see Appendix Table D-5). An unknown number of kokanee from an unknown stock were reportedly planted in Ozette Lake in 1958 (Dlugokenski et al. 1981).

Kemmerich's (1945) escapement counts for sockeye salmon to Ozette Lake were 3,241 in 1924 (a portion of the run was missed), 6,343 in 1925, and 2,210 in 1926. No information relative to the down-river catch of sockeye salmon in the Makah Tribal fishery was available for this time period. Dlugokenski et al. (1981) reported that smolt outmigration occurs during the hours of darkness and peaks around 6 May, and that Ozette Lake sockeye salmon have the third largest yearling smolt size of any population reported in the literature. Data on smolt size and age are presented in Appendix Table C-4 and smolt outmigration period in Appendix Table C-5.

In 1937, almost 450,000 sockeye salmon fingerlings cultured at the U.S. Bureau of Fisheries Quilcene Hatchery derived from eggs received from the Birdsview Hatchery on Grandy Creek (Skagit River Basin) were released into Ozette Lake (Kemmerich 1945, Boomer 1995) (see Appendix Table D-2). Sockeye salmon of the 1936 brood-year at the Birdsview Hatchery were composed primarily of Baker Lake broodstock and a probable Fraser River and Quinault Lake component (Kemmerich 1945). In 1983, 120,000 Quinault Lake sockeye salmon fry were released into Ozette Lake (MFMD n.d., Hill 1984). Between 1984 and 1995, almost 0.5 million Ozette Lake-origin sockeye salmon fry were reared at the Makah Tribal Hatchery on Umbrella Creek, a tributary of Ozette Lake, and released into the Ozette Lake drainage (MFMD n.d.) (see Appendix Table D-2). Spawning stock for this hatchery effort have been captured on the lakeshore spawning grounds (WDF et al. 1993).

Outside of that portion in Olympic National Park, virtually the entire watershed of Ozette Lake has been logged (Blum 1988). A combination of past overfishing and spawning habitat degradation, due to stream and tributary outwash fan siltation, associated with timber harvest and road building, have been cited as major causes of this stock’s decline (Bortleson and Dion 1979, Dlugokenski et al. 1981, Blum 1988, WDF et al. 1993). McHenry et al. (1994) found that percent fine sediments (<0.85 mm) averaged 18.7% in Ozette Lake tributaries (although these levels may be partly attributable to the occurrence of sandstones, siltstones, and mudstones in this basin) and fine sediment levels were consistently higher in logged watersheds than in unlogged watersheds on the Olympic Peninsula, as a whole.

During low water levels in summer, much of the beach habitat may become exposed (Bortleson and Dion 1979). The exotic plant, reed canary grass (*Phalaria arundinacea*), has been encroaching on sockeye salmon spawning beaches in Ozette Lake, particularly on the shoreline north of Umbrella Creek, where sockeye spawning has not occurred for several years. This plant survives overwinter submergence in up to 3 feet of water and may possibly provide cover for predators of sockeye salmon fry (J. H. Meyer[29]). Suitable lakeshore spawning habitat for sockeye salmon is reported to be extremely limited in Ozette Lake (Blum 1984, Pauley et al. 1989).

---

29 J.H. Meyer, Olympic National Park, 600 E. Park Ave., Port Angeles, WA 98362. Pers. commun., 19 March 1996.

Lake Pleasant

Sockeye salmon that spawn and rear in Lake Pleasant enter the Quillayute River and migrate up the Sol Duc River in May to September. Normally, this stock remains, throughout the summer, in the Sol Duc River at the confluence with Lake Creek (the Lake Pleasant outlet stream) until the creek receives sufficient water input to allow the fish to migrate up to Lake Pleasant. Sufficient stream discharge to allow upstream migration does not usually occur until late October to early November (WDF et al. 1993, J. Haymes[30]). Sockeye salmon spawn predominantly on lakeshore beaches from late November to early January. Little spawning has been observed in streams tributary to Lake Pleasant (WDF et al. 1993). In describing a survey of potential habitat for sockeye salmon introductions on the Olympic Peninsula undertaken prior to 1932, Kemmerich (1945) stated that

> It was found that a small run of sockeye or blueback salmon already enters Lake Pleasant by way of the Sol Duc River and Lake Creek and these natural run fish were found to be in individual size comparable with the size of the fish of the Lake Quinault and Columbia River runs.

Currently, sockeye salmon in the Lake Pleasant stock are said to weigh no more than about 2 to 3 pounds (0.9 to 1.4 kg) (J. Haymes[31]), which is considerably less than sockeye salmon from Quinault Lake, with the exception of the very few jacks and jills recorded from Quinault Lake (see Appendix Table C-8). Limited data on smolt size are presented in Appendix Table C-4. Average length of spawners collected in 1995 and 1996 for genetic analysis were 451 mm (n=10) and 460 (n=72) for males, and 459 mm (n=5) and 456 (n=28) for females, respectively (see Appendix Table C-8). This stock has the smallest average adult body size of any sockeye salmon stock in Washington.

The following out-of-basin introductions of sockeye salmon into Lake Pleasant occurred in the 1930s: 1) in 1933, 210,000, and in 1937, 75,000, fingerlings derived from the Birdsview Hatchery were released into Lake Pleasant (assuming a 4-year return cycle, the 1932 and 1936 Birdsview Hatchery broodstock were descended from mixed releases of the progeny of Fraser River sockeye salmon in 1908 and 1912; Quinault Lake sockeye salmon in 1916; and Baker Lake sockeye salmon in 1920 and 1928), and 2) in 1934, 175,000 fingerlings from the Birdsview Hatchery were released into Lake Pleasant (the 1933 broodyear was composed of Baker Lake broodstock) (Kemmerich 1945, Boomer 1995) (see Appendix Table D-2).

---

[30] J. Haymes, Quileute Natural Resources, Quileute Indian Tribe, P.O. Box 187, La Push, WA 98350-0187. Pers. commun., 14 February 1995.

[31] J. Haymes, Quileute Natural Resources, Quileute Indian Tribe, P.O. Box 187, La Push, WA 98350-0187. Pers. commun., 14 February 1995.

Fisheries biologists of the Washington Department of Fisheries undertook a survey of Lake Pleasant in July and September of 1952, in part to determine its suitability for sockeye salmon rearing (Smoker et al. 1952, Heg 1953). These two reports were written with the assumption that sockeye salmon were absent from, or very rare in, Lake Pleasant at this time. Smoker et al. (1952) stated that

> The suitability of Lake Pleasant for the rearing of sockeye can be better determined by further examination. Its carrying capacity can only be learned by making a plant and watching the results. . . . Local residents speak rather vaguely of occasional "bluebacks" being taken in the lower creek. These could be either sockeye or sea-run cutthroats. . . . Upper Lake Creek would provide good spawning for early-run sockeye. Spawning in the lake itself would be negligible.

Heg (1953) stated that

> Local residents report that Lake Pleasant used to support a small run of sockeye salmon. However, in view of the large scrap fish population, the unfavorable temperature conditions, and the occurrence of dry years of extreme low flows in the outlet stream, it does not appear likely that this lake can be developed into an important sockeye producer.

In 1956, Lake Pleasant was treated with rotenone by the Washington Department of Game in an attempt to eliminate all the resident fish in the lake and its tributaries in anticipation of using Lake Pleasant as rearing habitat for winter steelhead. Since the rotenone treatment only occurred in a single year, anadromous fish with multiple broodyear life histories were probably less affected by this program than resident fish. A box-lattice type fish trap was operated in the outlet creek (Lower Lake Creek) between 1958 and 1962 or 1963 during the winter steelhead run; however, this trap reportedly did not impede the adult sockeye salmon migration (J. Ayerst[32]).

Crutchfield et al. (1965) reported that an adult trap was operated in Lake Creek in the fall of 1960, 1961, and 1962. During these years, total counts of sockeye salmon at this trap were 1,223, 1,485, and 763, respectively. In the spring of 1958, 64,946 juvenile sockeye salmon smolts were counted in a downstream migrant trap placed in Lake Creek (Crutchfield et al. 1965). Migration of sockeye salmon up Lake Creek may have been interrupted for a few years in the early to mid-1970s due to operation of a weir to trap chinook salmon for artificial propagation (S. A. Chitwood[33]).

---

[32] J. Ayerst, Olympic National Forest, 1835 Black Lake Blvd. SW, Olympia, WA 98502. Pers. commun., 27 June 1995.

[33] S.A. Chitwood, Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., 19 Sept. 1995.

Kokanee-size *O. nerka* currently occur in Lake Pleasant, although their origin is uncertain. Smoker et al. (1952) stated that

> The State Game Department made apparently unsuccessful plants of silver trout [kokanee] in 1936, 1937 and 1938.

No further information on historical or recent kokanee introductions was available. Both kokanee-sized fish and sockeye salmon have been observed spawning at the same place and time on lakeshore beaches of Lake Pleasant (R. Gustafson, NMFS, Pers. observ., November 1995). Most Lake Pleasant sockeye salmon display a dirty red coloration on the spawning grounds (J. Haymes[34]).

Baker River

Rathbun (1900) indicated that, historically, sockeye salmon began arriving at the mouth of the Baker River in the middle of June and reached Baker Lake chiefly during July. Spawning occurred both in the lake and in Noisy Creek and “Sutter River” (upper Baker River?) beginning near the end of August or early September (Rathbun 1900, p. 269). The State of Washington established a hatchery, principally for sockeye salmon propagation, at Baker Lake in 1896. Baker Lake Hatchery was sold to the U.S. Fish Commission in 1899 and continued propagating the majority of returning sockeye salmon to this system until the end of 1933 (Kemmerich 1945).

Early reports of the Baker Lake Station included in Reports of the U.S. Commissioner of Fish and Fisheries (Ravenel 1901, 1902; Titcomb 1904), indicated that spawning sockeye salmon occurred both along the shoreline and in the Upper Baker River. Around the turn of the century, gill nets were used to capture adult sockeye salmon for hatchery broodstock along lake shore spawning beds, and racks were placed in the upper Baker River in an attempt to prevent sockeye salmon from ascending the river (Ravenel 1901, 1902; Titcomb 1904). Ravenel (1902) estimated that in 1900 over 25% of adult sockeye salmon in Baker Lake ascended the upper Baker River to spawn. Surveys conducted by WDF personnel in 1954 and 1955 showed that 95% of the sockeye salmon in the Baker River system at that time, spawned in Baker Lake on shoreline beaches (Quistorff 1954a,b,c; Quistorff 1959; PRO-Salmon 1994). Quistorff (1955) stated that

> Spawning sockeye salmon were observed in heaviest concentrations along the mid-south shore of Baker Lake where a condition of underground water movement was found.

---

[34] J. Haymes, Quileute Natural Resources, Quileute Indian Tribe, P.O. Box 187, La Push, WA 98350-0187. Pers. commun., 12 May 1995.

Some spawning sockeye salmon were also observed by Quistorff (1955) in Channel Creek and in the main upper Baker River one quarter mile downstream of Channel Creek. Hamilton and Andrew (1954) stated that sockeye salmon spawned in the upper Baker River without mention of shoreline spawning. However, Wayne (1961) stated that "the natural spawning areas for sockeye salmon . . . had been located along the north shore of the lake." It is unknown whether sockeye salmon that originally spawned on the shoreline of Baker Lake, and to some degree in tributaries of Baker Lake, consisted of a single genetic stock or multiple stocks. However, as pointed out in Hendry and Quinn (1997), between 1899 and 1933 hatchery operations "thoroughly mixed the descendants of any subpopulations that might initially have been present."

Construction of Lower Baker Dam just above the town of Concrete on the Baker River in 1924 to 1927 created Lake Shannon Reservoir (Wayne 1961). During dam construction in 1925, approximately 8,000-10,000 adult sockeye salmon were blocked from reaching Baker Lake, and only 40 sockeye salmon were successively lifted over the dam and eventually reached Baker Lake (Kemmerich 1945). Between 1926 and 1957, sockeye salmon were trapped at the base of Lower Baker Dam and transported over the dam in small steel tanks on a 244-m-long highline cableway and then chuted into the reservoir (Wayne 1961). Pre-spawner mortalities occurred below the dam (Wayne 1961), and escapement records for this period are for sockeye salmon that actually passed over the dam; Kemmerich (1945) estimated that 20-25% of sockeye salmon counted over the dam between 1926 and 1933 never reached Baker Lake due to mortalities resulting from this handling.

Following cessation of propagation efforts in 1933, and until construction of Upper Baker Dam in 1956, sockeye salmon that reached Baker Lake were allowed to spawn naturally. At that time, outmigrating sockeye salmon either passed over the surface spillway of Lower Baker Dam (where mortality was estimated at 64% when one spillway was open) or through the turbines (where mortality was estimated at 34%) (Hamilton and Andrew 1954). Hamilton and Andrew (1954) estimated that the sockeye salmon population had declined by 55% since dam construction. Use of a ski-jump spillway, first installed in 1955, considerably decreased spillway mortalities (Regenthal 1955) but resulted in loss of potential hydroelectric power (Wayne 1961).

Construction of Upper Baker Dam in 1959 inundated the original Baker Lake and created New Baker Lake (Upper Baker Reservoir), submerging the natural lakeshore spawning beaches and most of the potential tributary spawning areas beneath more than 18 m of water (Wayne 1961). Today this reservoir is commonly referred to as Baker Lake.

Fish handling facilities were updated in the late 1950s with construction of a new barrier dam and fish trap 0.8 km downstream of Lower Baker Dam. These events induced the use of tanker trucks for transporting adult sockeye salmon to Baker Lake, construction of artificial spawning beaches adjacent to Channel Creek above Baker Lake, the installation of turbine-pump-operated smolt collecting barges ("gulpers") at the head of each dam, and 20 to 25-cm-diameter fish transportation pipes that guided smolts from the gulpers through the face of each dam to be deposited into the tailrace channel below each dam (Wayne 1961, Quistorff 1966). Use of the transportation pipe through Upper Baker Dam was discontinued in 1987, and outmigrating juvenile sockeye salmon trapped since then at the Upper Baker Dam gulper have been trucked from Upper Baker Dam to the Baker River below Lower Baker Dam. Guide nets have subsequently been installed at both dams to discourage outmigrating fish from going over the spillways or through the turbines.

Artificial sockeye salmon spawning beaches 1, 2, and 3 were constructed in 1957, 1959, and 1966, respectively above Baker Lake off Channel Creek. Beach 1 ceased operation in 1965, but the spawner capacity of beaches 2 and 3 continues at 1,500 adult sockeye salmon each. Sockeye salmon fry from beaches 2 and 3 currently leave the beaches on their own volition through outlets into Channel Creek and from there into Baker Lake. The future of spawning beaches 2 and 3 is uncertain. According to WDFW (1996), “the state and tribes favor the continued use of beaches 2 and 3, but Puget Power and the Forest Service would like to close them.” Spawning beach 4, on Sulphur Creek, below Upper Baker Dam, began operating in 1990 with a spawner capacity of 3,000. Fry leaving beach 4 are captured and hauled by tanker truck to Baker Lake.

Since the construction in 1958 of a barrier dam and fish trap below Lower Baker Dam, adult sockeye salmon have been trapped and hauled by tanker truck to the spawning beaches or to Baker Lake. Since 1986, a portion of the fry leaving the spawning beaches have been collected and reared in net-pens in Lake Shannon Reservoir prior to being released as smolts through the Lower Baker Dam gulper. Total smolt releases between 1987 and 1992 were over 400,000 (WDF et al. 1993) (see Appendix Table D-2 and “Artificial Propagation” section). It was stated in WDFW (1996) that

> The future of the net pen program is uncertain. There have been three consecutive years of major IHN outbreaks in the net pens. Although the program did increase egg-to-smolt survival, it did not increase smolt-to-adult survival. In 1996, sockeye fry (brood year 1995) are not expected to be taken to the net pens.

Currently, adult sockeye salmon return to the Baker River trap from mid-June to mid-August and spawn in the artificial beaches from late September through December, peaking from late October to late November (WDF et al. 1993). In addition to releases into the artificial spawning beaches, significant numbers of adult sockeye salmon were released into Baker Lake in 1967, 1972, and 1994, and most likely in 1962, 1963, and 1964, as well (WDFW 1996). For instance, over 1,000 sockeye salmon (25% of the fish trap count) were released in Baker Lake in 1967 (Orrell 1969). The return of almost 16,000 sockeye salmon to Baker River in 1994 far exceeded the 4,000-fish capacity of the spawning beaches. Following consultations between WDFW and the Skagit System Cooperative (representing Skagit River area tribes) regarding a fishery on this stock, the remaining 12,000 adults were liberated into

Baker Lake in an experiment to determine survival rate and production potential for natural spawning of sockeye salmon in Baker Lake (J. Ames[35]).

The lower portion of the upper Baker River is now a braided stream subject to severe meander and, like shoreline spawning habitat, is subject to effects of reservoir drawdown in winter and spring (G. Sprague[36]). Baker Lake and beaches 2 and 3 near Channel Creek commonly freeze over in winter, but Lake Shannon and beach 4 never freeze over (G. Sprague[37]).

Kokanee are present in the system, although Ward (1929, 1930, 1932) and Kemmerich (1945) thought that "kokanee-sized" *O. nerka* in Baker Lake were derived from sockeye salmon residuals. Following construction of Lower Baker Dam, resident *O. nerka* were observed spawning in Baker Lake for the first time and were presumed to have originated from sockeye salmon residualizing in Lake Shannon Reservoir (Ward 1929, 1930, 1932, Kemmerich 1945).

Between 1991 and 1994, 1,158,200 hatchery reared Lake Whatcom kokanee were released in Lake Shannon (Knutzen 1995). Lake Whatcom kokanee were reportedly released into Baker Lake in the past,[38]Mill Creek, WA 98012-1296. Pers. commun., 19 April 1996. although we were unable to locate stocking records. In average years, 40-100 "kokanee-sized" *O. nerka* spawn in the outlet channel that drains the two upper sockeye salmon spawning beaches and flows into Channel Creek (W. Steuer[39]). It is possible that a portion of the kokanee that have been recently planted in Lake Shannon Reservoir from Lake Whatcom stock may have outmigrated through the Lower Baker Dam gulper. It is unknown whether these potential outmigrating kokanee have returned as sockeye salmon; however, if they have, they would presumably have been placed together with native sockeye salmon in the spawning beaches (G. Sprague[40]).

---

[35] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., April 1995.

[36] G. Sprague, Habitat Program, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 15 March 1995.

[37] G. Sprague, Habitat Program, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 15 March 1995.

[38] J. Johnston, Washington Department of Fish and Wildlife, 16018 Mill Creek Blvd., Mill Creek, WA 98012-1296. Pers. commun., 19 April 1996.

[39] W. Steuer, Washington Department of Fish and Wildlife, 121 N. Ball St., Sedro Wooley, WA 98284. Pers. commun., 1 November 1995.

[40] G. Sprague, Habitat Program, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 15 March 1995.

Lake Washington

The following historical overview of changes to the Lake Washington Basin has been compiled from Evermann and Meek (1898), Ajwani (1956), Woodey (1966), Larson (1975), Stickney and McDonald (1977), Corsaletti (1981), Chrzastowski (1983), and Buerge (1985, 1989).

Between 1911 and 1916, construction of the Lake Washington Ship Canal, and associated engineering projects, profoundly altered both the natural drainage patterns of Lake Washington and potential migratory routes of anadromous fish native to the basin. During this period, the Cedar River was diverted to discharge into Lake Washington, the level of Lake Washington was lowered approximately 3 m, the outlet into the Black River ceased to exist, the Sammamish River channel was widened and deepened, and the newly constructed Lake Washington Ship Canal became the new lake outlet.

Historically, Lake Washington drained to the south through the Black River, which flowed for 5.3 km to its confluence with the White River (now the Green River) to form the Duwamish River and then flowed into Puget Sound. The Cedar River entered the Black River less than 1 km below the Lake Washington outlet, and Lake Washington’s principal tributary was the Sammamish River (historically called Squak Slough). The Black River had an average depth of 1.2 m and ranged in width from 15 to 46 m. At flood stage, the Cedar River commonly reversed the flow of the upper segment of the Black River, causing Cedar River water to flow into Lake Washington. At these times, the Black River had water flowing in opposite directions at its two ends, north into Lake Washington and west into the Duwamish River. This is why the Black River was called “Mox La Push,” meaning “two mouths,” in the Chinook jargon. Prehistorically, the Cedar River may have been a major tributary to Lake Washington (Chrzastowski 1983).

In 1911, construction on the locks (now the Hiram M. Chittenden Locks), dam, and Fremont and Montlake Cuts began. According to Chrzastowski (1983) and Buerge (1985, 1989), the Cedar River was permanently diverted into Lake Washington in the summer of 1912 by excavation of a channelway 24 m wide and 610 m long. This diversion was precipitated by severe flooding on the Cedar River in the winter of 1911 that required the evacuation of the city of Renton. The locks were completed in the spring of 1916, and by 25 July 1916 the level of Salmon Bay had been raised to equal that of Lake Union. The lowering of the level of Lake Washington to that of Lake Union was gradual, occurring over a 4-month period from July to October 1916 (Stickney and McDonald 1977, Chrzastowski 1983). The lowering of Lake Washington also increased the gradient of the Sammamish River, making it too shallow and narrow for navigation, and leading to the widening, deepening, and channelization of the Sammamish River in 1916 by the U. S. Army Corps of Engineers (Stickney and McDonald 1977, Chrzastowski 1983). The opening of the Lake Washington Ship Canal was celebrated on 4 July 1917.

The lowering of Lake Washington in 1916 left the channel of the Black River high and dry, while the diversion of the Cedar River into Lake Washington in 1912 caused the Cedar River to become Lake Washington's principal tributary and approximately doubled the flow of freshwater into Lake Washington. Ajwani (1956) stated that

> Whether the runs of fish occurring at the time of these diversions were eliminated or what the degree of their reduction was, cannot be determined because of lack of data.

Reports in the literature are equivocal as to whether sockeye salmon were historically present in the Lake Washington/Lake Sammamish Basin prior to 1916, although kokanee were numerous. Prior to construction of the Lake Washington Ship Canal, fishing for "silvers" and "trout" was reported to be at its best near the confluence of the Black River and Lake Washington (Larson 1975, Slauson 1976). Silver salmon is a common local name for coho salmon, while in the early part of this century kokanee were called "silver trout" (and are still so designated in Washington State fishery regulations). Hammond (1886), in reference to Lakes Washington and Sammamish, stated that

> The only fish in them is a species of trout, very few in number, the largest of which are about a foot in length.

Seale (1895) reported the collection of "six large specimens" of "dark" *O. nerka* taken in Lake Washington on 7 November 1892 and two others, "more silvery in color," taken on 30 June 1895. No dimensions for these fish were recorded, although the species was reportedly "very abundant" (Seale 1895). Woodey (1966) surmised from the dates of collection and coloration of the specimens that the *O. nerka* reported by Seale (1895) were most likely kokanee. Four of Seale's (1895) specimens of *O. nerka* collected in Lake Washington on 7 November 1892 are currently deposited in the California Academy of Sciences fish collection (D. Catania[41]). The relatively short fork lengths of these 4 specimens (241-249 mm) indicate that Seale's (1895) "six large specimens" of *O. nerka* were kokanee, not sockeye salmon.

Jordan and Evermann (1896) reported that Prof. O. B. Johnson observed large "redfish," presumably sockeye salmon, at Lake Washington. Evermann (1896) reported that the "small redfish" was found at Lake Washington, and goes on to say that

> Prof. O. B. Johnson found the small form spawning in Lake Washington near the last of November, 1888, and on October 8, 1889.

---

[41] D. Catania, Ichthyology Department, California Academy of Sciences. Pers. commun., 27 March 1996.

Evermann and Meek (1898), in reference to Lake Washington, stated that

> Salmon are said to enter the lake through the Black River early in the fall, but none was seen. They are probably the large form of the redfish or sockeye (*Oncorhynchus nerka*). Redfish are said to run up into shallow places during the latter part of October and a part of November . . .

All stocks of sockeye salmon presently found in Lake Washington complete their migration into Lake Washington before the end of August (WDF et al. 1993), suggesting that the salmon Evermann and Meek (1898) reported as entering the Black River in the fall were not sockeye salmon, or that sockeye salmon had radically different run-timing in Lake Washington in the 1890s compared to the present day, and that this stock is now extinct. While seining in Lake Washington, Evermann and Meek (1898) collected 17 “small redfish” ranging in length from 24 to 27 cm, but did not collect anadromous-sized *O. nerka*.

In regard to Lake Sammamish, Evermann and Meek (1898) stated “no information could be obtained as to what kind of salmon enter the lake,” but reported that local residents said that redfish were plentiful in “Squak Slough” (Sammamish River) and that “salmon run with the redfish.” Evermann and Meek (1898) presumed that redfish, or “grayling” as they were called locally, spawned from the latter part of October to early or mid-November.

Subsequent authors either stated that a small population of sockeye salmon occurred in Lake Washington (Rathbun 1900; Evermann and Goldsborough 1907; Cobb 1911, 1914, 1930) or that Baker River had the only population of sockeye salmon in Puget Sound (Cobb 1927, Rounsefell and Kelez 1938, Royal and Seymour 1940, Kemmerich 1945). Pratt and Jewell (1972) reported that no record has been located of “sea-run” sockeye salmon in Lake Washington prior to their introduction in 1935. Surveys conducted on the Cedar River, Big Bear Creek, Cottage Lake Creek, and Evans Creek on 2 and 3 September 1930 did not report the occurrence of sockeye salmon (WDFG 1932). Currently, early September is near the beginning of sockeye salmon spawn timing for these streams (WDF et al. 1993). In reviewing the history of *O. nerka* in the Lake Washington/Lake Sammamish drainage, Hendry (1995) concluded that “limited runs of sockeye salmon . . . were probably present at the turn of the century,” and that

> The status of Lake Washington sockeye salmon during this period (1917-1937) will probably never be fully determined but it is certainly unlikely that large populations were present.

Sockeye salmon vertebral remains were identified in prehistoric fish remains from the Duwamish No. 1 archeological site (45-KI-23), located 3.8 km upstream from Elliot Bay on the Duwamish River, utilized by aboriginal humans between A.D. 15 and A. D. 1654 (Butler 1987). Fish remains from two archeological sites on the former Black River, Tualdad Altu (45-KI-59, Earlington site) and Sbabadid-D (45-KI-51-D), revealed numerous *Oncorhynchus* sp. remains, but identification to the species level was not undertaken in this study (Chatters 1988, Butler 1990).

Smith (1940), reporting on cultural interviews with local tribal elders, stated that "when asked about the red salmon (*O. nerka*) informants said the silver side might be called that as it turned red in freshwater, but they knew of no separate species by this name." Smith (1940) goes on to say

> A small salmon was said to live permanently in Lake Washington spawning in the creeks which emptied into the lake. The Duwamish of that section and even those at the intersection of the White and Green Rivers were said to prefer this salmon to that which entered the rivers from the Sound.

This reference to land-locked salmon most likely refers to the numerous kokanee then present in Lake Washington.

The undisputed historic presence of kokanee in Lake Washington indicates that sockeye salmon existed in Lake Washington, at least in prehistoric times. Several factors may have favored subsequent evolution of kokanee (and non-anadromy) at the expense of anadromous *O. nerka* in Lake Washington. Chrzastowski (1983) stated

> For most of the year, Lake Washington in its natural state was a poorly flushed lake, and water quality reportedly worsened noticeably during the dry season (July-Sept.) when the lake was relatively stagnant. Average residence time for the lake water in the natural state probably was about twice the present-day value, or nearly 5 years.

In addition, spring floods on the Cedar River that commonly backed up the Black River into Lake Washington (preventing the lake from draining for a time) would probably have occurred during the period of potential smolt outmigration (March to early June). Both these factors (low flushing rate and difficulty of locating the outlet during flood stages) may have inhibited smolt outmigration.

Foerster (1937) found that when surface epilimnion temperatures rose above 10^{o}C in Cultus Lake, a physiological temperature barrier was formed that terminated downstream migration of young sockeye salmon. The observations of Foerster (1937) may be used to support the hypothesis that prior to diversion of the Cedar River into Lake Washington, which more than doubled the lake's water budget, relatively low outflow and seasonal development of a deep epilimnion of warm water may have presented a physical and/or physiological impediment to downstream sockeye salmon smolt migration. Recent historical changes in the drainage pattern of Lake Washington may have created conditions that were more favorable to development of anadromous *O. nerka*. However, it should be noted that currently sockeye salmon smolts in Lake Washington are known to continue to outmigrate into June through 17^{o}C temperature water (Warner 1997).

WDF et al. (1993) recognized three separate stocks of sockeye salmon currently in the Lake Washington/Lake Sammamish drainage: Cedar River, Lake Washington/Lake Sammamish Tributaries, and Lake Washington beach spawning. WDF et al. (1993) indicated that sockeye salmon stocks that spawned in the Cedar River were of non-native origin, and stocks that spawned in other Lake Washington/Lake Sammamish tributaries and on lakeshore beach habitat in Lake Washington were of unknown origin and were perhaps native to the drainage.

Available artificial propagation data and transplantation records provide evidence that the current Cedar River and Issaquah Creek (a tributary of Lake Sammamish) sockeye salmon are introduced populations (Royal and Seymour 1940, Kolb 1971, Burgner 1991) (see Appendix Table D-2). The majority of Cedar River sockeye salmon spawn from mid-September into January (a few are still spawning in February), with a peak in mid- to late October (WDF et al. 1993). The Cedar River population was believed by Kemmerich (1945), Royal and Seymour (1940), Kolb (1971), and Pratt and Jewell (1972) to be derived from the direct planting of over 1 million fry and fingerlings between 1935 and 1944 (see Appendix Table D-2 and "Artificial Propagation" section). These introductions originated from a sockeye salmon stock perpetuated at the U.S. Bureau of Fisheries Birdsview Hatchery on Grandy Creek in the Skagit River Basin.

The Birdsview Hatchery stock was started in 1908 from Fraser River sockeye salmon captured in commercial traps at Point Roberts, and egg takes in 1912 and 1916 indicate that substantial numbers of adult fish returned from these initial releases in Grandy Creek and Grandy Lake (Kemmerich 1945). In 1916, fry derived from Quinault Lake were used to supplement the Birdsview Hatchery stock (Kemmerich 1945, see Appendix Table D-2). However, over the years 1914-1945 the parent stock for this hatchery program was overwhelmingly Baker Lake sockeye salmon (Kemmerich 1945).

Out-of-basin releases in the Lake Washington/Lake Sammamish Basin totaled over 3.4 million fry and fingerlings from releases of 1) an unknown stock in 1917, 2) Birdsview Hatchery stock between 1935 and 1945, and 3) Cultus Lake stock released in 1944, 1950, and 1954 (Woodey 1966, Kolb 1971, Hendry 1995) (see Appendix Table D-2). From 1947 to 1970, adult sockeye salmon returning to the Issaquah Hatchery provided broodstock for numerous additional fry and fingerling releases to Issaquah Creek, and limited releases to Lake Union and the Cedar River (Kolb 1971).

Sockeye salmon in the Lake Washington/Lake Sammamish tributaries stock spawn primarily in Big Bear Creek, Cottage Lake Creek, and East Fork Issaquah Creek, with minor numbers in other Lake Sammamish tributaries (WDF et al. 1993), such as Laughing Jacobs and Lewis Creeks (Ostergaard et al. 1994). Spawning in these creeks extends from early September through November, with a peak in mid- to late October, depending on stream flow. Issaquah Creek received sockeye salmon fry and fingerling plants of over 1.6 million Birdsview Hatchery-origin fish between 1935 and 1945, and over 59,000 Cultus Lake-origin fish in 1950 and 1954. North Creek, a Sammamish River tributary, received over 23,000 Cultus Lake sockeye salmon fry planted in 1944 (Kolb 1971).

Kemmerich (1945), reporting on the effectiveness of introductions of sockeye salmon of the 1934 broodyear from the Birdsview Hatchery into the Cedar River and Issaquah Creek, stated that two sockeye salmon were found “in the Bear Creek fish trap of the State Game Department” on 5 October 1938. No sockeye salmon had been planted in Big Bear Creek up to this point, with the exception of fry planted in the spring of 1937 which would not have reached maturity in 1938. However, Kemmerich (1945) pointed out that 76,000 sockeye salmon fry from Baker Lake had been planted in Issaquah Creek in the summer of 1935. Out-of-basin releases of *O. nerka* fry into Big Bear Creek and its two tributaries, Cottage Lake Creek and Evans Creek, included 576,000 sockeye salmon fry, primarily of Baker Lake origin, stocked in Big Bear Creek in 1937 (Royal and Seymour 1940, Kemmerich 1945, Kolb 1971). In addition, over 34 million Lake Whatcom kokanee were stocked in Big Bear and Evans Creeks between 1917 and 1969 (Pfeifer 1992), and over 177,000 kokanee from an unknown source population stocked in Big Bear Creek in 1917 (Pfeifer 1992) (see Appendix Tables D-2 and D-5).

Kokanee used for stock transfers in the early part of this century were most commonly derived from either Kootenay Lake, British Columbia or Lake Whatcom, Washington (Pfeifer 1992). Pfeifer (1992) stated that

> I cannot rule out the possibility that kokanee from Kootenay Lake were among the many early introductions for which the egg or fry source was not explicitly recorded. In the Lake Washington system, the kokanee found in Big Bear Creek exhibit a spawn timing intermediate to that of the Kootenay and Whatcom strains, and are found spawning alongside the anadromous form.

Currently, kokanee in the Lake Washington/Lake Sammamish Basin can be separated into two groups based on very different spawn timing; 1) a group of early-entry kokanee in Issaquah Creek (a tributary at the southern end of Lake Sammamish) that exhibit late July to early September spawn timing, and 2) kokanee in the Sammamish River and Lake Sammamish tributaries, including a second run of kokanee in Issaquah Creek that spawn in September/October in Big Bear Creek, October/November in Issaquah Creek, and late November/December in Laughing Jacobs and Lewis Creeks (Pfeifer 1992, Ostergaard et al. 1995). Ostergaard et al. (1995) stated that early entering kokanee in Issaquah Creek are known to be native, while kokanee in other tributaries to Lake Sammamish and the Sammamish River are believed to be non-native, based on their later run-timing. Ostergaard (1996) listed 8 creeks, tributary to the east and south shores of Lake Sammamish, that historically supported native early entering kokanee. Ostergaard (1996) estimated the 4-year (1992-1995) total spawning population of these kokanee in Issaquah Creek at 81 fish.

Kokanee once existed in streams tributary to Lake Washington, other than the Sammamish and Cedar Rivers. Shultz and Students (1935) observed kokanee spawning in

Swamp Creek, a tributary of the lower Sammamish River, from September to November 1933. The University of Washington Fish Collection has specimens of kokanee collected in Swamp Creek on 30 August 1920, 28 October 1928, and 27 November 1933. Since these observations and collections were made before the first recorded transplants of kokanee to Swamp Creek (see Appendix Table D-5), it is apparent that not all kokanee native to the Lake Washington/Lake Sammamish Basin had exclusively early run-timing.

Spawning sockeye salmon intermingle with spawning Big Bear Creek and late-entry Issaquah Creek kokanee (Pfeifer 1992), as well as with kokanee spawning in Laughing Jacobs and Lewis Creeks (Ostergaard et al. 1995). Kokanee are also reported to spawn together with sockeye salmon in the Cedar River (Pfeifer 1992), although the coloration of Cedar River kokanee-sized fish is typical of the coloration shown by residuals in other lake systems (J. Ames[42]).

Pfeiffer (1992) stated that fish traps were operated in Big Bear Creek by the King County Game Department and the Washington Department of Game in the 1930s. In reference to Big Bear Creek, Ajwani (1956, p. 67-68) stated that

> A wooden weir was constructed across the stream in 1925, when the County Game Commission was in operation. At that time the county would take all the eggs obtained from the silver trout run and either plant or trade these eggs elsewhere. . . . For its size, this stream is . . . one of the largest producers of silver trout in the state.

The run-timing of kokanee in Big Bear Creek is essentially concurrent with that of anadromous sockeye salmon: from early September to late November with a peak in the first to second week of October (Ostergaard et al. 1995). Therefore, kokanee fish traps and weirs operated in Big Bear Creek in the 1920s and 1930s would presumably have impeded migration of sockeye salmon that may have been in the system at that time. Prior to the single recorded transplant of 576,000 sockeye salmon fry into Big Bear Creek in 1937 and the recorded return of 2 adults in October 1938 and another 2 adults in October 1940, no mention of sockeye salmon in Big Bear Creek occurs in the published literature.

Surveys by King County Surface Water Management Division in 1992, 1993, and 1994 recorded only 242, 23, and 9 kokanee, respectively in the Big Bear Creek drainage (Ostergaard et al. 1995). In addition, Ostergaard et al (1995) stated that the 9 fish seen in 1994 may have been residual sockeye salmon or sockeye salmon x kokanee hybrids. Past results of electroshocking in Big Bear Creek by WDFW have indicated that the number of kokanee visually observed is a small fraction of the actual number of fish present (WDFW 1996), therefore it is probable that the kokanee population in Big Bear Creek during 1992-1994 was larger than the numbers in Ostergaard et al. (1995) suggest. Ostergaard

---

[42] J. Ames, Department of Fish and Wildlife, State of Washington, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., April 1995.

(1996) estimated an escapement of 317 kokanee to Big Bear Creek in the fall of 1995, based on WDFW survey numbers.

Beach spawning sockeye salmon are found in both Lake Washington and Lake Sammamish; WDF et al. (1993) considered the beach spawners in Lake Washington a separate stock, but the status of the Lake Sammamish beach spawners was undetermined due to lack of information. Berggren (1974) reported that the numbers of beach-spawning sockeye salmon in Lake Sammamish between 1969 and 1972 ranged from a low of 125-200 in 1969 to a high of 1,400-1,900 in 1971. Recent estimates of Lake Sammamish beach-spawning sockeye salmon were unavailable. Lake Washington beach spawning occurs primarily between October and January. Spawning has been observed in many locations around the perimeter of Lake Washington, but primarily at Pleasure Point Beach on the southeast shoreline, in the Bellevue area, near Juanita Point, along Enatai Beach (Buckley 1965), and around the shoreline of Mercer Island (Woodey 1966, WDF et al. 1993).

Riverine spawning sockeye salmon in Washington

Methow River—Prior to the hatchery program at the Winthrop National Fish Hatchery (NFH), sockeye salmon were apparently not present in the Methow River (WDF et al. 1938, Mullan 1986, Chapman et al. 1995). Over 1.8 million sockeye salmon of Rock Island and Bonneville Dam origin were released in the Methow River from Winthrop NFH between 1945 and 1957 as part of the GCFMP (Mullan 1986, Chapman et al. 1995) (see Appendix Table D-2). Chapman et al. (1995) indicated that small numbers of sockeye salmon continue to return to the Methow River every year and this population appears to be self-perpetuating. Allen and Meekin (1973) reported that, based on weir counts, about 1% of the sockeye salmon passing Wells Dam in 1965 and 1966 entered the Methow River. French and Wahle (1960) and Fryer and Schwartzberg (1993) reported that sockeye salmon spawning occurred between river kilometers 57 and 64 on the Methow River downstream of Twisp. Langness (1991) reported that sockeye salmon were observed spawning in the Methow River from 1987 to 1990 and that the distribution of spawning was essentially the same as reported in French and Wahle (1960). It has been postulated that sockeye salmon that spawn in the Methow River may rear in mainstem reservoirs on the Columbia River (Chapman et al. 1995).

Allozyme data presented by Chapman et al. (1995) indicate a closer association of Methow River sockeye salmon with Lake Wenatchee sockeye salmon than with Okanogan River sockeye salmon. However, recent analysis of allozyme data based on sockeye salmon collected in 1994 (Okanogan River fish collected at Wells Dam) indicate that sockeye salmon from the Methow River, Wenatchee River, and Okanogan River (Wells Dam) belong to a common gene pool (Utter 1995). The apparent genetic similarity between Wenatchee and Okanogan River sockeye salmon reported in Utter (1995) is inconsistent with findings of significant genetic distance between Wenatchee and Okanogan populations as reported in Utter et al. (1984), Brannon et al. (1994), Thorgaard et al (1995), and Winans et al. (1996).

Entiat River—Prior to the hatchery program at the Entiat National Fish Hatchery, sockeye salmon had not been observed in the Entiat River (WDF et al. 1938, Mullan 1986, Chapman et al. 1995). Approximately 161,787 juvenile sockeye salmon derived from Quinault Lake stock were released into the Entiat River in 1942 and 1943 (Chapman et al. 1995) (see Appendix Table D-2). In addition, 22,341 Lake Chelan kokanee, derived from Lake Whatcom stock, were released into the Entiat River in 1944 (Mullan 1986) (see Appendix Table D-5).

Barnaby (1946) indicated that of 60,010 marked sockeye salmon juveniles of the 1941 brood released in the Entiat River on 8 May 1943, 93 were recovered as adults in 1944 and 658 in 1945. In 1945, 33 marked sockeye salmon were recovered in the Entiat River, 3 in the Wenatchee River, and 622 in the Columbia River commercial fishery (Barnaby 1946). In contrast, Fulton and Pearson (1981) indicated that 670 adults from this experiment were recovered in the lower river fishery, with only one recovered in the Entiat River and 3 in the Wenatchee River. Apparently, these introductions established a small sockeye salmon population that provided enough returning adults to provide broodstock in the 1950s for release into Lake Wenatchee, Lake Osoyoos, and Icicle Creek (Mullan 1986, Chapman et al. 1995) (see Appendix Table D-2).

Although Mullan (1986) believed that transplants of Quinault Lake stock established sockeye salmon in the Entiat River, he postulated these three alternate hypotheses to explain their occurrence: 1) inadvertent inclusion of sockeye salmon with other species of salmon trapped at Rock Island Dam and released in 1939-1940 in the Entiat River, 2) escape of juvenile sockeye salmon from the Entiat Hatchery, and 3) straying from other stocks. Since natural sockeye salmon stocks had not become established in the Entiat River prior to the GCFMP, Mullan (1986) discounted straying as a possible origin for Entiat River sockeye salmon. Currently small numbers of sockeye salmon are observed in the Entiat River almost every year (Chapman et al. 1995). Chapman et al. (1995) considered these fish either as strays from Lake Wenatchee or Okanogan River or as artifacts of the hatchery stocking program carried on during the 1940s and 1950s. It was postulated that sockeye salmon that spawn in the Entiat River rear in mainstem reservoirs on the Columbia River (Chapman et al. 1995).

Similkameen River—Although the Similkameen River, which originates in British Columbia, is considered the main tributary of the Okanogan River downstream from Lake Osoyoos, it is considerably larger than the Okanogan, contributing some 3 to 4 times the water volume of the mainstem Okanogan (WDF et al. 1938, Bryant and Parkhurst 1950, Mullan 1986). Fulton (1970) and Allen and Meekin (1980) listed Palmer Lake and its inlet tributary Sinlahekin Creek as historical sockeye salmon habitat. In contrast, Mitchell (1980) suggested that prior to construction of Enloe Dam in 1920, the original Squantle (Similkameen) Falls was 7.6 to 9.1 m high and would have acted as a block to upstream migration of sockeye salmon to Palmer Lake. Bryant and Parkhurst (1950) reported that 500 dead unspawned sockeye salmon were found in the Similkameen River in 1936 and that these fish may have been part of the population that normally spawned above Lake Osoyoos.

French and Wahle (1954) observed sockeye salmon below Enloe Dam on the Similkameen River from early to mid-August, but not in late August or September of 1954. Other authors reporting the occurrence of sockeye salmon in the Similkameen River included Chapman (1941), French and Wahle (1960, 1965), CBFWA (1990), Langness (1991), and Chapman et al. (1995).

Currently, small numbers of sockeye salmon are seen almost every year below Enloe Dam on the Similkameen River (Chapman et al. 1995). The origin of these sockeye salmon is uncertain; hypotheses proposed include straying of sockeye salmon from the Okanogan River and returns of anadromous individuals derived from kokanee in upstream Palmer Lake (Chapman 1941, Rounsefell 1958a, Fulton 1966). WDFG (1921a, 1921b) recorded the release of 132,500 kokanee (silver trout) into Palmer Lake in 1919-1920. In 1966, Fulton (1966) reported that 45,000 kokanee and 87,000 sockeye salmon were released in Sinlahekin Creek and Palmer Lake (see Appendix Tables D-2 and D-5); 15 thermally marked outmigrants from this release were captured at Priest Rapids Dam.

Icicle Creek—Icicle Creek is a tributary of the Wenatchee River below Lake Wenatchee and is also the site of Leavenworth National Fish Hatchery. Over 1.5 million juvenile *O. nerka* were released directly into Icicle Creek between 1942 and 1969: 1.1 million of Rock Island Dam heritage, over 270,000 of Entiat River heritage (progeny of Quinault Lake stock), over 44,000 of Methow River heritage, over 100,000 of Lake Wenatchee heritage, about 3,000 from an unknown British Columbia sockeye salmon stock, and over 29,000 Lake Wenatchee kokanee (Chapman et al. 1995, NRC 1995) (see Appendix Table D-2). Chapman et al. (1995) stated that currently, small numbers of adult sockeye salmon are observed in Icicle Creek almost every year. Since the Leavenworth NFH is located only 4.5 km from the Wenatchee River, Mullan (1986) suggested that observations of sockeye salmon in Icicle Creek could represent some residual attraction of hatchery-reared fish to the water they were reared in before their release into Lake Wenatchee, or it could have represented straying into the wrong tributary. As pointed out by Chapman et al. (1995), no sockeye salmon have been reared at Leavenworth since the mid-1960s; however, “generally less than a few dozen” sockeye salmon are still seen in Icicle Creek each year.

Nooksack River—In reference to the glacially influenced Nooksack River, Rathbun (1900) stated that

> The sockeye have been said to enter it, but the evidence to that effect is not conclusive.

Kershaw (1902) stated that “the sockeye occasionally ascend the river in small numbers.” In reference to sockeye salmon, Crawford (1907) stated

> a few have been known to enter the Nooksack River and spawn in one of its small tributaries . . . those from the Nooksack . . . were noticed during the great run of 1905 when the sockeyes ran closer to the shore on the Sound than has ever been known before. Last season a great many salmon ascended the Nooksack River.

FWTC (1970) stated that

> At least one section of the Nooksack system supports a small run of sockeye salmon. It is a half-mile-long side channel of the North Fork, located 3.5 miles upstream from the town of Glacier. Other stream sections, and some tributaries, in both the North and South Fork Nooksack, also receive limited sockeye runs.

Williams et al. (1975) also reported that sockeye salmon spawn along a half-mile side channel of the North Fork Nooksack River about 3.5 miles above the town of Glacier and below Lookout Creek (RKm 100.5). Small numbers of spawners are still seen each year in the North and South Forks of the Nooksack and in Maple Creek (D. Hendrick[43]). As summarized in Appendix Table C-7, WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated several locations, dates, and peak numbers of spawning sockeye salmon in the Nooksack River.

Sockeye salmon are caught in the Nooksack River as by-catch in the Nooksack Tribal coho harvest during the months of September through October. This freshwater fishery occurs from the confluence of the North and South Forks of the Nooksack River, downstream to the mouth (D. Grieggs[44]). Recent tribal harvest has ranged from 15 in 1992 to 386 in 1991 (Hoines 1995). Run-timing of sockeye salmon caught in the Nooksack Tribal fishery is significantly later than either Baker River or Lake Washington sockeye salmon stocks, which terminate by mid-August, but Nooksack River sockeye salmon run-timing does overlap the timing of several lower Fraser River stocks (see Appendix Tables C-6 and C-7).

Several anecdotal reports indicated that early hatchery supplementation of sockeye salmon occurred at the Nooksack Hatchery on Kendall Creek (Pacific Fisherman 1905a), and that introductions into the Nooksack River of a small number of out-of-basin sockeye salmon fry also occurred (Pacific Fisherman 1905b, 1906).

Samish River—WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated several locations, dates, and peak numbers of spawning sockeye salmon in the Samish River (see Appendix Table C-7). Anecdotal records indicated that extensive culture of sockeye salmon, taken in fish traps in Puget Sound, occurred at the Samish State Hatchery at least in the years 1915-1917 (Pacific Fisherman 1915a, 1915b, 1916, 1918). WDFG (1916a, 1917, 1920) recorded the release into Lake Samish and Cain Lake of almost 9 million sockeye salmon fry between 1915 and 1918. They reported that the fish released were

---

[43] D. Hendrick, Washington Department of Fish and Wildlife, 333 E. Blackburn Rd., Mount Vernon, WA 98273. Pers. commun., 8 August 1995.

[44] D. Grieggs, Nooksack Tribal Fisheries Department, Deming, WA. Pers. commun., June 1995.

derived from sockeye salmon captured on the west side of Lummi Island (off Bellingham Bay) (see Appendix Table D-2). In 1920, over 165 sockeye salmon spawned naturally above the Samish Hatchery racks (WDFG 1921b).

Between 1934 and 1937, over 0.5 million sockeye salmon fry from the Birdsview Hatchery on Grandy Creek were released in Lake Samish (Royal and Seymour 1940, Kemmerich 1945) (see Appendix Table E-2). Several sockeye salmon were observed in 1937 and 1938 at the Samish State Hatchery and in the Samish River (Kemmerich 1945). An estimated 300-400 sockeye salmon returned to the Samish Hatchery in the fall of 1940 (Royal and Seymour 1940, Kemmerich 1945).

Skagit River Basin—In reference to riverine-spawning sockeye salmon in the glacially influenced Skagit River Basin, WDF et al. (1993) stated

> They are consistently found in very small numbers in the upper Sauk River and the mainstem Skagit near Newhalem. Whether these represent strays from the Baker or other river systems or are small self-sustaining populations of a few individuals is unknown.

WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated several locations, dates, and peak numbers of spawning sockeye salmon in the Skagit River Basin (see Appendix Table C-7). Juvenile sockeye salmon displaying parr marks have been observed in the mainstem Skagit River near the town of Lyman (D. Hendrick[45]).

In the 1930s, extensive sockeye salmon transplants were made from Birdsview Hatchery into the following Skagit River tributaries: Day Creek, Illabot Creek, Bacon Creek, and Diobsud Creek, as well as Lake McMurray, McMurray Creek, Big Lake, and Clear Lake on Nookachamps Creek (Kemmerich 1945) (see Appendix Table D-2). No returns were noted from these plantings to Nookachamps Creek, Illabot Creek, or Day Creek. About 300 sockeye salmon were seen in Bacon Creek in 1936, and 20 and 6 in Diobsud Creek in 1936 and 1937, respectively.

Stillaguamish River—WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated several locations, dates, and peak numbers of spawning sockeye salmon in the Stillaguamish River (see Appendix Table C-7). Between 1929 and 1937, 322,175 juvenile sockeye salmon were released into Lake Cavanaugh and Pilchuck Creek (see Appendix Table D-2). In the fall of 1935, 1936, 1937, and 1938, returning sockeye salmon adults counted at the base of the falls on Pilchuck Creek amounted to 40, 3,000-4,000, 1,000-2,000, and 200-300, respectively (Kemmerich 1945). Recent tribal freshwater harvest information recorded

---

[45] D. Hendrick, Washington Department of Fish and Wildlife, 333 E. Blackburn Rd., Mount Vernon, WA 98273. Pers. commun., 8 August 1995.

186 sockeye salmon taken in 1989 on the Stillaguamish River, but none in other years (Hoines 1995).

Duwamish River/Green River—WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated several locations, dates, and peak numbers of spawning sockeye salmon in the Green River (see Appendix Table C-7). Sockeye salmon have been observed spawning below Howard Hanson Dam on the Green River (E. Warner[46]). Recent tribal freshwater harvest of sockeye salmon in the Duwamish-Green River Basin has ranged from 0 in 1987 to 278 in 1984 (Hoines 1995). At least 392,050 sockeye salmon fry derived from Green River, Quinault Lake, and unspecified Alaska stocks were released into the Green River from the Green River State Hatchery between 1925 and 1931 (WDFG 1928, 1930, 1932) (see Appendix Table D-2).

Puyallup River—Anadromous fish trapped at the base of Mud Mountain Dam on the White River, a tributary of the Puyallup River in Puget Sound, are trucked around the dam and placed in the White River above Mud Mountain Dam. Small numbers of sockeye salmon have been reported in the yearly Mud Mountain Fish Haul Reports beginning in 1983, when 19 adult sockeye salmon were counted over the dam. Since 1985, when 378 sockeye salmon were counted at Mud Mountain Dam, small numbers ranging from 5 to 114 have been counted each year at this facility (MMDFHR 1996). Mud Mountain Reservoir is a run-of-the-river flood-control reservoir, and as such does not provide lake-rearing conditions for sockeye salmon. Information on possible spawning locations for sockeye salmon released above Mud Mountain Dam was not located.

Nisqually River—WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated that 19 sockeye salmon and 6 sockeye salmon redds were observed in August 1966 at river kilometer 20 on the Nisqually River (see Appendix Table C-7). In addition a few sockeye salmon have been reported in Mashel River and Ohop Creek, although none have been reported in Nisqually River surveys since 1982. A very few sockeye salmon are reported in the tribal freshwater harvest statistics for the Nisqually River (Hoines 1995).

Lewis River—According to WDFW (1996),

> Anadromous size sockeye are occasionally observed in the North Fork Lewis River downstream of Merwin Dam.

Hamilton and Rothfus (1963) reported that 890,000 sockeye salmon fry were released in Lake Merwin in 1961 and that over 3,000 sockeye salmon smolt were counted in a downstream migrant trap in spring 1962. Appendix Table D-2 also shows that large numbers of sockeye salmon fry (over 900,000) were released in the Lewis River in 1961, and an additional 38,000

---

[46] E. Warner, Muckleshoot Indian Tribe, 39015 172nd Ave. SE, Auburn, WA 98002. Pers. commun., 14 June 1995.

fry were released in a tributary of Lake Merwin in 1965. Returns of sockeye salmon to the Lewis River below Lake Merwin reported in WDFW (1996) may represent a remnant of these transplants.

Dungeness River—Brannon (1996) reported that sockeye salmon have been observed coming back to the same spawning ground on the Dungeness River and that "their timing was earlier than other sockeye in Washington, suggesting they were not strays." WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) indicated that 1-5 sockeye salmon are observed in the Dungeness River during the months of August-September in most survey years (see Appendix Table C-7).

Quillayute River/Calawah River—WDF (1973) reported that the Calawah and Bogachiel Rivers supported "a small run of sockeye salmon that must rear in the stream." Phinney and Bucknell (1975) reported that a small number of "river-race" sockeye salmon spawn in the lower reaches of the North Fork and South Fork Calawah Rivers as well as in several small tributaries. During the 1960s, 3 to 6 sockeye salmon were reportedly seen every year in the same place during July to August on the South Fork Calawah River near Hyas Creek (J. Ayerst[47]). Houston (1983, 1984) suggested that the Quillayute River may have a "river dwelling" population of sockeye salmon "of fewer than 10 fish per year average."

Hoh River—Wendler and Deschamps (1955) reported that small numbers of sockeye salmon are taken in the Hoh River in June and July. Houston (1983, 1984) suggested that the Hoh River may have a "river dwelling" population of sockeye salmon "of fewer than 10 fish per year average." Up to 50 sockeye salmon were observed schooling around RKm 47.5 on the Hoh River in mid-September 1985, and sockeye salmon were also observed around RKm 45.8 in 1994 and 1995 (J. Haymes[48]). The Hoh River receives a large glacial melt-water input and is milky in the summer, making fish identification difficult. Other indications are that a self-sustaining spawning population of sockeye salmon does not occur in the Hoh River (J. Jorgensen[49]). Recent tribal freshwater harvest of sockeye salmon in the Hoh River has ranged from 0 in 1991 to 26 in 1992 (Hoines 1995).

Queets River/Clearwater River—In some years a large tribal fishery catch of sockeye salmon occurred in the Queets River (Wendler and Deschamps 1955, Brix and Kolb 1971). Wendler and Deschamps (1955), citing the fact that there are few, if any, accessible lakes in the Queets River system, suggested that "sockeye salmon caught in the Queets River are

---

[47] J. Ayerst, Olympic National Forest, 1835 Black Lake Blvd. SW, Olympia, WA 98502. Pers. commun., 27 June 1995.

[48] J. Haymes, Quileute Natural Resources, Quiuleute Indian Tribe, P.O. Box 187, La Push, WA 98350-0187. Pers. commun., 1 June 1995.

[49] J. Jorgenson, Hoh Tribe, 2464 Lower Hoh Road, Forks, WA 98331. Pers. commun., 14 February 1995.

probably strays from the nearby Quinault River." Wendler and Deschamps (1955) also stated that

> In general, when the Quinault River has a good run of sockeyes, many are caught in the Queets. Also, the converse is true.

Dipping-in of Quinault Lake sockeye salmon into the Queets River most likely explains the bulk of the large sockeye salmon catch in the Queets River (Wendler and Deschamps 1955, S. A. Chitwood and D. Boyer, Jr.[50]).

Houston (1983, 1984) suggested that the Queets River may have a "river dwelling" population of sockeye salmon "of fewer than 100 fish per year average." Brown (1982, p. 30) observed mature sockeye salmon in Paradise Creek on the Queets River. WDF (1973) stated that "limited numbers of sockeye reportedly spawn in the Clearwater River" and Phinney and Bucknell (1975) stated that "sockeye salmon reportedly spawn in the mainstem of the Clearwater River and several tributary streams." The Clearwater River is a tributary of the Queets River. Analysis of over 300 Queets River sockeye salmon scales collected between 1975 and 1993 has revealed only one sea-type sockeye salmon in the Queets River fishery (QIN 1995a), however, river-type sockeye salmon (that do not outmigrate as underyearlings) cannot be differentiated by scale age from lake-type sockeye salmon (see "Life History of *O. nerka*" section). The Queets River receives a large glacial melt-water input from the Olympic Mountains. Both Edie (1975) and Cedarholm et al. (1978) stated that the Clearwater River, a tributary of the Queets River, had small populations of sockeye salmon.

British Columbia

A total of 917 anadromous sockeye salmon stocks have been identified in British Columbia (Slaney et al. 1996). Major sockeye salmon stocks on Vancouver Island are as follows: 1) Cheewhat Lake; 2) Hobiton River/Hobiton Lake; 3) Henderson Lake; 4) Sproat Lake and Great Central Lake in the Somass River Basin; 5) Kennedy Lake, Upper Kennedy River, Clayoquot River, Cold Creek, and Muriel Lake in the Kennedy River System; 6) Mahatta River/O'Connell Lake in Quatsino Sound; and 7) Woss Lake, Nimpkish Lake, and Vernon Lake in the Nimpkish River Basin (Aro and Shepard 1967).

Major sockeye salmon stocks in the Queen Charlotte Islands are these: 1)Mathers Lake, 2) Copper Creek/Skidegate Lake, 3) Yakoun Lake, 4) Mercer Creek/Mercer Lake, 5) Awun Lake, 6) Ian Lake, and 7) Naden River/Eden Lake. Major coastal sockeye salmon stocks in central to south mainland British Columbia include: 1) Sakinaw Lake, 2) Heydon Lake, 3) Phillips River, 4) Mackenzie Lake, 5) Klinaklini River, 6) Kakweiken River,

---

[50] S.A. Chitwood and D. Boyer Jr., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587. Pers. commun., June 1995.

7) Long Lake/Smokehouse Creek, 8) Rivers Inlet/Owikeno Lake, 9) Koeye Lake, 10) Atnarko River/Tenas Lake, 11) Tankeeah Lake, 12) Kimsquit Lake, and 13) Port John Lake. Major coastal sockeye salmon stocks in north mainland British Columbia are as follows: 1) Kitlope Lake, 2) Canoona Lake, 3) Banks Lake, 4) Mikado Lake, 5) Devon Lake, 6) Lowe Lake, 7) Curtis Lake, and 8) Bonilla Lake (Aro and Shepard 1967).

The following are major sockeye salmon stocks in the Fraser River: 1) Cultus Lake, 2) Upper Pitt River/Pitt Lake, 3) Weaver Creek/Harrison Lake, 4) Harrison River Rapids (river/sea-type), 5) Birkenhead River/Lillooet Lake, 6) Seymour Creek/Shuswap Lake, 7) Scotch Creek/Shuswap Lake, 8) Lower Adams River/Shuswap Lake, 9) Lower Shuswap River/Shuswap Lake, 10) Gates Creek, 11) Raft River, 12) Fennel Creek, 13) Chilko Lake, 14) Taseko River, 15) Horsefly River, 16) Mitchell River, 17) Nadina River/François Lake, 18) Stellako River/Fraser Lake, 19) early Stuart (= Takla Lake/Trembleur Lake/Stuart Lake), 20) late Stuart = Trembleur Lake/Stuart Lake, and 21) Bowron River (Aro and Shepard 1967).

Lake-type sockeye salmon in British Columbia inhabit nursery lakes that can be categorized as either coastal or interior, and as clear, humic-stained, or glacial. Coastal lakes are thermally stratified in summer and become continuously mixed in winter following turnover (monomictic); they experience cool, wet winters and warm, dry summers on the south coast and wetter, colder summers on the north coast. Interior lakes have episodes of mixing, before and after ice formation, and become thermally stratified in both summer and winter (dimictic). However, these lakes experience a more typically continental climate on the leeward side of the Coastal Mountains.

Coastal lakes experience peak flow and nutrient input in winter, when sunlight and temperatures are low, a pattern leading to low nutrient concentrations and low productivity. These lakes are generally classified as oligotrophic. Interior lakes, such as those upstream from Hell’s Gate on the Fraser River, experience maximum water and nutrient input in spring when light intensity and water temperatures are increasing. These lakes consequently have higher nutrient and productivity levels, and are classified as oligo-mesotrophic (Stockner 1987).

Many coastal lakes in central British Columbia are humic-stained and smaller than clear, larger lakes on the south mainland coast and Vancouver Island. Humic substances reduce light penetration and diminish the depth of the euphotic zone (Stockner 1987). Glacial lakes include both coastal and interior types, and their high turbidity is imparted by suspended silts and clays (glacial flour) carried down by tributaries during summer glacial-melt.

Glacial lakes produce some of the smallest 1-year-old sockeye salmon smolts recorded (Goodlad et al. 1974, Hyatt and Stockner 1985). Generally sockeye salmon smolts leaving interior lakes of British Columbia as yearlings are larger than similar age smolts from coastal systems. This may be due to the greater rearing area of interior lakes or to the higher productivity of interior lakes (Foerster 1968, Hyatt and Stockner 1985).

Genetics

Previous Genetic Studies

Early studies of sockeye salmon population genetics examined variation at two highly polymorphic loci coding the enzymes lactate dehyrogenase (Hodgins et al. 1969, Withler 1985) and phosphoglucomutase (Utter and Hodgins 1970) or both (Altukhov et al. 1975, 1983; Kirpichnikov and Ivanova 1977; Varnavskaya 1984; Varnavskaya et al. 1988). Subsequent studies have gradually incorporated additional polymorphic loci (currently up to about 48 loci) into their analyses of sockeye salmon population structure (Seeb and Wishard 1977; Grant et al. 1980; Altukhov and Varnavskaya 1983; Utter et al. 1984; Wilmot and Burger 1985; Quinn et al. 1987; Wood et al. 1987b, 1988, 1994; Foote et al. 1988; Kirpichnikov et al. 1990; Rutherford et al. 1992, 1994; Guthrie et al. 1994; Varnavskaya et al. 1994a,b; Wood 1995; Hendry et al. 1996, Winans et al. 1996). Some of these studies analyzed allozymic variation among sockeye salmon populations or subpopulations from geographically limited regions in Kamchatka (Altukhov et al. 1975, 1983; Kirpichnikov and Ivanova 1977; Altukhov and Varnavskaya 1983; Varnavskaya et al. 1988, 1994b; Kirpichnikov et al. 1990), Alaska (Grant et al. 1980, Wilmot and Burger 1985, Varnavskaya et al. 1994b), British Columbia (Wood et al 1987b; Rutherford et al. 1992, 1994; Varnavskaya et al. 1994b), and Washington (Seeb and Wishard 1977, Hendry 1995, Hendry et al. 1996). Additional studies have taken a broader approach, comparing allozymic variation in selected sockeye salmon populations from North America (Withler 1985), Kamchatka (Varnavskaya 1984), or from throughout the range of sockeye salmon (Hodgins et al. 1969, Utter and Hodgins 1970). However, these studies relied on variation in only one or two polymorphic loci and thus provided little resolution of population differences.

Utter et al. (1984) surveyed allozymic variation in 16 collections from southeast Alaska through the Columbia River Basin, including Quinault, Okanogan, and Wenatchee stocks, at 12 polymorphic loci and found a moderate degree of population structuring, significant genetic distance between Quinault River and all other samples, and an apparent genetic association between upper Fraser River and Columbia River sockeye salmon. Guthrie et al. (1994) surveyed sockeye salmon allozymic variation at 28 variable loci in populations from southeast Alaska and northern British Columbia and found substantial genetic divergence among populations, with an underlying geographic structure. Although there were several exceptions, sockeye salmon populations in this region generally fell into 3 main geographic clusters: 1) northern mainland, 2) the southern mainland and inside waters, and 3) the southern and central islands (Guthrie et al. 1994).

Wood et al. (1994) surveyed genetic variation at 33 allozyme loci in *O. nerka* from 83 sample sites throughout British Columbia. A hierarchical gene diversity analysis of sockeye salmon in eight river systems (Fraser, Nass, Skeena, etc.) was conducted using the eight most polymorphic loci. This procedure determines the relative contribution of different components to the overall gene diversity (Chakraborty 1980). Wood et al. (1994) found that variability was partitioned as follows:

Among river systems: 6.3%
among drainages within rivers: 2.9%
among lakes within drainages: 7.0%
among sites within lakes: 1.0%
within sites: 82.8%

Wood et al. (1994) concluded that most of the genetic variation occurred within spawning sites, and the most important level of differentiation among samples was the nursery lake. Variation among river systems that spanned the north-south breadth of British Columbia accounted for only 6.3% of the variation. A neighbor-joining tree of Cavalli-Sforza and Edwards chord distances based on six polymorphic loci revealed three large groups of populations: southern rivers, northern rivers, and Skeena River/coastal populations. The pattern of genetic similarity among populations within these groups was not strongly geographic. Wood et al. (1994) reported that a “mosaic” pattern of variation was also apparent in an “unweighted pair group method with arithmetic averages” (UPGMA) (Sneath and Sokal 1973) dendrogram based on Nei’s unbiased genetic distance (Nei 1978). A principal component analysis (PCA) also showed considerable overlap among regional groups of rivers. The most distinctive group was the southern rivers, consisting of samples from the upper Fraser River, the Thompson River, and the Columbia River (from the Okanogan River Basin). Wood et al. (1994, p. 124) concluded that “geographic structuring was far from perfect, and two populations in widely separated river systems sometimes resembled one another genetically more than they resembled populations in their respective watersheds.”

In his most recent work, Wood (1995) concluded that on a time scale of human generations, the best way to conserve genetic diversity in sockeye salmon was to preserve populations in as many different lake systems as possible. From a long-term, evolutionary perspective (> 10,000 yr), he felt it was prudent to save the genetically-diverse, large populations of river/sea-type sockeye salmon (present today in glacially-influenced habitats) that are adapted to a wide range of habitats and conditions and which might provide a source for colonization in favorable interglacial periods.

In a genetic survey of *O. nerka* in the Pacific Northwest, Winans et al. (1996) surveyed variation at 55 loci in 27 samples of sockeye salmon and kokanee from a total of 21 sites in Washington, Idaho, and British Columbia. They reported that sockeye salmon have the lowest level of allozyme variability of any species of Pacific salmon and a high level of interpopulation differentiation at a relatively few polymorphic loci. Using PCA and clustering of Nei’s genetic distance (Nei 1978) to study geographic variation, they reported first that there was no clear geographic pattern of differentiation among the populations of sockeye salmon in the area studied, and second that four genetic clusters of kokanee populations can be identified: 1) a Stanley Basin group including Redfish Lake and Alturas Lake, 2) a late-summer spawning group (from several lakes and reservoirs in central Idaho), 3) a late-fall spawning group (from Lake Whatcom and northern Idaho stocks), and 4) an Okanagan Lake-Shuswap River group.

Chapman et al. (1995) reported data for one additional sockeye salmon sample in the Columbia River Basin. They showed that 14 sockeye salmon collected in the Methow River (situated in the Columbia River Basin between the Wenatchee and Okanogan River systems) were genetically more similar at four loci to two White River samples (from the Wenatchee River basin) than to Okanogan River samples. In contrast, Utter (1995) reported that based on sockeye salmon samples collected in 1994 and analyzed for six polymorphic protein-coding (allozyme) loci and three nuclear DNA microsatellite loci, Wenatchee, Methow, and Okanogan (Wells Dam) River samples were not genetically distinct. Utter (1995) proposed that annual genetic monitoring of Okanogan River sockeye salmon and additional sampling of Methow River sockeye salmon be undertaken to determine the cause of apparent temporal fluctuations in allele frequencies in the Okanogan River population.

The lack of a discernible geographic pattern found by Winans et al. (1996) matches similar studies of sockeye salmon populations in British Columbia, Alaska, and Kamchatka (Varnavskaya et al. 1994a, Wood et al. 1994, Wood 1995). These studies generally indicate that the nearest geographic neighbors of sockeye salmon populations are not necessarily the most genetically similar. Whereas other species of Pacific salmon such as chinook, chum, and pink salmon exhibit clear regional patterns of geographic differentiation (Utter et al. 1989, Winans et al. 1994, Shaklee et al. 1991), geographic variability in sockeye salmon generally resembles a mosaic of genetically distinct populations, at least in the studied portions of the species' distribution. The disjunct nature of differentiation among populations of *O. nerka* may reflect the discontinuous nature of the habitat, the precise degree of homing to natal streams and lakes (perhaps due to the requirement for nursery lake habitat), and the concomitant decrease in gene flow among neighboring populations.

In a study of the structure and origins of sockeye salmon populations in Lake Washington, Seeb and Wishard (1977) detected identical allele frequencies at five loci for Baker Lake and Cedar River sockeye salmon, indicating that Cedar River sockeye salmon were primarily descended from Baker Lake stock. Seeb and Wishard (1977) stated that Big Bear Creek and Lake Washington beach-spawning sockeye salmon were genetically distinct from potential donor stocks and that these stocks represent remnant native anadromous sockeye salmon populations. However, Hendry (1995) and Hendry et al. (1996) could not detect statistically significant allelic differences at seven polymorphic loci between Lake Washington beach spawning and Cedar River sockeye salmon. Hendry (1995) and Hendry et al. (1996) identified two genetically distinct sockeye salmon groups in the Lake Washington Basin: 1) Cedar River, Lake Washington beach spawners, and Issaquah Creek, which showed genetic affinity with Baker Lake sockeye salmon and 2) Big Bear and Cottage Lake Creeks, which showed genetic distinctiveness from other stocks in the basin and from potential donor stocks. Hendry et al. (1996) inferred from these genetic affinities that the first group of sockeye salmon was of Baker Lake lineage and the second group was predominately of native ancestry.

Hershberger et al. (1982) surveyed genetic variation at 37 allozyme loci (only 2 of which were polymorphic) in sockeye salmon from Ozette Lake, Washington. Hershberger et al. (1982) reported that phenotype frequencies of one variable loci, *PGM-1**, suggested that two groups (or populations) of sockeye salmon may be present in Ozette Lake, separated by a difference in run-timing.

Several population surveys of DNA-level variation in *O. nerka* have been completed. Bickham et al. (1995) examined nucleotide sequence variation of the mtDNA cytochrome *b* gene in four sockeye salmon populations ranging from Kuril Lake in Kamchatka to Lower Shuswap River in the Fraser River. Three haplotypes were identified. The most common haplotype was found in all populations (in 58% of all individuals); the second most common haplotype was found in all samples (30% of all individuals) except the Fraser River samples. The third haplotype was found in the Skeena River system (at 10%) and the Fraser River (at 40%). Haplotypic frequencies in the Fraser River samples were significantly different from those in the three other samples. The Skeena River sample was also different from the Iliamna Lake samples. Despite this statistical heterogeneity, Bickham et al. (1995) concluded that the three northern samples and the Fraser River samples represent two biogeographic groups post-glacially derived from separate refugia (Beringia and Columbia River). They discussed the evidence for the presence of a generalized north-south phylogeographic break for anadromous fish on the west coast of North America.

Beacham et al. (1995) reported levels of variation in nuclear DNA of *O. nerka* using minisatellite probes. They used seven of the eight samples used by Bickham et al. (1995) (Pierre Creek, Skeena River was excluded) and two west coast Vancouver Island samples, as well as samples from Lake Wenatchee in the Columbia River Basin. Genomic DNA was digested with one of two restriction enzymes and probed with one of three repeat-sequence probes. Bands were scored for four restriction enzyme/probe marker combinations; three of these appeared to reflect single locus variation. Electrophoretic bands were pooled or binned into size classes for statistical analyses. They interpreted their results as did Bickham et al. (1995)—i.e., the Kamchatka and Iliamna Lake samples were different from the other samples. Other interpretations are also possible. In the cluster analysis, the Lake Wenatchee sample was different from all the other southern samples which, considered together, were different from both the Alaskan samples and Kamchatka samples. However, these latter two samples were also dissimilar from one another. Similarly, along the first two PC axes, the southern samples were different from the two northern groups (Kamchatka and Iliamna). Because only 51% of the variance was explained along PC1 and PC2, relationships may be distorted (viz. Lake Wenatchee) and an examination of PC3 might prove useful.

Thorgaard et al. (1995) examined the use of multilocus DNA fingerprinting to discriminate among 14 sockeye salmon and kokanee populations. DNA extracts were pooled among individuals within the populations. Five oligonucleotide probes were used to visualize bands following digestion with a restriction enzyme and electrophoresis. Electrophoretic bands were grouped by size classes, and each band class was scored as present or absent in each population. Dendrograms based on analysis of banding patterns for four of the five probes produced a concordant pattern of relationships. An analysis of all data produced a tree with a grouping of Redfish Lake, Wenatchee, and Okanogan *O. nerka* that was separate from kokanee of Oregon and Idaho and a sockeye salmon sample from the mid-Fraser River. Trees of relationship based on three of the five DNA probes showed a clustering of kokanee and sockeye salmon from Redfish Lake (the other two probes grouped Redfish Lake sockeye salmon with either Okanogan River or Lake Wenatchee sockeye salmon), while four of the five probes placed sockeye salmon from Okanogan River together with kokanee from a tributary of Okanagan Lake, British Columbia. None of the five DNA probes showed a close relationship between Lake Wenatchee and Okanogan River sockeye salmon. A portion of the data from the above study were presented in Brannon et al. (1994).

New Data

As part of the comprehensive status review of west coast sockeye salmon, NMFS biologists collected new allozyme genetic information for 17 sockeye salmon populations and 1 kokanee population in Washington and combined them with the existing Pacific Northwest sockeye salmon and kokanee data for analyses. Collection locations, dates, life stage sampled, and sample sizes are summarized in Table 3. We included samples from the Babine River in northern British Columbia (sockeye salmon) and Ozette Lake (kokanee) that were distinctive among their respective life history types (Winans et al. 1996). We examined allelic frequencies for 29 variable loci: *ADA-1**, *ADA-2**, *mAH-1,2** (treated as one locus), *mAH-3**, *sAH**, *mAH-4**, *mAAT-1**, *ALAT**, *CK-B**, *FH**, *PEPA**, *PEPC**, *mIDHP-1**, *mIDHP-2**, *sIDHP-1**, *sIDHP-2**, *LDH-A1** (used observed phenotypic frequencies of an alternate homozygote **86/*86* because **86/*100* was not distinguishable from **100/*100*), *LDH-B1**, *LDH-B2**, *LDH-C**, *sMDH-A1,2** (treated as one locus), *sMDH-B1,2** (treated as one locus), *MPI**, *PGDH**, *PGM-1** (used observed phenotypic frequencies of null allele), *PGM-2**, *sSOD-1**, *TPI-4**, and *TPI-3**. Genetic relationships among samples were examined in two ways: with ordination techniques of genetic distance statistics and with Principal Component Analyses (PCA). Nei’s unbiased genetic distances (Nei 1978) and Cavalli-Sforza and Edwards chord values (Cavalli-Sforza and Edwards 1967) among the 32 samples were calculated from the 29 variable loci using the computer program BIOSYS (Swofford and Selander 1981). The distance values were illustrated in UPGMA dendrograms (1-dimensional ordination technique) and multidimensional scaling analyses (2-dimensional ordination techniques) using the computer program NTSYS (Rohlf 1993). A minimum-length spanning tree (MST) was superimposed on the 2-dimensional plots. A PCA was performed using NTSYS (Rohlf 1993) with a correlation matrix for a subset of loci with frequencies of less-common alleles greater than 0.05. Our experience is that less frequent alleles do not contribute substantially to discrimination among samples in a PCA (Winans et al. 1994).

The results from both distance measures (Figs. 5-8) were similar. On a broad geographic scale, both Nei’s (Figs. 5-6) and Cavalli-Sforza and Edwards’ (Figs. 7-8) genetic distances indicate that: 1) samples of sockeye salmon from Lake Wenatchee, Redfish Lake, Ozette Lake, and Lake Pleasant are very distinct from other samples; 2) Lake Washington-Cedar River samples are distinct from a Big Bear Creek-Cottage Lake Creek association; 3) riverine-spawning sockeye salmon from the Nooksack, Skagit, and Sauk Rivers (n = 66) cluster together and have an affinity with Babine Lake and Ozette Lake sockeye salmon;

Table 3. Collection data for *Oncorhynchus nerka* genetic samples from the Pacific Northwest analyzed for 29 presumptive gene loci. A = adult, J = juvenile, BY = broodyear.

Sample number and location		Collection date	Life history type	Number of fish	Source of data[a]
1	Ozette Lake 1990/1991 (outmigrants)[b]	4/90-91	J	34	1
2	Ozette Lake	4/17/91	J (kokanee)	21	1
3	Ozette Lake 1994	11/21/94	A	80	2
4	Ozette Lake-Allen's Bay 1995[c]	11/17-11/21/95	A	33	2
5	Ozette Lake-Olsen's Beach 1995[c]	11/17-11/21/95	A	50	2
6	Ozette Lake-Siwash Creek	12/6/95	A (kokanee)	42	2
7	Lake Pleasant (outmigrants)	5/17/95	J	14	2
8	Lake Pleasant[c]	12/18/95	A	15	2
9	Quinault Lake (outmigrants)[c]	5/2-5/23/95	J	93	2
10	Nooksack River[c, d]	8/20-10/2/96	A	26	2
11	Skagit River[c]	9/27-10/17/96	A	25	2
12	Sauk River[c]	8/20-9/10/96	A	15	2
13	Baker Lake	12/19/91	A	80	1
14	Lake Whatcom	11/5/90	A (kokanee)	60	1
15	Lake Washington	8/13/91	A	100	1
16	L. Washington (Pleasure Point Beach)[c]	11/93	A	39	2
17	Cedar River 1989	10/18/89	A	100	1
18	Cedar River 1994[c]	10/26/94	A	80	2
19	Big Bear Creek 1992[c]	10-11/92	A	73	2
20	Big Bear Creek 1993[c]	10-11/93	A	46	2
21	Cottage Lake Creek[c]	10-11/92	A	40	2
22	Big Bear Creek 1994[c]	10/25/94	A	80	2
23	Okanogan River	10/13/90	A	63	1
24	Lake Wenatchee (BY 1987)	12/16/88	J	120	1
25	Lake Wenatchee (BY 1988)	1/5/90	J	160	1
26	Lake Wenatchee (BY 1989)	10/30/90	J	80	1
27	Lake Wenatchee (BY 1990)	10/31/91	J	80	1
28	Lake Wenatchee 1990	9/25/90	A	120	1
29	Redfish Lake (outmigrants)	4/91-93	J	138	2
30	Redfish Lake	10/91-93	A	13	2
31	Lower Shuswap River	10/14/90	A	60	1
32	Babine Lake	9/27/90	A	60	1

[a] Key to data sources: 1 - Winans et al. (1996), 2 - NMFS, unpublished.

[b] A pooled sample of outmigrant smolts sampled 17 April 1990 (n = 22) and 1 April 1991 (n = 12).

[c] Washington Department of Fish and Wildlife provided tissues for Big Bear Creek 1994, Cedar River 1994, Nooksack River, Skagit River, Sauk River, and Lake Pleasant adults; A. Hendry, University of Washington, provided tissues from Big Bear Creek 1992 and 1993, Cottage Lake Creek, and Lake Washington Pleasure Point beach (see Hendry et al. 1996); the Makah Fisheries Management Department provided tissues for Ozette Lake-Allen's Bay and Olsen's Beach; and the Quinault Indian Nation provided tissues from Quinault Lake.

[d] A pooled sample of adults from the North Fork and South Fork Nooksack Rivers.

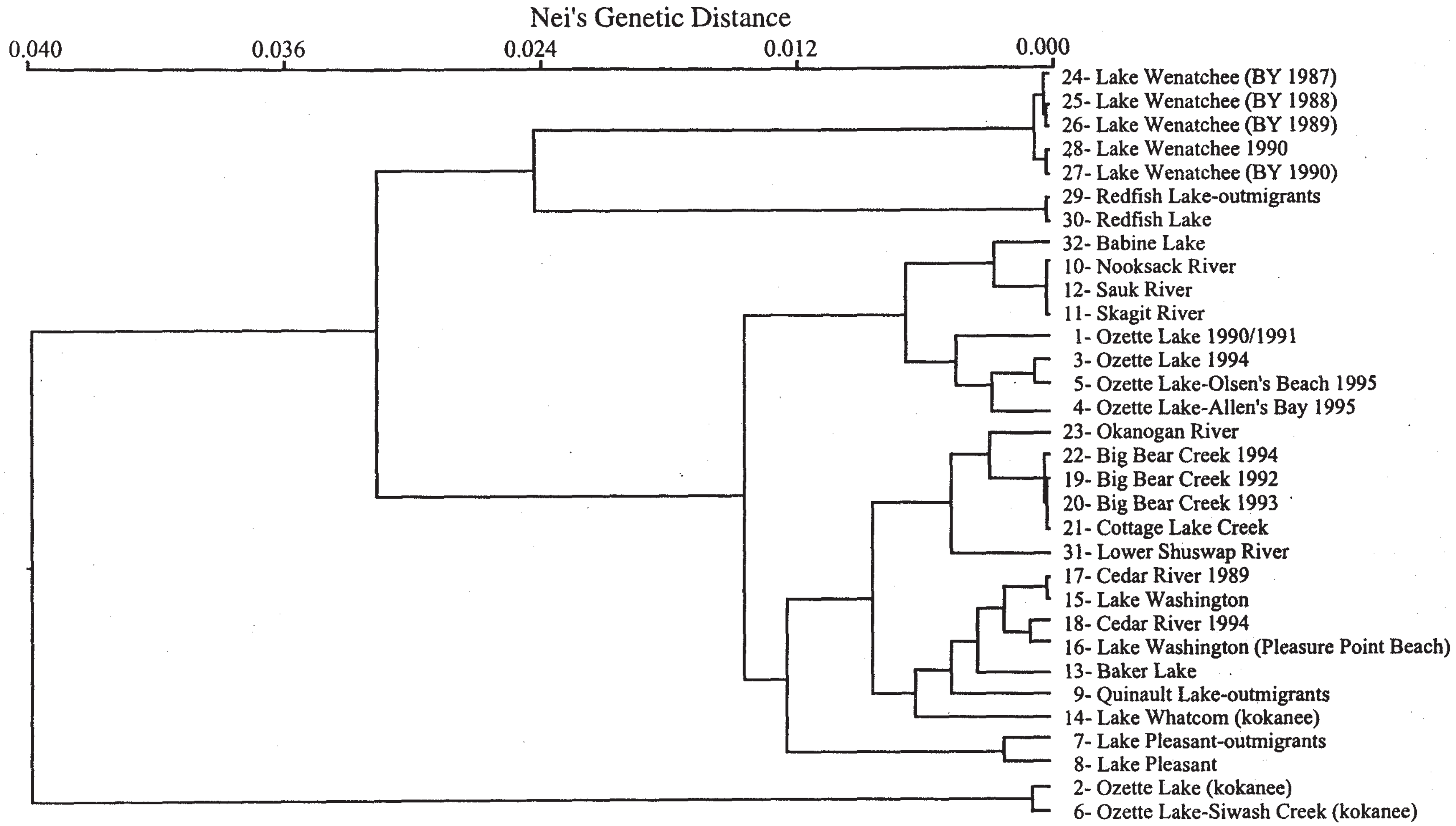


Figure 5. Dendrogram of Nei's (1978) unbiased genetic distances based on 29 loci for 32 samples of *O. nerka*. Sample numbers and designations correspond with those presented in Table 1. Loci used: *ADA-1**, *ADA-2**, *mAH-1,2** (treated as one locus), *mAH-3**, *sAH**, *mAH-4**, *mAAT-1**, *ALAT**, *CK-B**, *FH**, *PEPA**, *PEPC**, *mIDHP-1**, *mIDHP-2**, *sIDHP-1**, *sIDHP-2**, *LDH-A1** (used observed phenotypic frequencies of an alternate homozygote **86/*86* because **86/*100* was not distinguishable from **100/*100), LDH-B1**, *LDH-B2**, *LDH-C**, *sMDH-A1,2** (treated as one locus), *sMDH-B1,2** (treated as one locus), *MPI**, *PGDH**, *PGM-1** (used observed phenotypic frequencies of null allele), *PGM-2**, *sSOD-1**, *TPI-3*, and TPI-4**. Cophenetic correlation coefficient = 0.845 (a measure of "goodness-of-fit" of dendrogram distances compared to the distances in the distance matrix).

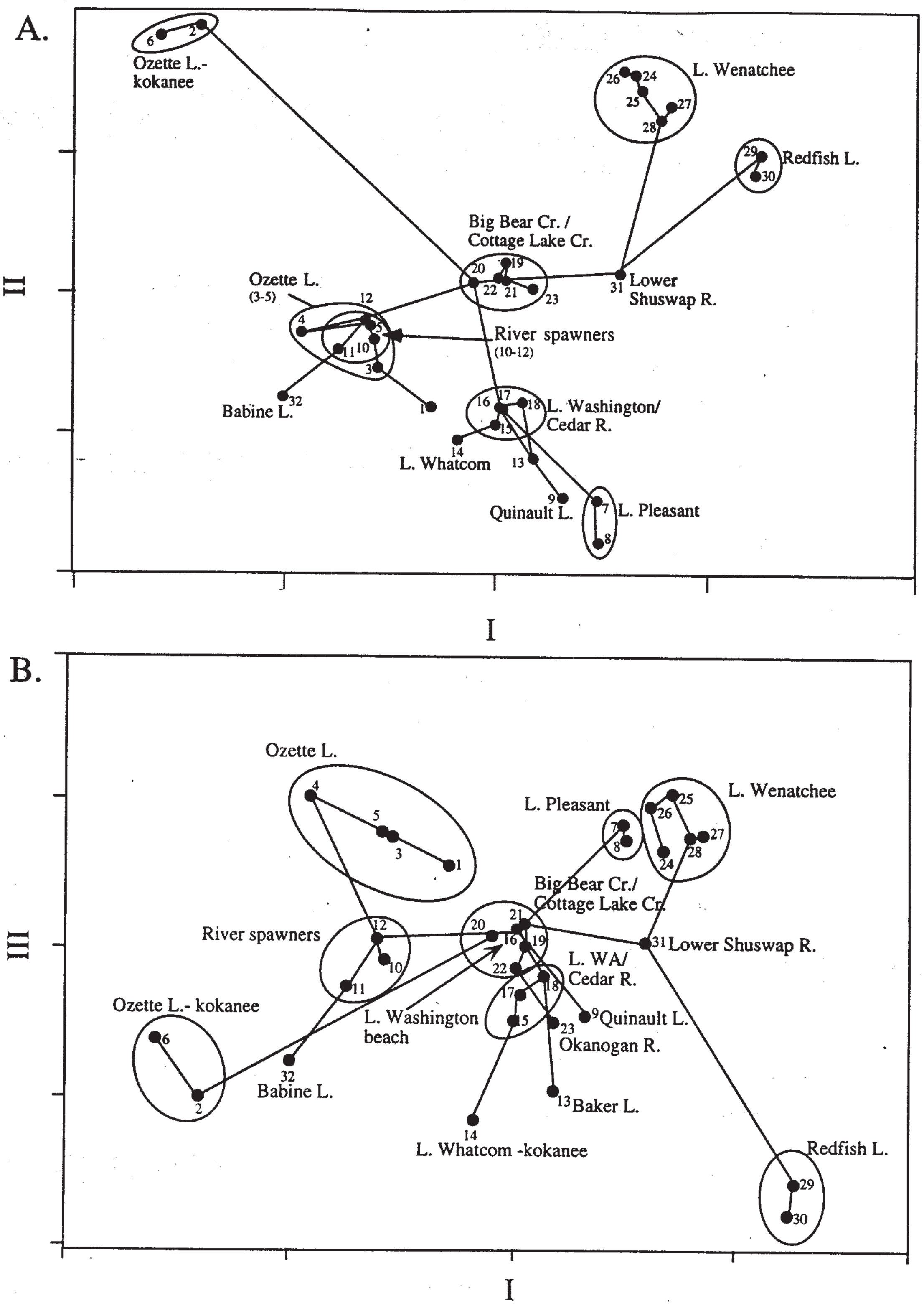


Figure 6. Multidimensional scaling plots of Nei's (1978) unbiased genetic distance along axes I and II (A) and axes I and III (B) based on 29 loci with a superimposed minimum-length spanning tree for 32 samples of *O. nerka*. Loci used and sample names are given in Figure 5 and Table 1, respectively.

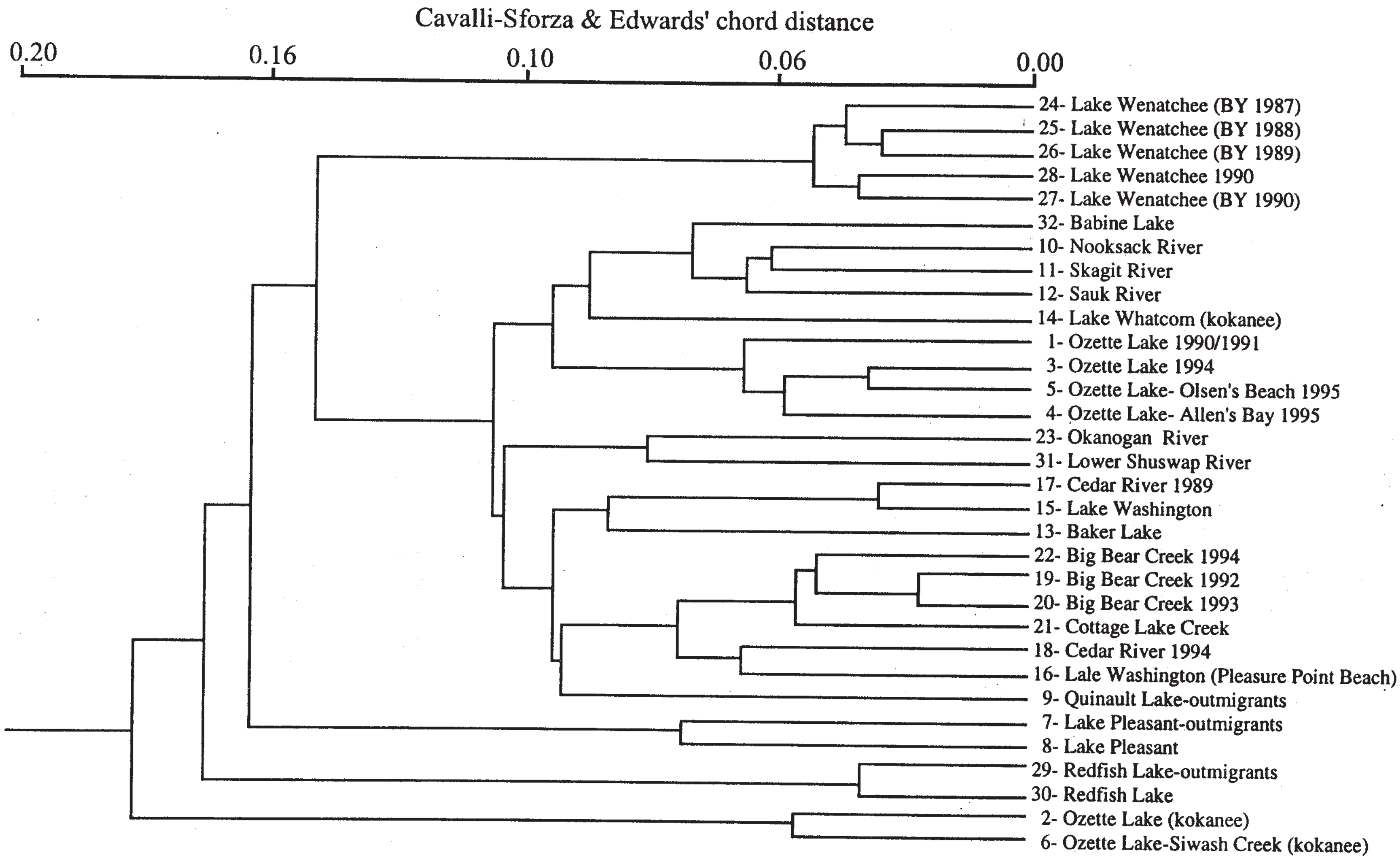


Figure 7. Dendrogram of chord distances (Cavalli-Sforza and Edwards 1967) based on 29 loci for 32 samples of *O. nerka*. Sample numbers and designations correspond with those presented in Table 1. Loci are given in Figure 5. Cophenetic correlation coefficient = 0.885.

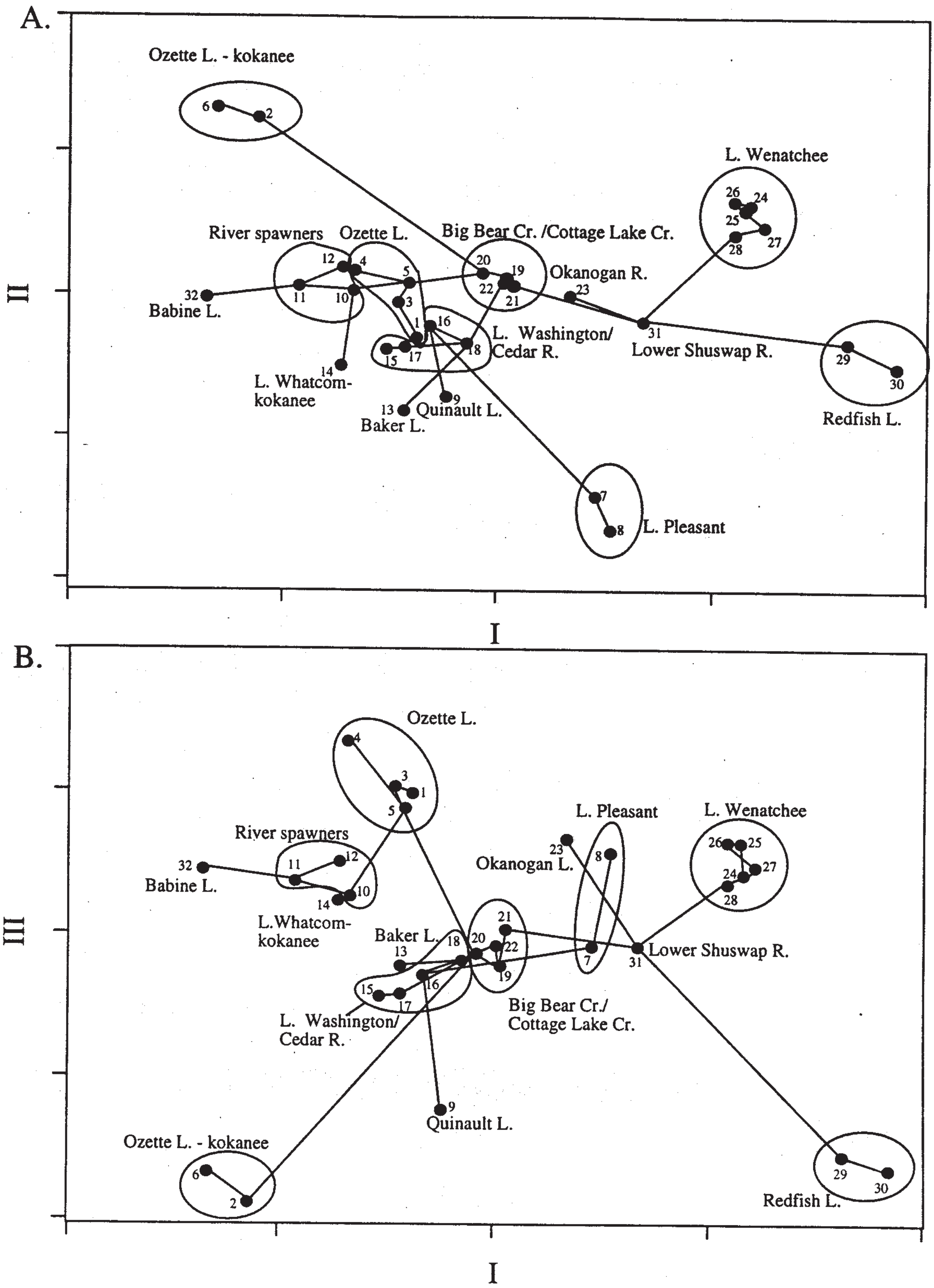


Figure 8. Multidimensional scaling plots of chord distance values (Cavalli-Sforza and Edwards 1967) along axes I and II (A) and axes I and III (B) based on 29 loci with a superimposed minimum-length spanning tree for 32 samples of *O. nerka*. Loci and sample names are given in Figure 5 and Table 1, respectively.

4) Baker River sockeye salmon are associated with a Lake Washington-Cedar River group, to which Quinault Lake is most similar; and 5) Babine Lake sockeye salmon and Ozette Lake kokanee are particularly distinctive. The Cavalli-Sforza and Edwards metric showed an affinity between Okanogan River sockeye salmon and Lower Shuswap River sockeye salmon, although several allele frequencies in the two samples were statistically different from each other (Winans et al. 1996). Although not indicated by Cavalli-Sforza and Edwards genetic distance (which does not adjust for different sample sizes, such as the small sample size for river-spawners), Nei's genetic distance indicated that riverine-spawning sockeye salmon from the Nooksack, Skagit, and Sauk Rivers have a genetic affinity with Big Bear Creek-Cottage Lake Creek sockeye salmon.

Results of the PCA generally paralleled the genetic distance analyses (Fig. 9). For example, in PC1-PC2 space, Lake Wenatchee, Lake Pleasant, Babine Lake, Big Bear Creek-Cottage Lake Creek sockeye salmon, and Ozette Lake kokanee were distinct from one another (Fig. 9A); along the PC1-PC3 axes, Redfish Lake and Quinault Lake sockeye salmon were distinctive (Fig. 9B). Riverine-spawning sockeye salmon from the Nooksack, Skagit, and Sauk Rivers were most closely related genetically to the Babine Lake sample.

Neither the ordination of genetic distances nor the PC analysis revealed a clear geographic pattern of genetic relationships for the sockeye salmon populations studied. For example, sockeye salmon from the Columbia River Basin (Lake Wenatchee, Okanogan River, and Redfish Lake) did not form a coherent genetic group. Likewise the three coastal populations of sockeye salmon in Washington (Ozette Lake, Lake Pleasant, and Quinault Lake) that are geographically closest, were not very similar to each other genetically.

We examined between-year variability in two locales. We found significant temporal variation in the five Lake Wenatchee samples. The log likelihood ratio statistic (G-test) (Sokal and Rohlf 1981) was used to compare allele frequencies of samples taken in different years in the same locale. G-tests were performed for each polymorphic locus, and the results were summed over all loci for an overall G-value and a standardized G-value. Low levels of statistical significance appeared among the 5 Lake Wenatchee samples: of 10 pair-wise comparisons using sum-*G* tests, 5 were statistically significant. Lake Wenatchee broodyear 1987 accounted for three of the significant comparisons; it had unusually high frequencies of *ALAT*95* and *ALAT*108* (Winans et al. 1996). On the other hand, there was no significant temporal variability in three samples from Big Bear Creek ($P = 0.27$) over 12 loci. In other species of Pacific salmon, temporal variation is usually a minor component of overall genetic variability (e.g., chum salmon (Winans et al. 1994) and pink salmon (Shaklee et al. 1991)). We conclude that, in general, temporal variation at a locale was considerably less than between-locale variation.

Substantial differences were seen among the four Ozette Lake samples of sockeye salmon. Only one of six pair-wise comparisons among the four samples was statistically nonsignificant. The two main remaining spawning beaches in Ozette Lake (at Allen's Bay and Olsen's Beach) are on opposite sides of the south end of Ozette Lake, separated by

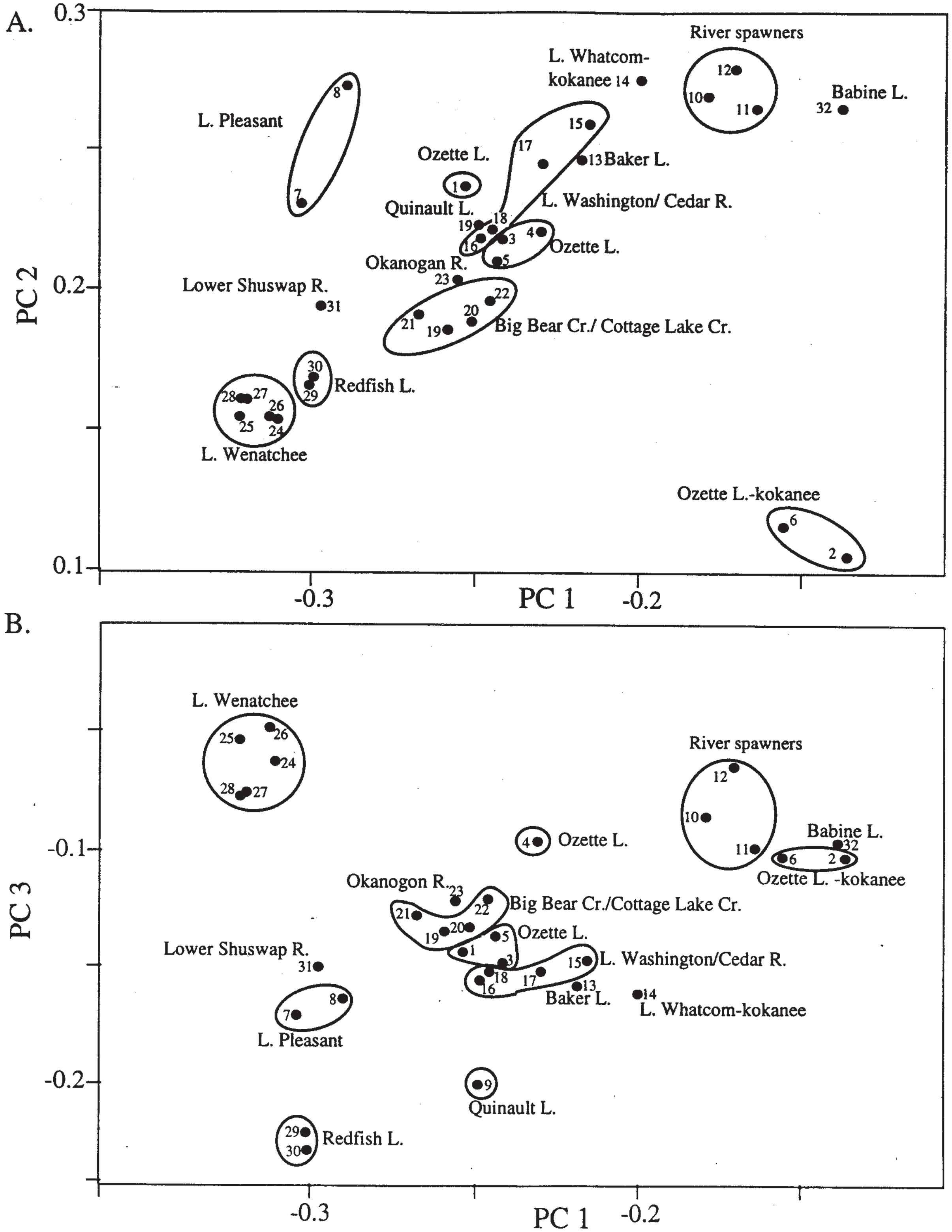


Figure 9. Scatter plots of principal component (PC) scores on PC1 - PC2 (A) and PC1 - PC3 (B) for 32 samples of *O. nerka* (see Table 1). Loci used were *ADA-1**, *mAH-1,2** (treated as a single locus), *sAH**, *mAH-3*, *mAAT-1**, *ALAT**, *PEPC**, *mIDHP-1**, *mIDHP-2**, *MPI**, *PGM-1**, and *PGM-2**. For *mAH-1,2** and *ALAT**, four allele classes were used; all other loci were considered single allele classes.

approximately 3.2 km. The 1995 sample of sockeye salmon from Allen’s Bay (adults, n = 33) was statistically different at seven loci from the 1995 Olsen’s Beach sample (adults, n = 50). Although precise records concerning the origins of the 1994 sockeye salmon collection from Ozette Lake (adults, n = 80) were not kept, this sample clustered with the Olsen’s Beach 1995 sample and differed at seven loci from the 1995 Allen’s Bay sample. Dlugokenski et al. (1981) suggested within-lake population subdivision may be present in Ozette Lake based on observed differences in peak spawning times between Allen’s Bay and Olsen’s Beach spawning aggregates. Additional samples of sockeye salmon from Ozette Lake are currently being pursued. The two samples of kokanee from the Ozette Lake Basin were not statistically different from one another ($P = 0.10$), but they were divergent from all other *O. nerka* in each analysis (Figs. 5-8).

We combined available data with information for British Columbia stocks to gain a broader perspective of sockeye salmon variability in the Pacific Northwest. Analyses of Nei’s unbiased and Cavalli-Sforza and Edwards chord distances based on nine loci revealed clustering patterns among the British Columbia samples (Figs. 10-13). Sockeye salmon from Vancouver Island, the Lower Fraser River, and the Babine River system formed distinctive groups and were associated together. Riverine-spawning sockeye salmon from the Nooksack, Skagit, and Sauk Rivers were similar to one sockeye salmon collection from Babine Lake, and Ozette Lake kokanee clustered with one of the Vancouver Island sockeye salmon groups. Several clusters of upper Fraser River sockeye salmon were recognized. However, Thompson River sockeye salmon did not associate closely with one another. Both Nei’s unbiased and Cavalli-Sforza and Edwards chord distances revealed that Washington coastal sockeye salmon (Ozette Lake, Lake Pleasant, and Quinault Lake), and Lake Wenatchee, Okanogan Lake, and Redfish Lake sockeye salmon were associated with one of several sockeye salmon clusters of the upper Fraser River (with the exception of Lake Ozette, which was associated with Big Bear Creek samples according to Nei’s unbiased genetic distance).

Artificial Propagation

Artificial propagation of sockeye salmon has been conducted since before 1900 throughout the Pacific Rim. Efforts at sockeye salmon supplementation in Asia began as a small-scale operation in the 1870s on Hokkaido Island using local stocks, probably kokanee, and then later using sockeye salmon eggs from Alaska (Moberly and Lium 1977). Recent releases of *O. nerka* (sockeye salmon and kokanee) have continued to be a minor part of overall Pacific salmon artificial propagation efforts in Japan (Kobayashi 1980).

The first salmon hatcheries in the Republic of Korea were not built until the 1960s, and chum salmon were the principal species reared (Atkinson 1976). In Russia, experimental sockeye salmon hatcheries were constructed around 1910 on the Kamchatka Peninsula, and large-scale sockeye salmon fish-rearing facilities were constructed in 1928, also in Kamchatka (Konovalov 1980). The number of sockeye salmon released from Russian hatcheries is small compared to the numbers of artificially reared pink and chum salmon (Roukhlov 1982, Knapp and Johnson 1995). There are hatcheries on the Kamchatka Peninsula producing sockeye

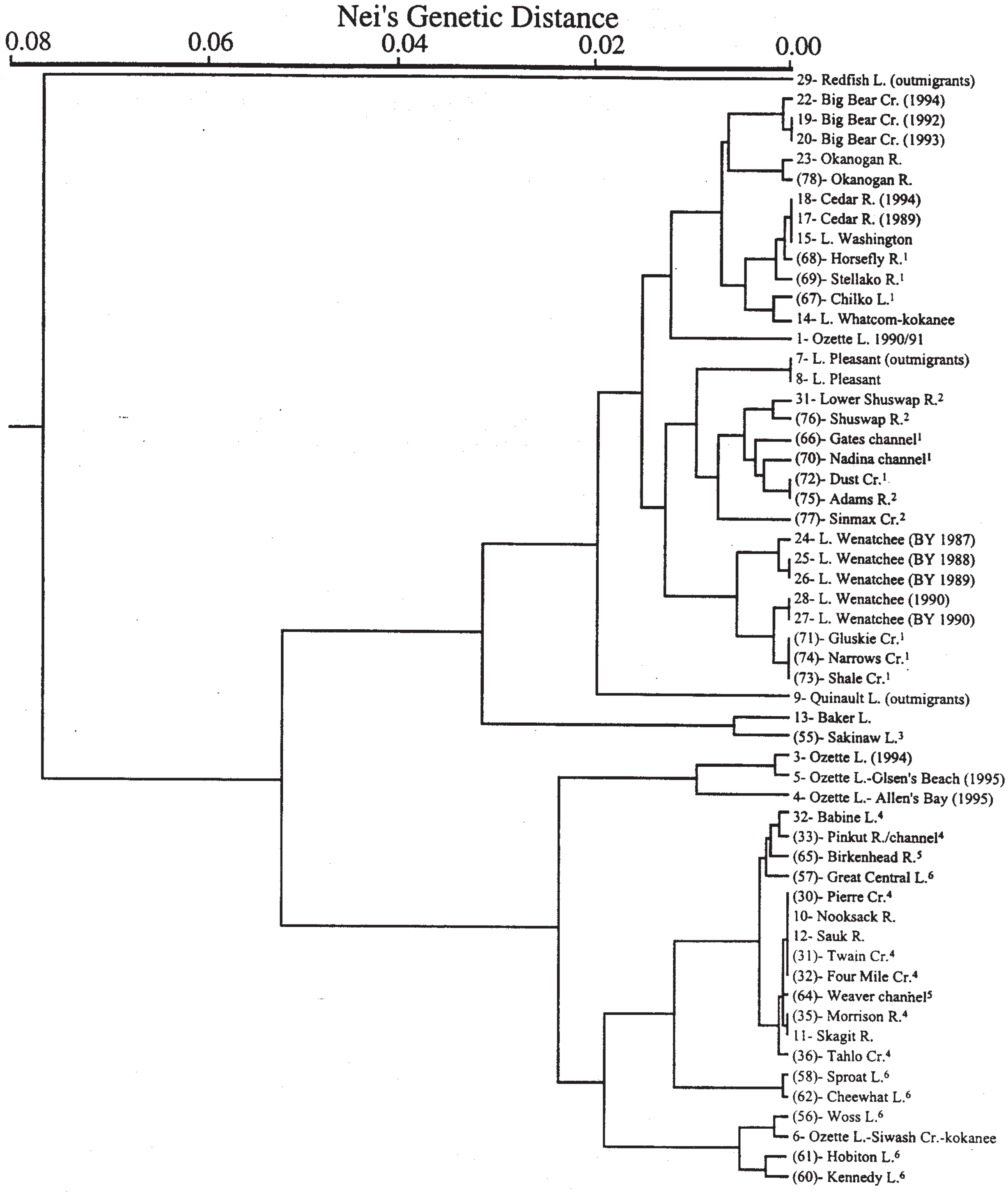


Figure 10. Dendrogram of Nei's (1978) unbiased genetic distances based on 9 loci in 56 samples of *O. nerka*, including 29 samples from Canada. Data for sample numbers 1-32 are listed in Table 1. Remaining samples from Wood et al. (1994) using the original site numbers, in parentheses. Loci used were: *ADA-1**, *sAH**, *ALAT**, *PEPC**, *mIDHP-1**, *LDH-C**, *MPI**, *PGM-1** (used observed phenotypic frequencies of null allele), and *PGM-2**. [1]Upper Fraser River, [2]Thompson River, [3]Lower Mainland B.C., [4]Skeena River, [5]Lower Fraser River, and [6]Vancouver Island. Cophenetic correlation coefficient = 0.704.

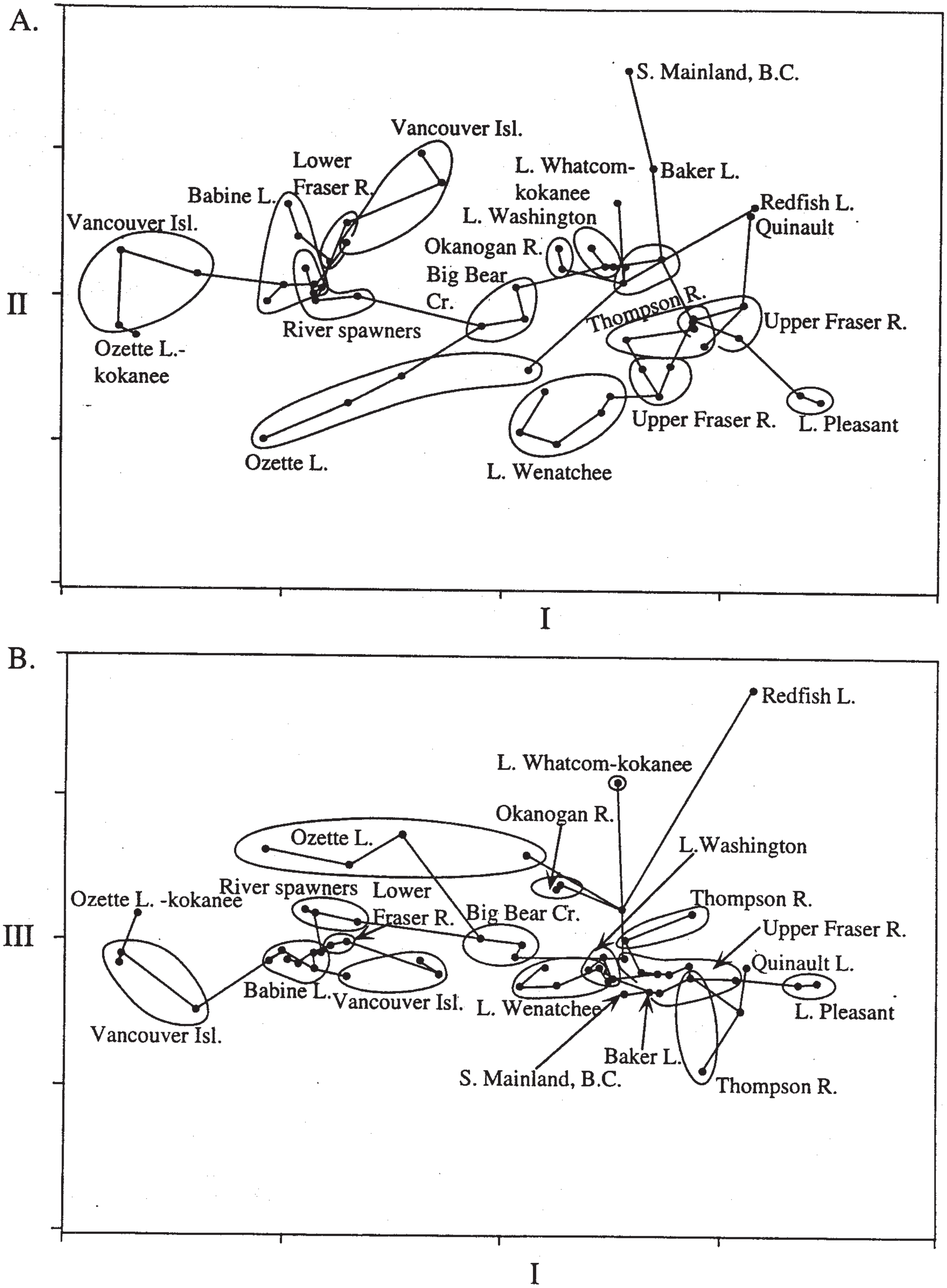


Figure 11. Multidimensional scaling plots of Nei's (1978) unbiased genetic distances along axes I and II (A) and axes I and III (B) based on 9 loci with a superimposed minimum-length spanning tree for 56 samples of *O. nerka*. Loci used and sample names are listed in Figure 10. * is (55) Sakinaw Lake in Wood et al. (1994).

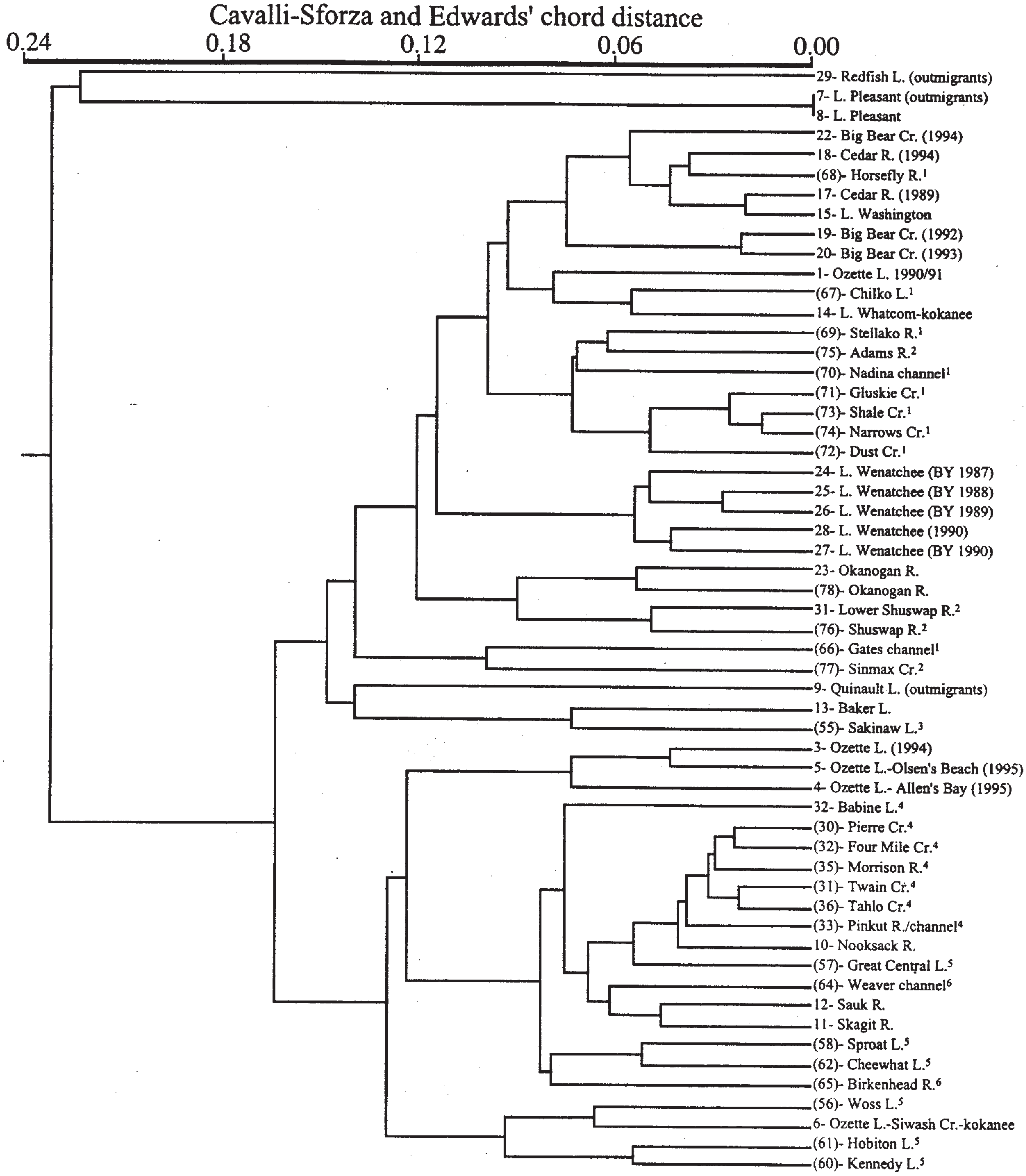


Figure 12. Dendrogram of chord distances (Cavalli-Sforza and Edwards 1967) based on 9 loci in 56 samples of *O. nerka,* including 29 samples from Canada. Data for sample numbers 1-32 are listed in Table 1; remaining samples from Wood et al. (1994) using the original site numbers, in parentheses. Loci used are listed in Figure 10. [1]Upper Fraser River, [2]Thompson River, [3]Lower Mainland B.C. [4]Skeena River, [5]Vancouver Island, and [6]Lower Fraser River. Cophenetic correlation coefficient = 0.791.

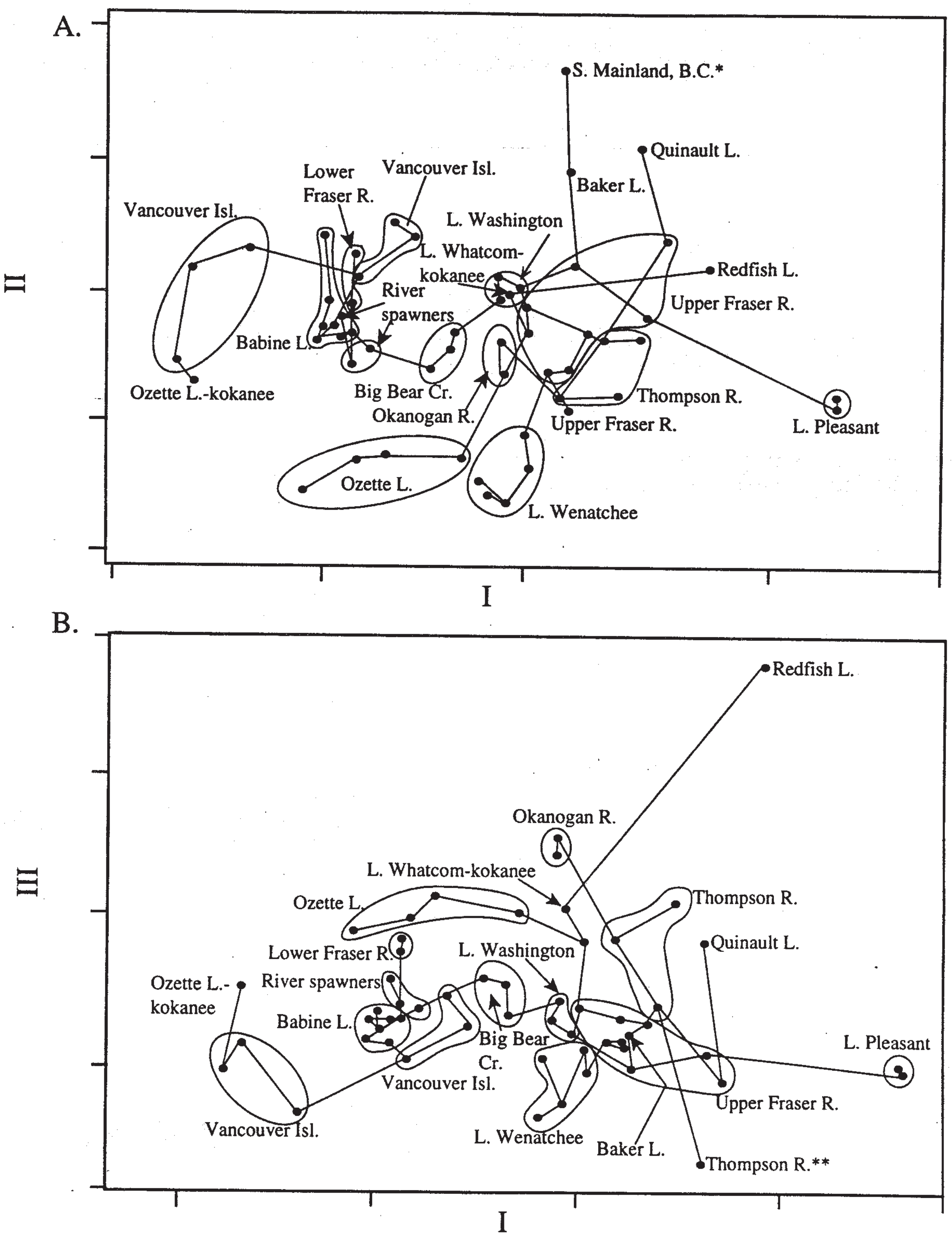


Figure 13. Multidimensional scaling plots of chord distance values (Cavalli-Sforza and Edwards 1967) along axes I and II (A) and axes I and III (B) based on 9 loci with a superimposed minimum-length spanning tree for 56 samples of *O. nerka*. Sample names are given in Figure 10. *(55) Sakinaw Lake and **(77) Sinmax Cr./ Adams Lake from Wood et al. (1994).

salmon (Knapp and Johnson 1995), and Folsom et al. (1992) stated that about 80% of Russia's total hatchery production of sockeye salmon occurs on the Kamchatka Peninsula. Long-term plans formulated by Russian authorities in the 1970s called for the annual release of approximately 80 million juvenile sockeye salmon by the year 2000 (Konovalov 1980). However, Knapp and Johnson (1995) reported that in 1993, approximately 1,880,000 and 500,000 sockeye salmon were released from "enhanced production" and "fed fry only" programs, respectively, in the Russian Far East (Kamchatka and Magadan Provinces).

Because sockeye salmon have always been an extremely valuable commercial species in Alaska, artificial propagation of sockeye salmon was initiated there before the turn of the century (Roppel 1982). During this period, two federal hatcheries were the most important sockeye salmon facilities: Afognak Hatchery (located on Afognak Island, northeast of Kodiak Island) and Yes Bay Hatchery (at Yes Bay, off Behm Canal north of Ketchikan). These facilities took millions of eggs per year, and not only planted sockeye salmon from the facilities, but transferred eggs to hatcheries in the contiguous United States, sometimes even to Atlantic coast states such as Maine (see Appendix Table D-1).

Catastrophic problems with IHN in ADFG production-scale sockeye salmon hatcheries in Alaska limited sockeye salmon enhancement through the 1970s in Alaska. In 1980, new sockeye salmon culture policies of IHN containment have served to minimize the effects of each outbreak (Burke 1996).

Currently, the Alaska Department of Fish and Game has sockeye salmon smolt production facilities at Snettisham Hatchery near Juneau; Main Bay Hatchery in Prince William Sound; Kitoi Bay Hatchery on Afognak Island; and Trail Lakes, Kasilof and Eklutna Hatcheries in Cook Inlet. Several of these hatcheries have large fry and pre-smolt production programs, as do Beaver Falls Hatchery in Ketchikan, English Bay Hatchery in Cook Inlet, Gulkana Hatchery in the Copper River Basin, and Pillar Creek Hatchery on Kodiak Island. In addition, some of the above fry and pre-smolt facilities are associated with lake enrichment programs (Burke 1996).

Eleven sockeye salmon hatcheries were constructed in British Columbia between 1894 and 1917, all of which were situated near healthy natural populations of sockeye salmon (Foerster 1968). No consistent benefits were evident as a result of the operation of these facilities (e.g., increases in sockeye salmon stocks and/or expansions of commercial fisheries), and it was concluded that artificial propagation in British Columbia did not result in a significant increase in efficiency over natural production in areas where there was a reasonable expectation of successful natural propagation. As a consequence, most of these turn-of-the-century facilities are no longer in operation (Foerster 1968). However, in recent years, artificial propagation programs for sockeye salmon in British Columbia (especially methods using natural rearing strategies and indigenous broodstocks (Miller et al. 1990)) have received renewed attention.

Spawning channels, lake fertilization, barrier removal, and habitat improvement are the primary enhancement methods used for sockeye salmon in British Columbia (Miller et al. 1990). On the lower Fraser River below Hope, B. C., a hatchery on the Pitt River has been releasing sockeye salmon since 1961, and the Weaver Creek and Seabird spawning channels have been in operation since 1966 and 1985, respectively. The Gates, Nadina, Adams, and Horsefly sockeye salmon spawning channels have operated in the upper Fraser River Basin since 1969, 1974, 1981, and 1990, respectively (NRC 1995). The Fulton River and Pinkut Creek spawning channels have operated in the Skeena River system from the mid-1960s to the present. Vancouver Island artificial propagation facilities releasing sockeye salmon were established in 1981 on the Nimpkish River, which empties into Johnstone Strait. In 1989, similar programs were established on Hobiton, Cheewhat, and Nitinat Lakes on the southwest section of the island.

Artificial propagation of sockeye salmon in the contiguous United States began in 1896 at Baker Lake Station in the Skagit River Basin of Washington State. This hatchery remained in operation until its closure in 1933 (Kemmerich 1945). The Birdsview Station on Grandy Creek, also in the Skagit River drainage, reared sockeye salmon from 1908 to 1945. This facility also provided stock for many attempts at establishing populations of sockeye salmon in various watersheds throughout western Washington, with the most notable success being the introduction of a self-sustaining population of sockeye salmon into the Lake Washington watershed.

Despite numerous stocking attempts, establishment of self-perpetuating sockeye salmon runs have been documented only at these three sites: 1) Lake Washington (Royal and Seymour 1940, Kolb 1971), 2) Frazer Lake, Kodiak Island (Blackett 1979), and 3) Upper Adams River in the Fraser River system (Williams 1987). Successful, documented transplants have all involved donor populations originating less than 100 km from the transplant site (Wood 1995). The remainder of this section is intended to provide a summary of the nature and scope of artificial propagation activities for west coast sockeye salmon considered in this status review.

Grand Coulee Fish-Maintenance Project

The construction of Grand Coulee Dam completely blocked the passage of sockeye salmon to the upper Columbia River. WDF et al. (1938) and Mullan (1986) reported that about 85% of the sockeye salmon passing Rock Island Dam between 1935 and 1936 originated from natural stocks up-river from Grand Coulee Dam. To compensate for loss of habitat resulting from the total blockage of up-river fish passage by Grand Coulee Dam, the federal government initiated the Grand Coulee Fish-Maintenance Project in 1939 to maintain fish runs in the Columbia River above Rock Island Dam. For sockeye salmon, this was accomplished through relocation of adults returning to Rock Island Dam, improving habitat, and establishing hatchery operations (Fish and Hanavan 1948). The foremost method of habitat improvement used by the GCFMP was installation of screens on irrigation diversions in tributaries entering the Columbia River above Rock Island Dam, which prevented juvenile salmon from being drawn into irrigation systems (Waknitz et al. 1995).

Between 1939 and 1943 all sockeye salmon adults returning to Rock Island Dam were trapped and transported either to Lake Wenatchee or Lake Osoyoos, or to one of three national fish hatcheries (Leavenworth, Entiat, or Winthrop) for artificial propagation (Fish and Hanavan 1948, Mullan 1986). After 1944, all sockeye salmon passing Rock Island Dam and returning to the Wenatchee and Okanogan Rivers were essentially the progeny of relocated stock.

Mullan showed that between 1944 and 1948, hatchery-reared sockeye salmon constituted 5-98% of the total run. By the mid-1960s, the contribution of hatchery fish as a percentage of all returning adult sockeye salmon had decreased to about 10-22%; about one third of what it had been in the 1940s. Mullan (1986) reported that artificial propagation efforts at the GCFMP hatcheries were abandoned in the 1960s due to “low benefits to costs and catastrophic losses from IHN.”

Releases from the GCFMP were thought to contribute to reestablishing healthy sockeye salmon populations in the Wenatchee and Okanogan River Basins (Chapman et al. 1995), as well as producing small populations in the Methow and Entiat Rivers, which previous to the GCFMP apparently did not have sockeye salmon populations (Mullan 1986, Chapman et al. 1995). Mullan (1986) thought it likely that releases of juvenile sockeye salmon (derived from Rock Island Dam, Bonneville Dam, and Lake Wenatchee broodstock) at Winthrop NFH (on the Methow River) gave rise to the Methow River sockeye salmon population, while other releases (derived from Quinault Lake broodstock and their progeny) at the Entiat NFH (on the Entiat River) gave rise to the Entiat River sockeye salmon population.

Stock Transfers and Artificial Propagation

Okanogan River

During the GCFMP (1939-1944), about 2 million sockeye salmon juveniles of the aforementioned upper Columbia River mixed stock (as well as an unknown number of Quinault Lake stock in 1942) were planted into the Okanogan River system, and a total of about 2 million local sockeye salmon have been released since then (see Appendix Table D-2). Average return rates from early plants (1940s) into the Okanogan River system (GCFMP) averaged 0.93% (Fulton and Pearson 1981) and have decreased since then (Mullan 1986).

Current artificial propagation programs in the Okanogan River watershed are intended to replace adult production lost to juvenile sockeye salmon mortality at mainstem hydroelectric projects without reducing natural production or changing the fitness and genetic diversity of natural stocks (Chapman et al. 1995). The Colville Indian Nation has recently initiated an annual release program from its Cassimer Bar Hatchery. Adult sockeye salmon will be collected at Wells Dam and the progeny will be released from net-pens in Lake Osoyoos.

In addition to releases of juveniles during the GCFMP, 19,795 adult sockeye salmon were trapped at Rock Island Dam and released into Lake Osoyoos between 1939 and 1940 (Chapman et al. 1995). There are very limited reports of introductions of artificially-propagated kokanee into the Okanogan River system (see Appendix Table D-5).

Lake Wenatchee

Between 1941 and 1969 almost 60 million sockeye salmon juveniles (only a small percentage of which were of non-upper Columbia River origin (see Appendix Table D-2)) were released into the Wenatchee River system. The Wenatchee River system has been the largest recipient of hatchery fish in the upper Columbia River. Sockeye salmon now returning to the White and Little Wenatchee Rivers are undoubtedly the descendants of stock manipulations during the GCFMP, since Lake Wenatchee sockeye salmon were extremely depressed prior to the construction of Grand Coulee Dam (Fish and Hanavan 1948, see above "Information Specific to Sockeye Salmon Populations Under Review" section). Small numbers of fish that continue to return to Icicle Creek may also be descendants of the GCFMP (Chapman et al. 1995).

Returns from releases of sockeye salmon into the Wenatchee watershed in the 1940s were about 0.90%, which decreased to about 0.15% to 0.67% by the early 1960s (Chapman et al. 1995). However, hatchery fish still contributed to Columbia River sockeye salmon runs in appreciable numbers in some years (Mullan 1986).

No releases of artificially-reared sockeye salmon occurred in the Wenatchee watershed during the years 1970 to 1989 (see Appendix Table D-2). Since 1990, releases into Lake Wenatchee have resumed, these being from the Rock Island Fish Hatchery Complex, constructed and funded by Chelan PUD, and operated by WDFW (Chapman et al. 1995). This facility was designed to supplement the natural production of sockeye salmon in the White and Little Wenatchee Rivers, primarily through the use of extended rearing strategies in net-pens in Lake Wenatchee (Chapman et al. 1995).

In addition to releases of juveniles during the GCFMP, over 32,000 mixed upper Columbia River stock adult sockeye salmon trapped at Rock Island Dam were released into Lake Wenatchee between 1939 and 1943, over 90% of which successfully spawned according to surveys in 1939 and 1942 (Fish and Hanavan 1948).

Over 23 million Lake Whatcom kokanee were released into Lake Wenatchee between 1934 and 1983 (Mullan 1986) (see Appendix Table D-5). Experimental releases in 1946 of fin-marked Lake Wenatchee kokanee, which had been reared at Leavenworth Hatchery, into Icicle Creek and Lake Wenatchee resulted in adult anadromous returns to the Columbia River of 0.27% and 0.50%, respectively (Fulton and Pearson 1981). Fulton and Pearson (1981) questioned whether broodstock used for these experiments were "far enough removed from seaward migratory behavior to be classified as kokanee." Mullan (1986) thought it possible that Lake Wenatchee kokanee may have evolved from the lake's sockeye salmon population within the last 90 years (due to migrational problems for anadromous individuals imposed by water diversions, dams, and resultant high water temperatures in the Wenatchee River) and that, consequently, there may be an incomplete separation of kokanee and sockeye salmon in this lake.

Quinault Lake

Artificial propagation of sockeye salmon has long been a significant feature of sockeye salmon management in Quinault Lake. Since 1916, over 196 million hatchery sockeye salmon have been released in the Quinault River Basin, although most of these were released as fry or fingerlings (see Appendix Table D-2). Two periods of hatchery production of sockeye salmon have occurred in this watershed. The first period spanned the years 1914 to 1947, when the federal government was the primary agency responsible for hatchery efforts in the Quinault Basin. During the second period, from 1973 to the present, an artificial propagation program in Quinault Lake has been operated by the Quinault Indian Nation, while WDFW released sockeye salmon in Quinault Lake in 1985 (NRC 1995).

Prior to 1947, fish were released from the U.S. Bureau of Fisheries Hatchery at Falls Creek on Quinault Lake ("Quinault, Washington Station"), and were mostly native stock, although about 20 million Alaskan sockeye salmon eggs were transferred to the Falls Creek facility prior to 1920 (see Appendix Table D-1). All tribal and WDFW releases since 1973 have been of current Quinault Lake stock; the tribal releases came mostly from an extended rearing program utilizing net-pen rearing in Quinault Lake (Donaldson 1980, NRC 1995, QIN 1995b). To the best of our knowledge, only minor kokanee releases into Quinault Lake have occurred (see Appendix Table D-5).

Although the actual impact of these hatchery programs on native stock are unknown, it is possible to roughly evaluate their relative contribution to total production. Between 1914 and 1947 estimated total escapement of female sockeye salmon to Quinault Lake was about 2,154,000 (assuming a 1:1 sex ratio, total escapement was 4,309,237), and the Quinault, Washington Station on Falls Creek took 237,783,455 native sockeye salmon eggs and released 191,696,000 juvenile sockeye salmon (QIN 1981) (see Appendix Table D-2). Since average fecundity at this hatchery was 2,700 (QIN 1981), total egg production of naturally spawning fish (minus the egg output of the estimated 88,068 females taken at the hatchery) is estimated at over 5.5 billion. Using Foerster's (1968) estimate of egg-fry mortality of 0.88, approximately 669,562,000 naturally produced fry are estimated to have recruited to Quinault Lake between 1914 and 1947. Using these values, approximately 22% of the fry entering Quinault Lake over this period of time were hatchery produced. In reference to the Quinault, Washington Station, QIN (1981) reported that "hatchery releases were of sufficient size to have potentially large effects on the estimated returns per spawner" and "termination of the hatchery operation in 1947 certainly contributed to at least part of the subsequent loss of productivity."

Between 1974 and 1994, over 5 million juvenile sockeye salmon were released in Quinault Lake, and estimated female escapement was 398,562 (assuming a 1:1 sex ratio, total escapement was 797,124), and the calculated natural egg production (again assuming average fecundity of 2,700 and subtracting for the estimated 2,596 female spawners taken for hatchery efforts) was approximately 1,069,100,000. Again using Foerster's (1968) estimate of egg-fry mortality of 0.88, approximately 128,292,000, naturally produced fry are estimated to have recruited to Quinault Lake between 1974 and 1994. Therefore, approximately 3.8% of the fry entering Quinault Lake over this time period were hatchery produced.

Ozette Lake

Artificial propagation has not been extensive in this population. Approximately one million sockeye salmon have been released into the Ozette Lake watershed from 1937 to the present (see Appendix Table D-2). Although this number is small compared to some other sockeye salmon populations discussed in this review, non-indigenous sockeye salmon introductions have been prominent in this watershed. The largest single release of 449,000 fish in 1937 was entirely of Grandy Creek (Birdsview Hatchery) stock, which were reared at the Quilcene National Fish Hatchery before transfer to Ozette Lake (Kemmerich 1945, Boomer 1995, NRC 1995). In addition, 120,000 Quinault stock sockeye salmon were released in 1983 (NRC 1995). Small-scale releases since 1984, when hatchery efforts were undertaken by the Makah Indian Nation, were primarily of Ozette Lake stock (NRC 1995). About 14,400 Ozette Lake kokanee/sockeye salmon hybrids were released in 1991-1992 (MFMD 1995, NRC 1995).

Although the actual impact of the recent hatchery program on the native sockeye salmon stock in Ozette Lake is unknown, it is possible to roughly evaluate the relative hatchery contribution to total production. Between 1988 and 1995, about 330,340 juvenile sockeye salmon were released in Ozette Lake, estimated female escapement between 1988 and 1994 was 3,486 (assuming a 1:1 sex ratio, estimated total escapement was 6,971), and the calculated natural egg production (assuming average fecundity of 2700 and subtracting for the estimated 171 female spawners taken for hatchery efforts) was 8,950,500. Using Foerster's (1968) estimate of egg-fry mortality of 0.88, approximately 1,074,000 naturally produced fry are estimated to have recruited to Ozette Lake between 1988 and 1995. This very coarse approximation leads to the conclusion that about 24% of the fry entering Ozette Lake over this time period were hatchery produced.

Baker River

Artificial propagation has a long history in this population. Between 1896 and 1933, over 202 million sockeye salmon eggs were taken for culture efforts at Baker Lake Hatchery and essentially 100% of the native population was under cultivation (with the exception of some fish that escaped holding pens to spawn naturally) (Kemmerich 1945) (see Appendix Table D-2). Baker Lake Hatchery was constructed in 1896 by the State of Washington (and subsequently sold to the U.S. Commission of Fish and Fisheries in 1899, which later became the U.S. Bureau of Fisheries), while the U.S. Bureau of Fisheries Birdsview Station on Grandy Creek, a nearby tributary of the Skagit River, was established in 1901.

The Grandy Creek-Birdsview Hatchery sockeye salmon stock was started in 1908 with sockeye salmon captured at Point Roberts near Blaine, Washington (Kemmerich 1945). Initially, sockeye salmon propagated at Birdsview Hatchery most likely consisted of mixed stocks of sockeye salmon bound for the Fraser River. In later years, large numbers of Baker Lake (and some Quinault Lake) sockeye salmon were released in Grandy Lake and Creek, together with progeny of sockeye salmon returning to Grandy Creek and the Birdsview Hatchery (Kemmerich 1945) (Appendix table D-2). After 1917 this hatchery population was maintained entirely by propagation of sockeye salmon returning to Grandy Creek and from transfers of eyed eggs from the Baker Lake hatchery.

Over 0.5 million Birdsview Hatchery sockeye salmon fry were released in Baker Lake between 1941 and 1944 (Kemmerich 1945, Appendix table D-2). Birdsview Hatchery sockeye salmon, together with some Baker Lake stock, were extensively transplanted to other locations in Washington, including numerous releases in the Skagit River watershed, the Lake Washington drainage, the Samish River, the Stillaguamish River Basin, Lake Stevens, Mason Lake, Isabella Lake, the Big Quilcene River, Ozette Lake, Beaver Lake, and Lake Pleasant (see Appendix Table D-2). Baker Lake and Birdsview Hatcheries ceased operations in 1934 and 1942, respectively.

Between 1934 and 1957, artificial enhancement efforts for Baker Lake sockeye salmon were suspended (with the exception of lifting adult fish over Lower Baker Dam), and fish spawned and reared naturally in Baker Lake. Between 1957 and 1993, combined enhancement efforts of WDFW and Puget Sound Power and Light Co. contributed over 42 million sockeye salmon juveniles to the Baker River Basin, with over 41.5 million of these produced as fry from the Baker Lake spawning beaches, and the remainder coming from releases from a net-pen program in Lake Shannon (Lower Baker Reservoir) (see Appendix Table D-2).

Most enhancement efforts in Baker Lake used native stock; one small release of fish in 1959 was from Issaquah Creek, which itself was established from Baker River stock (NRC 1995), while some mixed Fraser River and Quinault Lake sockeye salmon were released in Grandy Creek in 1909 and 1917, respectively (Kemmerich 1945) (see Appendix Table D-2). Approximately 955,000 sockeye salmon fry derived from Yes Bay, Alaska stock are known to have been released in Baker Lake in 1931 (Leach 1932) (see Appendix Table D-2). However, the disposition of almost 7 million sockeye salmon eggs transferred from the Samish River Hatchery in 1917-1918, and of over 11 million sockeye salmon eggs transferred from Yes Bay, Alaska in 1925-1926, to the Baker Lake Hatchery is unknown (see Appendix Table D-1). Similarly, the disposition of about 900,000 Quinault Lake stock eggs, 278,000 Afognak, Alaska stock eggs, and 1.2 million Yes Bay, Alaska stock eggs (see Appendix Table D-1) transferred to Birdsview Hatchery between 1917 and 1930, in 1922, and in 1931, respectively, is unknown.

To the best of our knowledge, this watershed was not planted with kokanee until very recently. Approximately 1.1 million Lake Whatcom kokanee were released into Lake Shannon (Lower Baker Reservoir) between 1991 and 1994 to bolster the sport fishery (Appendix Table D-5).

Lake Washington/Sammamish River tributaries

With the exception of sockeye salmon currently in Big Bear Creek, it is likely that most sockeye salmon currently in the Lake Washington Basin result from transplants that occurred between 1935 and 1954, primarily from the Birdsview Hatchery in the Skagit River Basin (Kolb 1971). The Lake Washington Basin received an initial plant of 19,700 sockeye salmon fry from an unknown source in 1917 (Appendix Table D-2). In the 1930s, populations of sockeye salmon were established in Issaquah Creek, the main tributary of Lake Sammamish, and in the Cedar River, the main tributary of Lake Washington, from Birdsview Hatchery stock (Kemmerich 1945, Kolb 1971). Over 0.5 million sockeye salmon juveniles from Birdsview Hatchery (Skagit River) were released in Big Bear Creek in 1937, while approximately 23,600 Cultus Lake sockeye salmon were released in North Creek in 1944 (see Appendix Table D-2). Both Big Bear and North Creeks are tributaries of the Sammamish River.

Egg-box projects released a total of over 25 million juveniles derived from in-basin egg sources into the Cedar River between 1978 and 1982. This project was terminated after it was determined that IHN-mediated mortalities were likely close to 100%. Washington Department of Fish and Wildlife currently operates a “portable hatchery” facility for sockeye salmon enhancement at the base of the Landsburg Dam on the Cedar River, with an 8 million egg/year capacity. This facility is scheduled to increase capacity to 17 million eggs/year in 1996 (WDF et al. 1993, J. Ames[51]). The percentage of fry emigrating from the Cedar River that were hatchery-produced was estimated at 6%, 6%, 27%, and 40% in the years 1992, 1993, 1994, and 1995, respectively (Seiler and Kishimoto 1996).

Between 1917 and 1969, over 44 million kokanee were introduced into Big Bear Creek and its tributaries. Over 35 million of these kokanee were from Lake Whatcom in northwest Washington (see Appendix Table D-5). Lake Sammamish proper, as well as the Sammamish River, have also received extensive plants of kokanee. Between 1917 and 1951, over 18 million kokanee were planted here, at least 6 million of which were Lake Whatcom stock (see Appendix Table D-5).

---

[51] J. Ames, Department of Fish and Wildlife, State of Washington, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., April 1995 and 13 March 1996.

Lake Pleasant

Lake Pleasant received just under half a million Grandy Creek (Skagit River, Birdsview Hatchery) and Baker Lake sockeye salmon juveniles between 1933 and 1937 (Kemmerich 1945, Boomer 1995) (see Appendix Table D-2). NRC (1995) did not locate records of sockeye salmon stocking in this lake after 1937. A recreational sport fishery exists for kokanee in Lake Pleasant, and Smoker et al. (1952) stated that kokanee (silver trout) from an unknown source were planted in Lake Pleasant in 1936, 1937, and 1938. No further evidence of kokanee plants in Lake Pleasant was found (Kloempken 1996).

Riverine-spawning sockeye salmon

There are very few records of artificial propagation programs for populations of sockeye salmon in Washington or Oregon that spawn in rivers without access to lake-rearing habitat (NRC 1995). Rivers without accessible lake-rearing habitat, with present-day occurrence of spawning sockeye salmon (see Appendix Table C-7), and with a history of sockeye salmon stocking (see Appendix Table D-2) include Icicle Creek and portions of the Skagit, Samish, Stillaguamish, Snohomish, Green, Sol Duc, Chelan, Entiat, Methow, and Similkameen Rivers. Locations where records of spawning sockeye salmon and stocking release location overlap include Icicle Creek and the Samish, Entiat, and Methow Rivers. Sockeye salmon stocking history and present day spawning activity in these rivers are discussed in the above “Information Specific to Sockeye Salmon Populations Under Review” section.

Deschutes River, Oregon

Between 1937 and 1960, Suttle Lake and the headwaters of the Metolius River, into which it drains, were planted with 1.3 million juvenile sockeye salmon, the majority of which were from stock developed during the Grand Coulee Fish Maintenance Project in the upper Columbia River (see Appendix Table D-3). Most of these plants were made directly into the lake. The effect of these plants, if any, on any remnant sockeye salmon that might be indigenous to the Deschutes River basin is unknown. Between 1963 and 1973, 210,658 kokanee of unknown origin were planted into Suttle Lake (ODFW 1995b) (see Appendix Table D-5).

Discussion and Conclusions for ESU Determinations

Based on genetic, life-history, and ecological evidence presented above, the BRT identified six ESUs for sockeye salmon in the state of Washington; fish from one of these ESUs spawns in British Columbia, rears in a lake that straddles the U.S./Canadian border, and migrates to and from the sea through Washington. In addition, sockeye salmon from Big Bear Creek in the Lake Washington/Lake Sammamish Basin of Washington were provisionally identified as an ESU. There was insufficient evidence to determine the ESU status for two additional groupings of sockeye salmon, one in Washington and the other in Oregon. In the following discussion, we describe these ESUs and outline the issues that were important to the BRT in making each ESU determination.

Status of Transplanted Populations

Available artificial propagation data and transplantation records provide evidence that within the Lake Washington Basin, the current Cedar River and Issaquah Creek sockeye salmon are introduced populations, originating from transplants of Baker Lake stock that had been perpetuated at the Birdsview Hatchery. Allozyme data based on 29 allozyme loci indicate a close genetic relationship between Cedar River, Lake Washington beach-spawning, and Baker River sockeye salmon. Similar artificial propagation data and transplantation records provide evidence that spawning aggregations of sockeye salmon that are annually seen in Icicle Creek and the Methow and Entiat Rivers in the Columbia River Basin are the result of transplants that occurred during the Grand Coulee Fish Maintenance Project.

Waples (1991a, p. 18-19), in the NMFS "Definition of Species" paper, suggested that

> In general, populations resulting from the introduction of fish into a local area not occupied by the biological species... are probably not ESU's because they do not contribute to maintaining diversity of the species in its native habitat.

However, Waples (1991a, p. 19) went on to say that

> Some introduced populations should not be excluded from ESA consideration, and these include populations occupying habitat that is ecologically similar and geographically proximate to the source population, and those that represent the only remaining component of the native gene pool.

These ecological and geographic criteria do not appear to apply in the present case. Although introduced sockeye salmon populations in the Lake Washington/Lake Sammamish system and native Baker River sockeye salmon are both geographically within Puget Sound, the natural ecosystems are dissimilar. Baker Lake is a cold-water, glacially influenced, low productivity mountain lake system, and the Lake Washington/Lake Sammamish drainage is a relatively warm-water, high productivity coastal lake system.

The BRT concluded that historical records, stocking history, and genetic data indicate that sockeye salmon that spawn in the Cedar River, Issaquah Creek, on lakeshore beaches in Lake Washington (in the Lake Washington drainage), and in Icicle Creek and the Methow and Entiat Rivers (in the Columbia River Basin) originated from transplants from outside the basins. As these populations are considered non-native and not part of any ESU, they are not considered to be an ESA issue.

Status of Nonanadromous *Oncorhynchus nerka*

Within the range of west coast sockeye salmon, “kokanee-sized” *O. nerka* occur sympatrically with several sockeye salmon populations in their respective spawning and/or juvenile rearing environments. In the Okanogan River, Lake Wenatchee, Sammamish River tributaries, Cedar River, Lake Pleasant, and Ozette Lake populations, sockeye salmon and kokanee-sized *O. nerka* are often observed together on the spawning grounds at the same time and in the same place. In addition, kokanee-sized *O. nerka* are often observed at the time of sockeye salmon spawning in the channel which drains the upper spawning beaches at Baker Lake, but these fish cannot gain access to these artificial sockeye salmon spawning beaches. Kokanee-sized fish have not been reported on the sockeye salmon spawning grounds of Quinault Lake to any appreciable degree. On the other hand, native kokanee that have relatively easy access to the ocean spawn in the absence of anadromous sockeye salmon in several tributary streams of Ozette Lake and in Issaquah Creek, a tributary of Lake Sammamish. Juvenile kokanee from these two populations rear sympatrically with sockeye salmon in Ozette Lake and Lake Sammamish, respectively.

Several native and numerous introduced populations of kokanee exist within the geographic range of west coast sockeye salmon. Several of these native kokanee populations may be genetically distinct and reproductively isolated from one another and from other *O. nerka* populations. The BRT acknowledged that it has long been known that kokanee can produce anadromous fish; however, the number of outmigrants that successfully return as adults is typically quite low. In three instances where populations of native kokanee occur in coastal lakes in the Pacific Northwest and where access from the ocean is relatively easy (Ozette Lake and Lake Sammamish in Washington, and Cowichan Lake on Vancouver Island), the sockeye salmon morphology is absent on the kokanee spawning grounds. If kokanee in these populations were producing anadromous outmigrants in any appreciable numbers that were surviving to adulthood, the sockeye salmon morphology should be visible on the kokanee spawning grounds.

Occasionally, a proportion of the juveniles in an anadromous sockeye salmon population will remain in the rearing-lake environment throughout life and will be observed on the spawning grounds together with their anadromous siblings. For the purposes of this review, we have defined these fish as “resident sockeye salmon,” to indicate that they are the progeny of anadromous sockeye salmon parents, yet spend their adult life in freshwater and are observed together with their anadromous siblings on the spawning grounds.

Foote et al. (1989), Wood and Foote (1990), Foote et al. (1994), Taylor and Foote (1991), Taylor et al. (1996), Wood and Foote (1996), and Winans et al. (1996) provide evidence that sympatric populations of sockeye salmon and kokanee can be both genetically distinct and reproductively isolated. In the following compilation of sockeye salmon ESUs, the status of kokanee-sized *O. nerka* that spawn together with sockeye salmon will be addressed on a case-by-case basis for each ESU.

In considering the ESU status of resident forms of *O. nerka*, a key issue is evaluating the strength and duration of reproductive isolation between resident and anadromous forms. Many kokanee populations appear to have been strongly isolated from sympatric sockeye salmon populations for long periods of time. Since the two forms experience very different selective regimes over their life cycle, reproductive isolation provides an opportunity for adaptive divergence in sympatry. Kokanee populations that fall into this category will generally not be considered part of sockeye salmon ESUs. On the other hand, resident fish appear to be much more closely integrated into some sockeye salmon populations. For example, in some situations anadromous fish may give rise to progeny that mature in freshwater (as is the case with residual sockeye salmon), and some resident fish may have anadromous offspring. In these cases, where there is presumably some regular or at least episodic genetic exchange between resident and anadromous forms, they should be considered part of the same ESU.

Sockeye Salmon ESUs

1) Okanogan River

This ESU consists of sockeye salmon that return to Lake Osoyoos through the Okanogan River via the Columbia River and spawn primarily in the Canadian section of the Okanagan River above Lake Osoyoos. Genetic, environmental, and life history information were the primary factors in distinguishing this ESU. Factors important to the BRT in identifying this ESU were these: 1) the very different environmental and habitat conditions encountered by sockeye salmon in Lakes Osoyoos and Wenatchee during juvenile rearing; 2) the near absence of 3-year-old sockeye salmon returns to Lake Wenatchee coupled with the tendency for a large percentage of 3-year-olds to return to the Okanogan population; 3) the apparent 1 month separation in juvenile outmigration-timing between Okanogan and Wenatchee-origin fish; and 4) the adaptation of Okanogan River sockeye salmon to much higher temperatures during adult migration in the Okanogan River. Protein electrophoretic data (with the exception of Utter’s (1995) preliminary report) also indicate that this population is genetically distinct from other sockeye salmon currently in the Columbia River drainage. Utter’s (1995) data, which show sockeye salmon collected in 1994 (at Wells Dam on the Columbia River and presumably bound for the Okanogan River) and Wenatchee sockeye salmon (collected in multiple years) to be genetically indistinguishable, is at odds with all other genetic studies that have shown high levels of genetic differentiation between Okanogan River and Lake Wenatchee sockeye salmon (Winans et al. 1996, Wood et al. 1996, Thorgaard et al. 1995)

The overall effect of the Grand Coulee Fish Maintenance Project (GCFMP) on the current composition of sockeye salmon in this ESU is difficult to determine. A majority of the sockeye salmon returning to the mid- to upper Columbia River prior to the operation of Grand Coulee Dam most likely spawned in the Arrow Lakes region of British Columbia. The redistribution and long-term propagation of mixed Arrow Lakes, Okanogan, and Wenatchee stocks of adult sockeye salmon originally captured at Rock Island Dam, as well as introductions of Quinault Lake sockeye salmon stocks, may have altered the genetic make-up of indigenous sockeye salmon in the Okanogan River, particularly considering the relatively low estimated returns of native sockeye salmon immediately prior to the beginning of the GCFMP. However, electrophoretic analysis of current Okanogan River sockeye salmon reveals little affinity with either Lake Wenatchee or Quinault Lake sockeye salmon or with kokanee currently residing in Lower Arrow Lake (see statement above concerning Utter (1995)).

Kokanee are reported to occur in Lake Osoyoos, and one known plant of 195,000 kokanee from an unknown source occurred in this lake in the years 1919-1920. Kokanee-sized fish (L. LaVoy[52]) or residuals (Chapman et al. 1995) with a reportedly olive drab or "typically dark" coloration, respectively, have been observed spawning with sockeye salmon in the Okanogan River. Genetic samples of kokanee-sized fish from Lake Osoyoos have not been obtained. However, kokanee from Okanagan Lake, above Vaseux Dam and Vaseux Lake on the Okanagan River, are genetically quite distinct from Okanogan River sockeye salmon (Wood et al. 1994, Thorgaard et al. 1995, Utter 1995, Robison 1995, Winans et al. 1996). Robison (1995) suggested that Okanagan Lake kokanee may have been transplanted into this system, as they appear genetically similar to Shuswap Lake kokanee.

The BRT concluded that if "kokanee-sized" *O. nerka* observed spawning with sockeye salmon on the Okanogan River are identified as resident sockeye salmon they are to be considered part of this sockeye salmon ESU. Based on the large genetic distance between Okanagan Lake kokanee and Okanogan River sockeye salmon, the BRT decided that Okanagan Lake kokanee are not part of the Okanogan sockeye salmon ESU. The BRT concluded that spawning aggregations of sockeye salmon that are occasionally observed downstream from Lake Osoyoos and below Enloe Dam on the Similkameen River are most likely wanderers from the Okanogan River population and are therefore to be considered part of this ESU.

2) Lake Wenatchee

This ESU consists of sockeye salmon that return to Lake Wenatchee through the Wenatchee River via the Columbia River and spawn primarily in tributaries above Lake Wenatchee (the White River, Napeequa River, and Little Wenatchee River). Genetic, environmental, and life history information were the primary factors in distinguishing this ESU. Allozyme data indicate that, of the populations examined, the Lake Wenatchee sockeye salmon population is genetically very distinctive (but see discussion above concerning Utter (1995)). Several ecological and biological factors were important in distinguishing the Okanogan River and Lake Wenatchee sockeye salmon ESUs. These include: 1) the very different environmental conditions encountered by sockeye salmon in Lakes Wenatchee and

---

[52] L. LaVoy, Washngton Department of Fish and Wildlife, 3860 Chelan Highway North, Wenatchee, WA 98801-0452. Pers. commun., 31 May 1995.

Osoyoos, 2) the near absence of 3-year-old sockeye salmon returns to Lake Wenatchee coupled with the tendency for a large percentage of 3-year-olds to return to the Okanogan population, and 3) the apparent 1 month separation in juvenile outmigration-timing between Okanogan- and Wenatchee-origin fish.

The overall effect of the GCFMP on the current make-up of sockeye salmon in this ESU is difficult to determine. The redistribution and long-term propagation of mixed Arrow Lakes, Okanogan, and Wenatchee stocks of sockeye salmon originally captured at Rock Island Dam, as well as introductions of Quinault Lake sockeye salmon stocks, may have altered the genetic makeup of indigenous sockeye salmon in the Lake Wenatchee system, particularly considering the low estimated returns of native sockeye salmon to Lake Wenatchee immediately prior to the beginning of the GCFMP. It is possible that a significant portion of the current gene pool of Lake Wenatchee sockeye salmon is derived from introduced Arrow Lakes sockeye salmon. However, electrophoretic analysis of current Lake Wenatchee sockeye salmon reveals little affinity with either Okanogan River (but see discussion of Utter (1995) in Okanogan River ESU section) or Quinault Lake sockeye salmon or with kokanee from Lower Arrow Lake.

Spawning aggregations of sockeye salmon that appear in the Entiat and Methow Rivers and in Icicle Creek (a tributary of the Wenatchee River) were presumed by the BRT to be nonnative and the result of transplants carried on during the GCFMP. Both the Methow and Entiat Rivers had no history of sockeye salmon prior to stocking (WDF et al. 1938, Mullan 1986). Leavenworth National Fish Hatchery is located on Icicle Creek, and between 1942 and 1969 over 1.5 million sockeye salmon juveniles (of mixed Columbia, Entiat, Methow Rivers heritage) were liberated from this facility into Icicle Creek (Mullan 1986, Chapman et al. 1995).

Kokanee-sized fish with a reportedly olive-drab coloration have been observed spawning with sockeye salmon in the White, Napeequa, and Little Wenatchee Rivers (L. LaVoy[53]). Over 23 million Lake Whatcom kokanee were released in Lake Wenatchee between 1934 and 1983; however, the current genetic make-up of the Lake Wenatchee sockeye salmon population reveals little or no affinity with Lake Whatcom kokanee. Genetic samples of kokanee-sized fish from Lake Wenatchee have not been obtained.

The BRT concluded that if "kokanee-sized" *O. nerka* observed spawning with sockeye salmon on the White and Little Wenatchee Rivers are identified as resident sockeye salmon they are to be considered part of the Lake Wenatchee sockeye salmon ESU.

---

[53] L. LaVoy, Washngton Department of Fish and Wildlife, 3860 Chelan Highway North, Wenatchee, WA 98801-0452. Pers. commun., 31 May 1995.

3) Quinault Lake

This ESU consists of sockeye salmon that return to Quinault Lake and spawn in the mainstem of the upper Quinault River, in tributaries of the upper Quinault River, and in a few small tributaries of Quinault Lake itself. The BRT felt that Quinault Lake sockeye salmon deserved separate ESU status based on its unique life history characteristics and degree of genetic differentiation from other sockeye salmon populations.

Key factors in identifying this ESU were: 1) the distinctive early river-entry timing, 2) the protracted adult run-timing, 3) the long 3- to 10-month lake-residence period prior to spawning, 4) the unusually long spawn timing, and 5) the genetic differences from other coastal Washington sockeye salmon. In addition, the relative absence of red skin pigmentation and the presence of an olive-green spawning coloration by the majority of the Quinault stock appear to be unique among major sockeye salmon stocks in Washington (Storm et al. 1990, D. Boyer, Jr.[54]), although at least two sockeye salmon stocks in British Columbia appear more green than red at spawning (C. C. Wood[55]). The rather large genetic distance between U.S. and Vancouver Island sockeye salmon, together with the apparently unique life-history characters of Quinault Lake sockeye salmon (very early, yet protracted run-timing, and lengthy lake-residency as adults), persuaded the BRT to exclude Vancouver Island stocks from this ESU.

Kokanee-sized *O. nerka* have not been identified within the Quinault River Basin; however, stocking history reveals over 300,000 kokanee transplanted into Quinault Lake between 1917 and 1922 from an unknown source and 260,000 kokanee eggs transferred from Lake Whatcom to the “Quinault, Washington Station” in 1925.

4) Ozette Lake

This ESU consists of sockeye salmon that return to Ozette Lake through the Ozette River and currently spawn primarily in lakeshore upwelling areas in Ozette Lake (particularly at Allen’s Bay and Olsen’s Beach). Minor spawning may occur below Ozette Lake in the Ozette River or in Coal Creek, tributary of the Ozette River. Sockeye salmon do not presently spawn in tributary streams to Ozette Lake, although they may have spawned there historically. Genetic, environmental, and life history information were the primary factors in distinguishing this ESU. The BRT felt that Ozette Lake sockeye salmon were a separate ESU based on the degree of genetic differentiation from other sockeye salmon populations and on life history characteristics.

---

[54] Del Boyer, Jr., Quinault Fisheries Division, P.O. Box 189, Taholha, WA 98587. Pers. commun., 24 April 1995.

[55] C.C. Wood, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C., Canada V9T 5K6. Pers. commun., August 1996.

Ozette Lake sockeye salmon are genetically distinct from all other sockeye salmon stocks in the Northwest. Sockeye salmon stocks from west coast Vancouver Island were excluded from this ESU, in part because of the large genetic distance between Vancouver Island and Ozette Lake sockeye salmon. On the other hand, Ozette Lake kokanee proved to be the most genetically distinct *O. nerka* stock examined in the contiguous United States (based on 29 allozyme loci). However, Ozette Lake kokanee were closely allied to several sockeye salmon stocks on Vancouver Island (based on analysis of a nine allozyme loci data set).

Kokanee are very numerous in Ozette Lake and spawn in inlet tributaries, whereas sockeye salmon spawn on lakeshore upwelling beaches. Sockeye salmon have not been observed on the inlet spawning grounds of kokanee in Ozette Lake, although there are no physical barriers to prevent their entry into these tributaries. On the other hand, kokanee-sized *O. nerka* are observed together with sockeye salmon on the sockeye salmon spawning beaches at Allen’s Bay and Olsen’s Beach. One recorded plant of over 100,000 kokanee from an unknown source stock occurred in 1940, and anecdotal reports of another kokanee plant in 1958 were found.

Based on the very large genetic distance between Ozette Lake kokanee that spawn in tributaries and Ozette Lake sockeye salmon that spawn on shoreline beaches, the BRT excluded Ozette Lake kokanee from this sockeye salmon ESU. In addition, the BRT concluded that if “kokanee-sized” *O. nerka* observed spawning with sockeye salmon on sockeye salmon spawning beaches in Ozette Lake are identified as resident sockeye salmon, then they are to be considered as part of the Ozette Lake sockeye salmon ESU.

5) Baker River

This ESU consists of sockeye salmon that return to the barrier dam and fish trap on the lower Baker River after migrating through the Skagit River. Adults are trucked to one of three artificial spawning beaches above either one or two dams on the Baker River, and are held in these enclosures until spawning.

The BRT felt that Baker River sockeye salmon are a separate ESU based on genetic, life history, and environmental characters. Baker River sockeye salmon are genetically distinct from sockeye salmon populations that spawn in the lower Fraser River (allozyme data based on 9 loci) and are genetically distinct from all other native populations of Washington sockeye salmon (allozyme data based on 29 loci). Prior to inundation behind Upper Baker Dam, Baker Lake was a typical cold, oligotrophic, well-oxygenated, glacially turbid sockeye salmon nursery lake, in contrast to other sockeye salmon systems under review, with the exception of Lake Wenatchee.

The Birdsview Hatchery population on Grandy Creek in the Skagit River Basin was established from Baker Lake sockeye salmon together with a probable mixture of Quinault Lake stock and an unknown Fraser River stock. This stock was the ultimate source for the apparently successful transplants of sockeye salmon to the Lake Washington/Lake Sammamish system in the mid-1930s to early 1940s (Royal and Seymour 1940, Kolb 1971).

Numerous reports indicate that residual or resident sockeye salmon began appearing in Baker Lake and Lake Shannon Reservoir following the installation of Lower Baker Dam in 1925 (Ward 1929, 1930, 1932; Ricker 1940; Kemmerich 1945). A spring-time recreational kokanee fishery exists in Baker Lake, although substantial aggregations of spawning kokanee have yet to be identified. We found no historical records of kokanee stocking in Baker Lake. However, approximately 40-100 kokanee-sized *O. nerka* spawn each year in the outlet channel that drains the two upper sockeye salmon spawning beaches at Baker Lake.

6) Lake Pleasant

A majority of the BRT concluded that Lake Pleasant sockeye salmon constituted a separate ESU, while a minority thought that insufficient information existed to make a decision as to its ESU status. Allozyme data for Lake Pleasant sockeye salmon indicate genetic distinctiveness from other sockeye salmon populations. Sockeye salmon in this population enter the Quillayute River from May through September and hold in the Sol Duc River before entering Lake Pleasant, usually in early November, when sufficient water depth is available in Lake Creek. Spawning occurs on beaches from late November to early January. Kemmerich (1945) indicated that native sockeye salmon occurred in Lake Pleasant prior to 1932 and that they were of an “individual size comparable with the size of the fish of the Lake Quinault and Columbia River populations”; however, sockeye salmon currently in Lake Pleasant are said to be small and no bigger than about 2 to 3 pounds (0.9 to 1.4 kg) (J. Haymes[56]). Adult male and female Lake Pleasant sockeye salmon have an average fork length of 460 mm or less for all ages combined, which is the smallest body size of any anadromous *O. nerka* population in the Pacific Northwest. In some years, a majority of Lake Pleasant sockeye salmon spend 2 years in freshwater prior to migrating to sea (Appendix Table C-1).

Over 0.5 million sockeye salmon fry from Baker Lake and the Birdsview Hatchery in the Skagit River Basin were released in Lake Pleasant in the 1930s; however, electrophoretic analysis of current Lake Pleasant sockeye salmon reveals little genetic affinity with Baker Lake sockeye salmon. It is assumed that poisoning of Lake Pleasant during “lake rehabilitation” activities in the 1950s and 1960s (see previous information section) may have impacted one or two broodyears of sockeye salmon in Lake Pleasant. Sockeye salmon escapement to Lake Pleasant was between about 760 and 1,500 fish in the early 1960s; indicating that “lake rehabilitation” failed to eliminate sockeye salmon from this system. Although kokanee-sized *O. nerka* spawn together with sockeye salmon on the beaches in

---

[56] J. Haymes, Quileute Natural Resources, Quileute Indian Tribe, P.O. Box 187, La Push, WA 98350-0187. Pers. commun., 12 May 1995.

Lake Pleasant, only anecdotal reference to kokanee being stocked in Lake Pleasant during the 1930s were found.

The BRT concluded that if “kokanee-sized” *O. nerka* observed spawning with sockeye salmon on sockeye salmon spawning beaches in Lake Pleasant are identified as resident sockeye salmon, then they are to be considered as part of the Lake Pleasant sockeye salmon ESU.

Sockeye Salmon of Provisional ESU Status

Big Bear Creek

The BRT was divided on the ESU status of sockeye salmon that currently spawn in Big Bear Creek and its two tributaries, Cottage Lake and Evans Creeks. Members did agree that the available evidence does not clearly resolve this issue. In spite of various uncertainties, about half of the BRT felt that the current sockeye salmon population in Big Bear and Cottage Lake Creeks is a separate ESU that represents either an indigenous Lake Washington/Lake Sammamish sockeye salmon population or a native kokanee population that has naturally re-established anadromy. About half the members felt that the available information was insufficient to determine the ESU status of sockeye salmon in Big Bear Creek. This issue is particularly difficult due to the equivocal nature of historical accounts concerning the presence and distribution of sockeye salmon within the Lake Washington/Lake Sammamish Basin.

Genetically, Big Bear and Cottage Lake Creek sockeye salmon are quite distinct from other stocks of sockeye salmon in the Lake Washington/Lake Sammamish Basin; they are genetically more similar to Okanogan River sockeye salmon than they are to any other sockeye salmon population examined. It was acknowledged that the genetic distinctiveness of the current Big Bear Creek/Cottage Lake Creek sockeye salmon as revealed through analysis of allozyme data could have resulted from genetic change (founder effect and/or subsequent genetic drift) following the recorded transplant of Baker Lake sockeye salmon in 1937 and observation of 2 adults in October 1940, or it could be indicative of a native population of *O. nerka* indigenous to the Lake Washington/Lake Sammamish Basin.

A native kokanee population once spawned in Big Bear Creek and its tributaries, although it is uncertain whether a remnant of this native stock still exists in this drainage. Big Bear Creek was once the largest producer of kokanee for artificial propagation in Washington, although relatively few kokanee currently spawn there. Currently a small number of kokanee-sized *O. nerka* spawn in Big Bear Creek together with sockeye salmon. The spawn timing of kokanee in Big Bear Creek is currently much later than the only remaining recognized native kokanee stock in the Lake Washington Basin (early entry Issaquah Creek kokanee). There were over 35 million Lake Whatcom kokanee fry released in Big Bear Creek between 1917 and 1969, and what effect this stocking program had on the native kokanee is open to speculation. In addition, potential genetic interactions of these introduced kokanee with sockeye salmon are unknown.

Sockeye Salmon of Uncertain ESU Status

Riverine-spawning sockeye salmon

Spawning ground survey data of the Washington Department of Fish and Wildlife and numerous anecdotal references dating back to the turn of the century indicate that riverine-spawning aggregations of sockeye salmon exist in certain rivers within Washington that lack lake-rearing habitat. Consistent riverine- spawning aggregations of sockeye salmon have been documented over a period of decades in the North and South Fork Nooksack, Skagit, Sauk, North Fork Stillaguamish, Samish (D. Hendrick[57]), and Green Rivers. Riverine-spawning sockeye salmon have also been reported in the Nisqually, Skokomish, Dungeness, Calawah, Hoh, Queets, and Clearwater Rivers, and are occasionally seen in small numbers in a number of other rivers and streams in Washington.

Protein electrophoretic data for riverine spawners from the Nooksack, upper Skagit, and Sauk Rivers indicate that these aggregations are genetically similar to one another and genetically distinct from other sockeye salmon in Washington. Genetic data of equal resolution (29 allozyme loci) for comparison with river/sea-type and lake-type sockeye salmon populations in the lower Fraser River are not available.

The BRT considered these hypotheses that might explain river-spawning aggregations of sockeye salmon in Washington: 1) they represent multiple U.S. populations, 2) they represent one U.S. population, 3) they represent strays from U.S. lake-type sockeye salmon, 4) they represent strays from British Columbia lake-type sockeye salmon, and 5) they represent strays from river-type populations in British Columbia. Genetic data for river spawning sockeye salmon in the Nooksack, Skagit, and Sauk Rivers do not support hypothesis 3. The disjunct timing and geographic distance between individual aggregations of riverine-spawning sockeye salmon suggest that more than one process may be responsible for the occurrence of these aggregations.

The small size of the spawning aggregations of sockeye salmon periodically reported in rivers without lake-rearing habitat in Washington raises the question of historic population size and persistence of Pacific salmon over evolutionarily significant time scales. Because many populations of Pacific salmon show large temporal fluctuations in abundance, Waples (1991a, p. 19) argued in the NMFS “Definition of Species” paper that

---

[57] D. Hendirck, Washington Department of Fish and Wildlife, 333 E. Blackburn Rd., Mount Vernon, WA 98273. Pers. commun., 8 August 1995.

> there must be some size below which a spawning population is unlikely to persist in isolation for a long period of time. The fact that small spawning aggregations are regularly observed may reflect a dynamic process of extinction, straying, and recolonization. Such small populations are unlikely to be ESU's, although a collection of them might be.

However, Waples (1991a, p. 19) went on to say that

> In making this evaluation, the possibility should be considered that small populations observed at present are still in existence precisely because they evolved mechanisms for persisting at low abundance.

The BRT acknowledged the evolutionary importance of existing river/sea-type sockeye salmon in British Columbia and Alaska but felt that the evidence was insufficient to determine whether sockeye salmon seen in rivers without lake-rearing habitat in Washington were distinct populations. The ESU status of riverine-spawning sockeye salmon in Washington remains an open question.

Deschutes River, Oregon

The BRT concluded that sockeye salmon that historically migrated up the Deschutes River via the Columbia River to spawn in Suttle Lake were a separate ESU, but it is uncertain whether remnants of this ESU exist. Fish passage into and out of Suttle Lake was blocked sometime around 1930. Currently, sockeye salmon adults that are consistently seen each year in the Deschutes River below the regulatory dam downstream from Pelton Dam may be derived from 1) a self-sustaining population of sockeye salmon that spawn below Pelton Dam on the Deschutes River, 2) strays from elsewhere in the Columbia River, or 3) outmigration of smolts from populations of "kokanee-sized" *O. nerka* that exist above the Pelton/Round Butte Dam complex. Two kokanee populations are present above the dams: one population resides in Suttle Lake and spawns in the lake inlet stream (Link Creek), and a second population resides in Lake Billy Chinook, behind Round Butte Dam, and spawns in the upper Metolius River. Both kokanee populations have a distinctive blue-black body coloration that distinguishes them from hatchery kokanee that are released in Lake Simtustus and other Deschutes River Basin hatcheries.

Allozyme data for Deschutes River sockeye salmon do not exist; however, mtDNA data (Brannon 1996), suggest the possibility that Lake Billy Chinook kokanee and Deschutes River sockeye salmon are related. Protein electrophoretic data indicate that kokanee in Suttle Lake and in Lake Billy Chinook cluster together genetically (unpublished data, NMFS, Northwest Fisheries Science Center, 2725 Montlake Blvd East, Seattle, WA 98112). Over 1.2 million sockeye salmon were planted in the Metolius River and its tributaries before 1962, and a significant portion of the adult sockeye salmon returns recorded at the Pelton Dam fish trap, starting in 1956, may have been descended from these plantings.

The majority of the BRT concluded that a remnant component of this historical population cannot be identified with any certainty. A minority of the BRT felt that the extensive transplant history of non-native sockeye salmon into this basin explains the continued occurrence of anadromous *O. nerka* in the Deschutes River Basin and, as the descendants of transplants, these sockeye salmon are not an ESA issue. It should be noted at this point that sockeye salmon continue to return to the base of reservoir dams on the Middle and South Santiam Rivers in Oregon, long after sockeye salmon fry were released into these reservoirs. Sockeye salmon that return to the Santiam River are the putative progeny of residualized sockeye salmon. The majority of the BRT agreed that the possibility exists that recent sockeye salmon in the Deschutes River may result from some remnant outmigrants of residualized sockeye salmon or kokanee. The ESU status of sockeye salmon returning to the Deschutes River remains an open question.

ASSESSMENT OF EXTINCTION RISK

Background

As outlined previously in the “Introduction,” NMFS considers a variety of information in evaluating the level of risk facing an ESU. Aspects of several of these risk considerations are common to all sockeye salmon ESUs. These are discussed in general below; more specific discussion of factors for each of the ESUs under consideration here can be found in the following sections. Because we have not taken future effects of conservation measures into account (see “Introduction”), we have drawn scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue. Future effects of conservation measures will be taken into account by the NMFS Northwest Regional Office in making listing recommendations.

Absolute Numbers

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

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

Because the ESA (and NMFS policy) mandates that we focus on viability of natural populations, in this review we attempted to distinguish natural fish from hatchery-produced fish. All statistics are based on data that indicate total numbers or density of adults that spawn in natural habitat (“naturally spawning fish”). The total of all naturally spawning fish (“total escapement”) is divided into two components (Fig. 14): “Hatchery produced” fish are reared as juveniles in a hatchery but return as adults to spawn naturally; “Natural” fish are progeny of naturally spawning fish.

Historical Abundance and Carrying Capacity

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

Although the relationship of present abundance to present carrying capacity is important for understanding the health of populations, the fact that a population is near its current capacity does not in itself mean that it is healthy. If a population is near capacity, there will be limits to the effectiveness of short-term management actions in increasing abundance, and competition and other interactions between hatchery and natural fish may be an important consideration because hatchery fish will further increase population density in a limited habitat.

All populations of sockeye salmon in this region have been affected by substantial loss and degradation of freshwater habitat, although the causes vary among populations. Much of the original sockeye salmon habitat in the Columbia River Basin has been blocked by irrigation diversions, hydroelectric development, and other human actions: accessible nursery lake habitat in the upper Columbia River is now only 4% (by surface area) of historical habitat, and only one remnant population remains in the Snake River (Mullan 1986, TAC 1991, Fryer 1995). This has resulted in widespread extinctions of populations that formerly occupied these areas. Coastal populations have also been affected by a variety of habitat factors, particularly hydroelectric development (Baker River) and forest management practices.

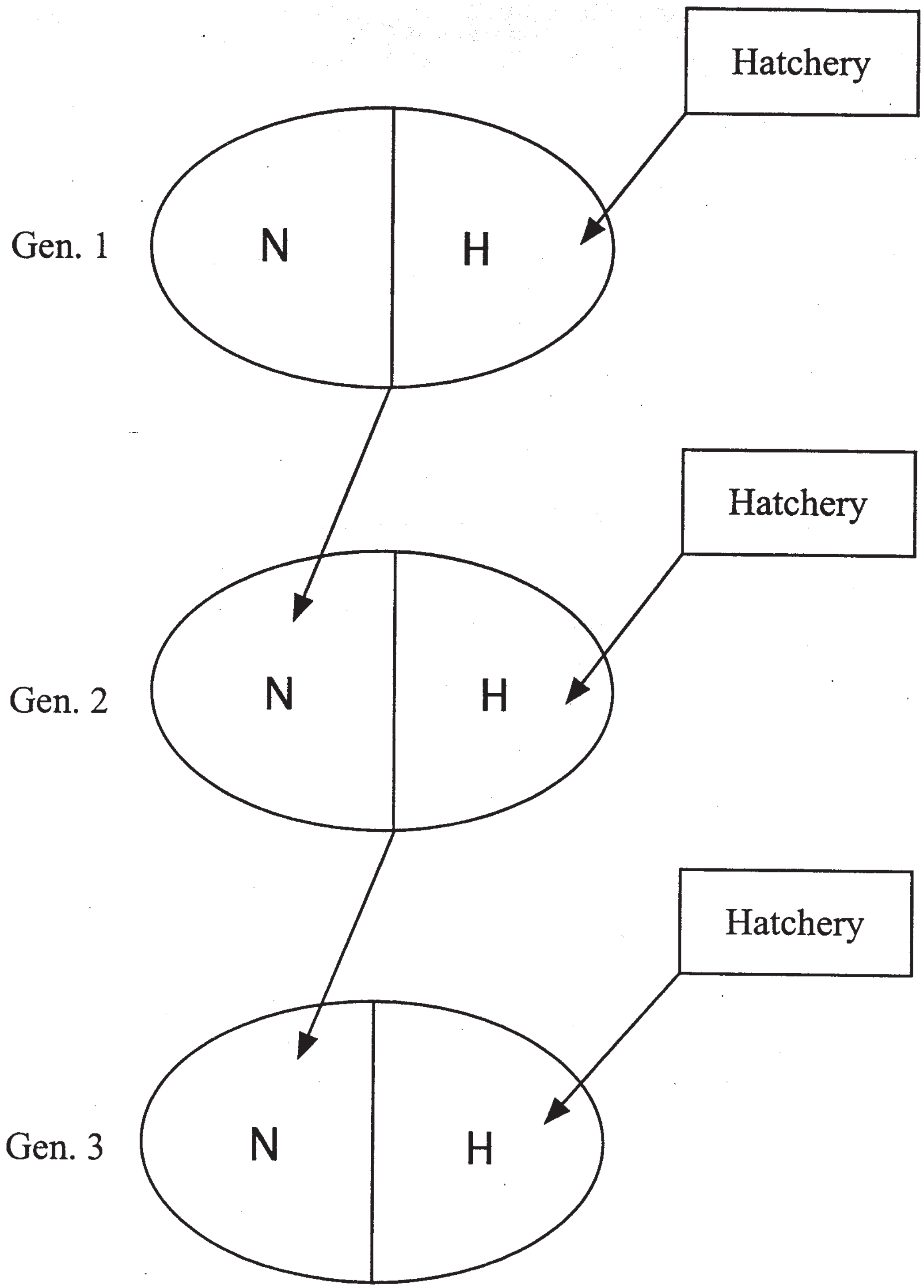


Figure 14. Schematic diagram of mixing of natural and hatchery-produced fish in natural habitat. Ovals represent the total spawning in natural habitat each generation. This total is comprised of natural (N) and hatchery-produced (H) offspring of individuals in the previous generation.

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 (see “Approach”).

The important role of artificial propagation (in the form of hatcheries) for Pacific salmon requires careful consideration in ESA evaluations. Artificial propagation has implications for evaluating both production trends and the genetic integrity of populations. Waples (1991a, b) and Hard et al. (1992) discussed the role of artificial propagation in ESU determination and emphasized the need to focus on natural production in the threatened or endangered status determination. A fundamental question in ESA risk assessments for mixed-production stocks is whether natural production is sufficient to maintain the population without the continued 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.

Long-term trends in abundance of sockeye salmon in the Pacific Northwest can only be approximated from historical records of commercial fishery landings (Fig. 15). However, these trends largely reflect the harvest of Fraser River sockeye salmon in British Columbia and Washington, and therefore do not provide a good indication of the status of ESUs we are considering here. To the extent that landings reflect population abundance, these records suggest fairly constant populations of sockeye salmon in this region except for large short-term fluctuations (discussed in the next section). Harvest was somewhat higher near the turn of the century than during 1920-1980, and increasing harvest in British Columbia since 1980 has restored harvest levels to near those of the early 1900s.

A major determinant of trends in salmon abundance is the condition of the freshwater, estuarine, and ocean habitats on which salmon depend. While we rarely have sufficient information to precisely predict the population-scale effects of habitat loss or degradation, it is clear that habitat availability imposes an upper limit on the production of salmon, and any reduction in habitat reduces potential production. Even in areas where we have no information on trends in population abundance, evidence of widespread loss of habitat can indicate a serious risk for sustainability of natural populations.

The National Research Council Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (NRCC 1996) identified habitat problems as a primary cause of declines in wild salmon runs. NMFS (1996) identified habitat concerns as one of a suite of factors affecting the decline of salmon within the range of west coast steelhead. Some of the habitat impacts identified were: 1) the fragmentation and loss of available spawning and rearing habitat; 2) alteration of stream flows and stream-bank and channel morphology; 3) migration delays; 4) degradation of water quality; 5) alteration of ambient stream water temperatures; 6) sedimentation; 7) loss of spawning gravels, pool habitat and large woody debris; 8) removal of riparian vegetation; and 9) decline of habitat complexity.

The Pacific Fishery Management Council (PFMC 1995) also identified loss of habitat as one of the main reasons for declines in salmon stocks and identified fourteen “vital habitat concerns.” Their concerns relative to sockeye salmon are Columbia-Snake River hydropower operations, instream flow, unscreened or inadequately screened water diversions, inadequate fish passage at road culverts, water spreading (unauthorized use of federally-developed water supplies), upland land-use practices and polluted runoff, fish passage at existing hydroelectric projects, agricultural practices, urban growth and land conversion, contaminants in coastal wetlands and estuaries, offshore oil and gas development and transportation, and dredge spoil disposal.

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

Factors Causing Variability

Abundance of sockeye salmon populations tends to fluctuate around a general level, either displaying predictable cyclic fluctuations or unexpected upward or downward changes (Burgner 1991). In some populations, a large part of this variability is attributable to the phenomenon of brood-cycle dominance, which is the tendency of single year-classes to consistently dominate abundance trends in populations that return to spawn largely at a single age (Ricker 1950, Ward and Larkin 1964, Eggers and Rogers 1987). This phenomenon was seen in the 1901-brood cycle of sockeye salmon in the Fraser River in the early 1900s (Fig. 15), which clearly displayed dominance. This pattern in the overall Fraser River run was disrupted by the Hells Gate slide, but is still apparent in the abundance trends of individual Fraser River stocks. Ricker (1997) reviewed cycles in Fraser River sockeye salmon, and suggested that interactions among dominant and other brood lines are the most plausible cause of the cycles. Brood-cycle dominance is less evident in the U.S. populations we are considering here, possibly because spawning age-structure is more variable in most of these populations or because relative abundance has not been high enough to establish the pattern. Where it occurs, however, cyclic dominance could be a major influence in abundance analysis and recovery planning.

Variations in the freshwater and marine environments are also thought to be a primary factor driving fluctuations in salmonid run size and escapement (Pearcy 1992, Beamish and

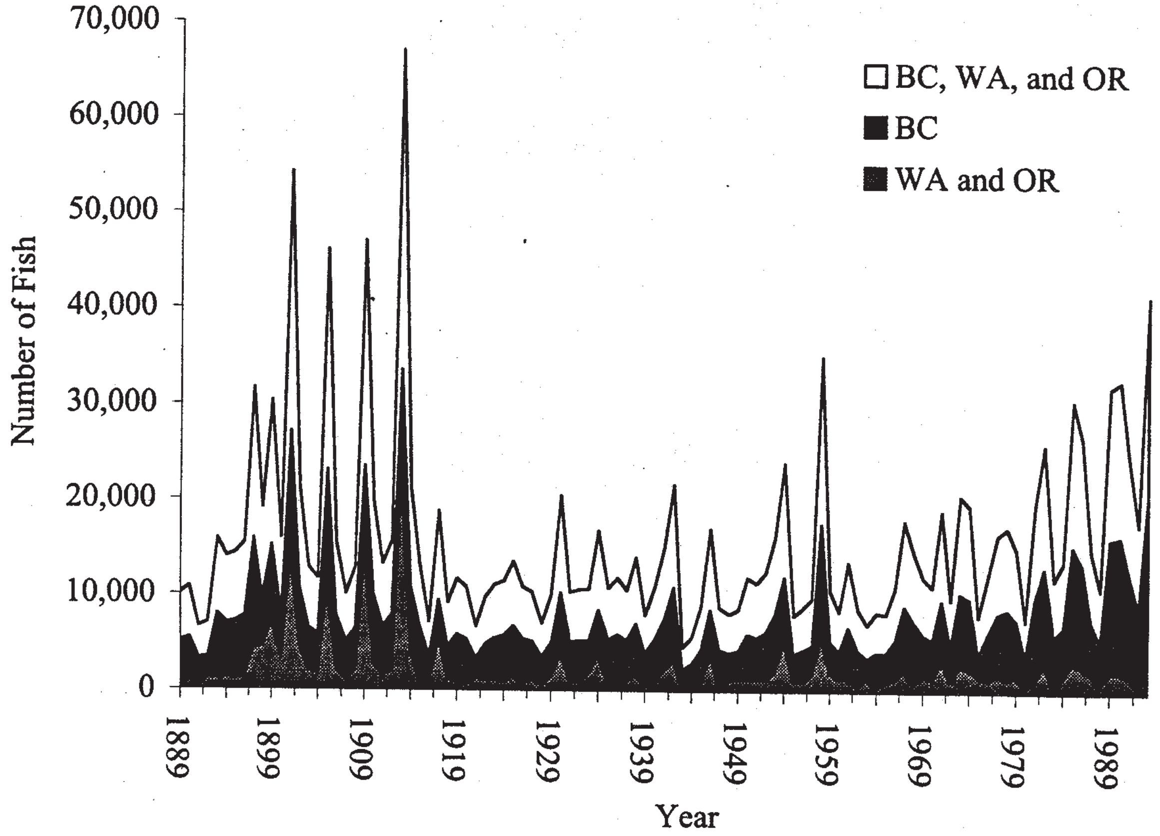


Figure 15. Historical sockeye salmon catch (thousands of fish) for Washington and Oregon (combined, "WA and OR") and British Columbia ("BC"), 1890-1993. Data for 1873-1980 from Shepard et al. (1985); for 1981-1993 from Foy et al. (1995a). The upper curve represents total catch in BC, OR, and WA.

Bouillon 1993, Lawson 1993). Recent changes in ocean conditions are an additional factor and are discussed in the "Recent Events" section. Habitat degradation and harvest have probably made stocks less resilient to poor climate conditions, but these effects are not easily quantifiable.

Threats to Genetic Integrity

In addition to being a factor in evaluating natural replacement rates, artificial propagation can have a substantial impact on genetic 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 loss of fitness in local populations and loss of diversity among populations. The latter is important to 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 (Riggs 1990, Fagen and Smoker 1989). Ricker (1972) and Taylor (1991) summarized some of the evidence for local adaptations in Pacific salmonids that may be affected by stock transfers.

Second, because a successful salmon 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 1991b). These changes are unlikely to be beneficial to naturally reproducing fish.

Third, even if naturally spawning hatchery fish leave few or no surviving offspring, they still can have ecological and indirect genetic effects on natural populations. On the spawning grounds, hatchery fish may interfere with natural production by competing with natural fish for territory and/or mates. If they successfully spawn with natural fish, they may divert production from more productive natural x natural crosses. The presence of large numbers of hatchery juveniles or adults may also alter the selective regime faced by natural fish.

Not all of these concerns will apply to every hatchery population, and the seriousness of the concerns that do apply can vary considerably among different programs. For example, although stock transfers are a major issue for some hatchery programs, many others have exclusively used local broodstock. Some hatchery programs have also taken a number of measures (e.g., in broodstock collection, spawning, rearing, and release protocols) to minimize adverse effects on natural populations. Therefore, threats posed by hatchery programs should be evaluated on a case-by-case basis whenever available data allow such an evaluation. It should be recognized, however, that some changes associated with fish culture cannot be avoided, and some risks are also inescapable because they involve a trade-off with other risks. For example, changing the hatchery environment to more closely mimic selective regimes faced in the wild can reduce opportunities for domestication, but there is a limit to how far this process can go without sacrificing the early life history survival advantage that is the primary benefit of a salmon hatchery. Similarly, although releasing hatchery fish as smolts reduces opportunities for ecological interactions with natural fish, it also increases opportunities for genetic change associated with fish culture compared to releases at an earlier life history stage.

For smaller salmon stocks (either natural or hatchery), small-population effects (inbreeding, genetic drift) can also be important concerns for genetic integrity. Inbreeding 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 with anadromous Pacific salmonids have the potential to affect genetic integrity. However, we have not found empirical evidence for inbreeding depression or loss of genetic variability in any natural or hatchery populations of Pacific salmon.

Recent Events

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

For example, climate conditions are known to have changed recently in the Pacific Northwest, and Pacific salmon stocks south of British Columbia have been affected by changes in ocean production that occurred during the 1970s (Pearcy 1992, Lawson 1993). There is mounting evidence that salmon populations are influenced by decadal-scale shifts in climate patterns; such effects were discussed at a recent workshop sponsored by NMFS and Oregon State University (Emmett and Schiewe 1997). Beamish et al. (1997) have related production of Fraser River sockeye salmon to decadal-scale shifts in ocean productivity. Much of the Pacific coast has also been experiencing drought conditions in recent years, which may depress freshwater production. However, at this time we do not know whether these climate conditions represent a long-term change that will continue to affect stocks in the future or whether these changes are short-term environmental fluctuations that can be expected to be reversed in the near future.

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.

Approach

Previous Assessments

In considering the status of the ESUs, we evaluated both qualitative and quantitative information. Qualitative evaluations included aspects of several of the risk considerations outlined above, as well as recent published assessments of population status by agencies or conservation groups of the status of west coast sockeye salmon stocks (Nehlsen et al. 1991, WDF et al. 1993). Nehlsen et al. (1991) considered salmonid stocks throughout Washington, Idaho, Oregon, and California and enumerated all stocks that they found to be extinct or at risk of extinction. Stocks that do not appear in their summary were either not at risk of extinction or were not classifiable due to insufficient information. They classified stocks as extinct, possibly extinct, at high risk of extinction, at moderate risk of extinction, or of special concern. They considered it likely that stocks at high risk of extinction have reached the threshold for classification as endangered under the ESA. Stocks were placed in this category if they had declined from historic levels and were continuing to decline, or had spawning escapements less than 200. Stocks were classified as at moderate risk of extinction if they had declined from historic levels but presently appear to be stable at a level above 200 spawners. They felt that stocks in this category had reached the threshold for threatened under the ESA. They classified stocks as of special concern if a relatively minor disturbance could threaten them, insufficient data were available for them, they were influenced by large releases of hatchery fish, or they possessed some unique character. For sockeye salmon, they classified 22 stocks as follows: 16 extinct, 1 possibly extinct, 2 high risk, 1 moderate risk, and 2 special concern (Table 4).

WDF et al. (1993) categorized all salmon and steelhead stocks in Washington on the basis of stock origin (“native,” “non-native,” “mixed,” or “unknown”), production type (“wild,” “composite,” or “unknown”) and status (“healthy,” “depressed,” “critical,” or “unknown”). Status categories were defined as follows: healthy, “experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock”; depressed, “production is below expected levels . . . but above the level where permanent damage to the stock is likely”; and critical, “experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred.” Of the nine sockeye salmon stocks identified, three (Quinault, Wenatchee, and Okanogan) were classified as healthy, four (Cedar, Lake Washington/Sammamish Tributaries, Lake Washington Beach, and Ozette) as depressed, one (Baker) as critical, and one (Lake Pleasant) as unknown.

Table 4. Sockeye salmon stock evaluations by Nehlsen et al. (1991).

Category	**Stock name**
Extinct	Payette River, ID Metolius River, OR Wallowa River, OR Yakima River, WA Skaha Lake, BC Okanagan Lake, BC Alturas Lake, ID Pettit Lake, ID Stanley Lake, ID Yellowbelly Lake, ID Upper Arrow Lake, BC Lower Arrow Lake, BC Whatshan Lake, BC Slocan Lake, BC
Possibly Extinct	Redfish Lake, ID
High Risk of Extinction	Deschutes River, OR Baker River, WA
Moderate Risk of Extinction	Ozette Lake, WA
Special Concern	Okanogan River, WA Wenatchee River, WA

There are problems in applying results of these studies to ESA evaluations. One problem is the definition of categories used to classify stock status. Nehlsen et al. (1991) used categories intended to relate to ESA "threatened" or "endangered" status; however they applied their own interpretations of these terms to individual stocks, not to ESUs as defined here. WDF et al. (1993) used general terms describing status of stocks that cannot be directly related to the considerations important in ESA evaluations. For example, the WDF et al. (1993) definition of healthy could conceivably include a stock that is at substantial extinction risk due to loss of habitat, hatchery fish interactions, and/or environmental variation, although this does not appear to be the case for any west coast sockeye salmon stocks. Another problem is the selection of stocks or populations to include in the review. Nehlsen et al. (1991) did not evaluate (or even identify) stocks not perceived to be at risk, so it is difficult to determine the proportion of stocks they considered to be at risk in any given area. There is also disagreement regarding status of some stocks; for example, IDFG (1996) disagrees with the classification of Alturas and Stanley Lakes' populations as extinct by Nehlsen et al. (1991).

Data Evaluations

Quantitative evaluations of data included comparisons of current and historical abundance of west coast sockeye salmon, calculation of recent trends in escapement, and evaluation of the proportion of natural spawning attributable to hatchery fish. Historical abundance information for these ESUs is largely anecdotal, although estimates based on commercial harvest are available for some coastal populations (Rounsefell and Kelez 1938).

Time series data were available for many populations, but data extent and quality varied among ESUs. We compiled and analyzed this information to provide several summary statistics of natural spawning abundance, including (where available) recent total spawning run-size and escapement, percent annual change in total escapement, recent naturally produced spawning run-size and escapement, and average percentage of natural spawners that were of hatchery origin. Information on harvest and stock abundance was compiled from a variety of state, federal, and tribal agency records (Foy et al. 1995a, b). Additional data were provided directly to us by state and tribal agencies and private organizations. We believe these records to be complete in terms of long-term adult abundance for sockeye salmon in the region covered. Principal data sources were adult counts at dams or weirs and spawner surveys.

Computed statistics

To represent current run size or escapement where recent data were available, we have computed the geometric mean of the most recent 5 years reported (or fewer years if the data series is shorter than 5 years). We tried to use only estimates that reflect the total abundance for an entire river basin or tributary, avoiding index counts or dam counts that represent only a small portion of available habitat.

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 7 years of data, based on total escapement or an escapement index (such as fish per mile from a stream survey). Separate trends were estimated for each full data series and for the 1985-1994 period within each data series. As an indication of overall trend in individual sockeye salmon populations, we calculated average (over the available data series) percent 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 zero ($P<0.05$) were noted. The regressions provided direct estimates of mean instantaneous rates of population change (a); these values were subsequently converted to percent 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 include any supplementation effect of hatchery fish.

These computed statistics, along with published estimates of historical abundance and results of previous status assessments, are summarized in Appendix Table E-1 for all stocks examined in this review.

Analysis of Biological Information by ESU

1) Okanogan River

The major abundance data series for Okanogan River sockeye salmon consists of spawner surveys conducted in the Okanogan River above Lake Osoyoos since the late 1940s, counts of adults passing Wells Dam since 1967, and records of tribal harvest (Colville and Okanogan) since the late 1940s. Longer-term data were available for dams lower on the Columbia River (notably Rock Island Dam counts starting in 1933), but these counts represent a combination of this ESU with the Wenatchee populations and other historical ESUs from the upper Columbia River above Grand Coulee Dam.

Blockage and disruption of freshwater habitat pose some risk for this ESU. Adult passage is blocked by dams above Lake Osoyoos, prohibiting access to former habitat in Vaseux, Skaha, and Okanagan Lakes (Chapman et al. 1995). (However, it is not known whether sockeye salmon in these upper lakes belonged to the same ESU as those in Lake Osoyoos.) Other problems in the Okanogan River include inadequately screened water diversions and high summer water temperatures (Chapman et al. 1995), and channelization of spawning habitat in Canada. Mullan (1986) stated that hydroelectric dams accounted for the general decline of sockeye salmon in the mainstem Columbia River, while Chapman et al. (1995) suggested that hydropower dams have “probably” reduced runs of sockeye salmon to the Columbia River, particularly to Lake Osoyoos.

The most recent 5-year average annual escapement for this ESU was about 11,000 adults, based on 1992-1996 counts at Wells Dam (see Appendix Table E-1). No historic abundance estimates specific to this ESU are available. However, analyses conducted in the late 1930s indicated that less than 15% of the total sockeye run in the upper Columbia River went into Lakes Osoyoos and Wenatchee (Chapman et al. 1995). At that time, the total run to Rock Island Dam averaged about 15,000, suggesting a combined total of less than 2,250 adults returning to the Okanogan River and Lake Wenatchee ESUs. Thus, abundance for the Okanogan River ESU during the late 1930s was clearly substantially lower than recent abundance. Trend estimates for this stock differ depending on the data series used (see Appendix Table E-1), but the recent (1986-1995) trend has been steeply downward (declining at 2-20% per year); however, this trend is heavily influenced by high abundance in 1985 and low points in 1990, 1994, and 1995, which may reflect environmental fluctuations (Fig. 17). The long-term trend (since 1960) for this stock has been relatively flat (-3% to +2% annual change).

For the entire Columbia River basin, there has been a considerable decline in sockeye salmon abundance since the turn of the century. Columbia River commercial sockeye salmon landings that commonly exceeded 1,000,000 pounds in the late 1800s and early 1900s had been reduced to about 150,000 pounds by the late 1980s (TAC 1991). Since 1988, harvest has been fewer than 3,500 fish each year. The TAC (1991) attributes this decline to habitat degradation and blockage, overharvest, hydroelectric development, and nursery lake management practices. The two remaining productive stocks (Okanogan and Wenatchee) occupy less than 4% of historic nursery lake habitat in the upper Columbia River basin.

Both Okanogan and Wenatchee runs have been highly variable over time. For harvest purposes, these two ESUs are managed as a single unit, with an escapement goal of 65,000 adults returning to Priest Rapids Dam (TAC 1991). This goal has been achieved only ten times since 1970, and has been met in 2 of the last 5 years. Examination of the historical trend in total sockeye salmon escapement to the upper Columbia River (Fig. 16) shows very low abundance (averaging less than 20,000 annually) during the 1930s and early 1940s, followed by an increase to well over 100,000 per year in the mid-1950s. Since the mid-1940s, abundance has fluctuated widely, with noticeable low points reached in 1949, 1961-62, 1978, and 1994. The escapement of about 9,000 fish to Priest Rapids Dam in 1995 was the lowest since 1945, but 1996 escapement (preliminary estimate, Fish Passage Center 1996) was considerably higher, although still far below the goal. Escapement to Wells Dam (i.e., this ESU) was at its lowest recorded value in 1994, but increased in both 1995 and 1996.

Past and present artificial propagation of sockeye salmon poses some risk to the genetic integrity of this ESU. The GCFMP (discussed in the “Artificial Propagation” section above) interbred fish from this ESU with those from adjacent basins for several years, with unknown impacts on the genetic composition of this ESU. Current artificial propagation efforts use local stocks and are designed to maintain genetic diversity, but there is some risk of genetic change resulting from domestication. There is only one record of introduction of sockeye salmon from outside the Columbia River Basin into this ESU: 395,420 mixed Quinault Lake/Rock Island Dam stock released in 1942 (Mullan 1986) (see Appendix Table D-2). Records of kokanee transplants are most likely incomplete (see Appendix Table D-5).

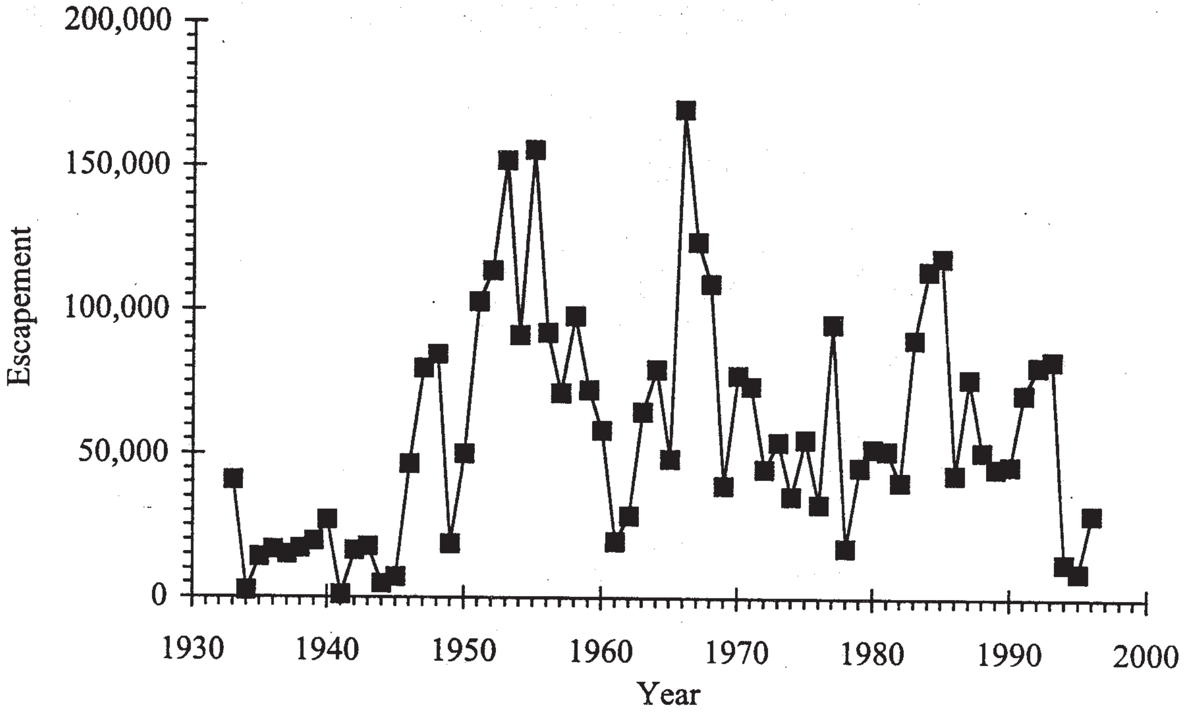


Figure 16. Sockeye salmon escapement past Rock Island Dam (1933-1960) and Priest Rapids Dam (1961-present). Data from CIS database (O'Conner et al. 1993), Chapman et al. (1995) and Fish Passage Center (1996).

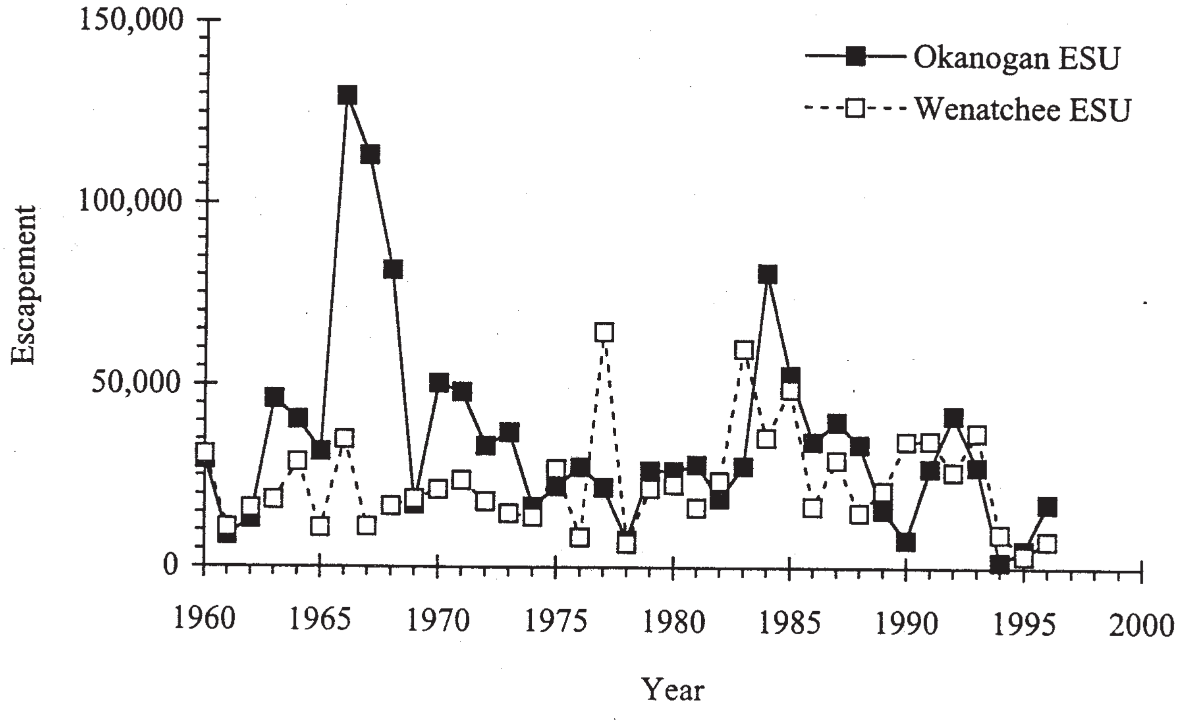


Figure 17. Estimated sockeye salmon escapement to the Okanogan River and Lake Wenatchee. Based on dam counts (TAC 1994, Fish Passage Center 1996).

In previous assessments of this stock, Nehlsen et al. (1991) considered Okanogan River sockeye salmon to be of special concern because of “present or threatened destruction, modification, or curtailment of its habitat or range,” including mainstem passage, flow, and predation problems. While WDF et al. (1993) classified this stock as of native origin, wild production, and healthy status they also suggested that this “native” classification will be changed to “mixed” in the future (WDFW 1996).

2) Lake Wenatchee

The major abundance data series for Wenatchee River sockeye salmon consists of spawner surveys conducted in the Little Wenatchee River and the White River since the late 1940s, counts of adults passing Tumwater Dam (sporadic counts 1935 to present), and reconstructions based on adult passage counts at Priest Rapids, Rock Island, and Rocky Reach Dams (early 1960s to present). Longer-term data are available for dams lower on the Columbia River (notably Rock Island Dam counts starting in 1933), but these counts represent a combination of this ESU with the Okanogan River ESU and other historic potential ESUs from the upper Columbia River above Grand Coulee Dam.

There are no substantial blockages of sockeye salmon habitat in the Wenatchee basin, and habitat condition in the basin is generally regarded as good, although production is limited by the oligotrophic nature of Lake Wenatchee (Chapman et al. 1995). Mullan (1986) and Chapman et al. (1995) concluded that the main freshwater-habitat problem presently facing this ESU is hydropower dams in the mainstem Columbia River, which have probably reduced runs of sockeye salmon.

The most recent 5-year average annual escapement for this ESU was about 19,000 adults, based on the 1992-1996 difference in adult passage counts at Priest Rapids and Rocky Reach Dams (see Appendix Table E-1). No historic abundance estimates specific to this ESU are available. However, as discussed above for the Okanogan River ESU, abundance of the Lake Wenatchee ESU during the late 1930s was clearly substantially lower than recent abundance. The recent (1986-1995) trend in abundance has been downward (declining at 10% per year), but this trend was heavily influenced by 2 years of very low abundance in 1994 and 1995 (Fig. 17). The long-term (1961-1996) trend for this stock is flat. Escapement to this ESU in 1995 (counts at Priest Rapids Dam minus those at Rocky Reach Dam) was the lowest since counting began in 1962, but 1996 escapement was somewhat higher (Fig. 17). Other risk factors common to this ESU and other Columbia River Basin sockeye salmon populations were discussed under the Okanogan River ESU above.

Past and present artificial propagation of sockeye salmon poses some risk to the genetic integrity of this ESU. As for the Okanogan River ESU, the GCFMP interbred fish from this ESU with those from adjacent basins for several years and introduced many sockeye salmon descended from Quinault Lake stock (Mullan 1986) (Appendix D-2), with unknown impacts on the genetic composition of this ESU. Current artificial propagation efforts use local stocks and are designed to maintain natural genetic diversity, but there is some risk of genetic change resulting from domestication. Hatchery-raised kokanee have been released in Lake Wenatchee, including native Lake Wenatchee stock and nonnative Lake Whatcom stock (Mullan 1986) (see Appendix Table D-5). The effect of Lake Whatcom kokanee introductions on the genetic integrity of this ESU is unknown.

Previous assessments of this ESU are similar to those for the Okanogan River ESU. Nehlsen et al. (1991) considered Wenatchee River sockeye salmon to be of special concern because of "present or threatened destruction, modification, or curtailment of its habitat or range," including mainstem passage, flow, and predation problems. WDF et al. (1993) classified this stock as of mixed origin, wild production, and healthy status. Huntington et al. (1996) identified this stock as "healthy–Level I," indicating that current abundance is high relative to what would be expected without human impacts.

3) Quinault Lake

The major abundance data series for Quinault River sockeye salmon consists of escapement estimates derived from hydroacoustic surveys conducted in Quinault Lake since the mid-1970s, supplemented with earlier estimates (beginning in 1967) based on spawner surveys. The most recent (1991-1995) 5-year average annual escapement for this ESU was about 32,000 adults, with a run-size of about 39,000 (see Appendix Table E-1 and Fig. 18). Approximate historical estimates indicate escapements ranging between 20,000 and 250,000 in the early 1920s, and run sizes ranging between 50,000 and 500,000 in the early 1900s (Rounsefell and Kelez 1938). Comparison of these estimates indicates that recent abundance is probably near the lower end of the historical abundance range for this ESU.

This ESU has been substantially affected by habitat problems, notably those resulting from forest management activities in the upper watershed outside Olympic National Park. Early inhabitants of the area described the upper Quinault River as flowing between narrow, heavily-wooded banks, but by the 1920s the river was in a wide valley with frequent course changes and much siltation and scouring of gravels during winter and spring freshets (Davidson and Barnaby 1936, QIN 1981); resultant loss of spawning habitat in the Quinault River above Quinault Lake has continued to recent times (QIN 1981).

While stock abundance has fluctuated considerably over time (recent escapements ranging from a low of 7,500 in 1970 to 69,000 in 1968), the overall trend has been relatively flat. For the full data series (1967-1995), abundance has increased by an average of about 1% per year; for the 1986-1995 period, abundance declined by about 3% per year.

Artificial propagation of sockeye salmon in the Quinault River basin has a long history (see "Artificial propagation" section above). Releases have been primarily native Quinault Lake stock, although Alaskan sockeye salmon eggs were brought into the system prior to 1920 (see Appendix Tables D-1 and D-2). Genetic effects of this introduction are unknown. Since 1973, all releases have been of local stock, but there is some risk of genetic change resulting from unnatural selective pressures.

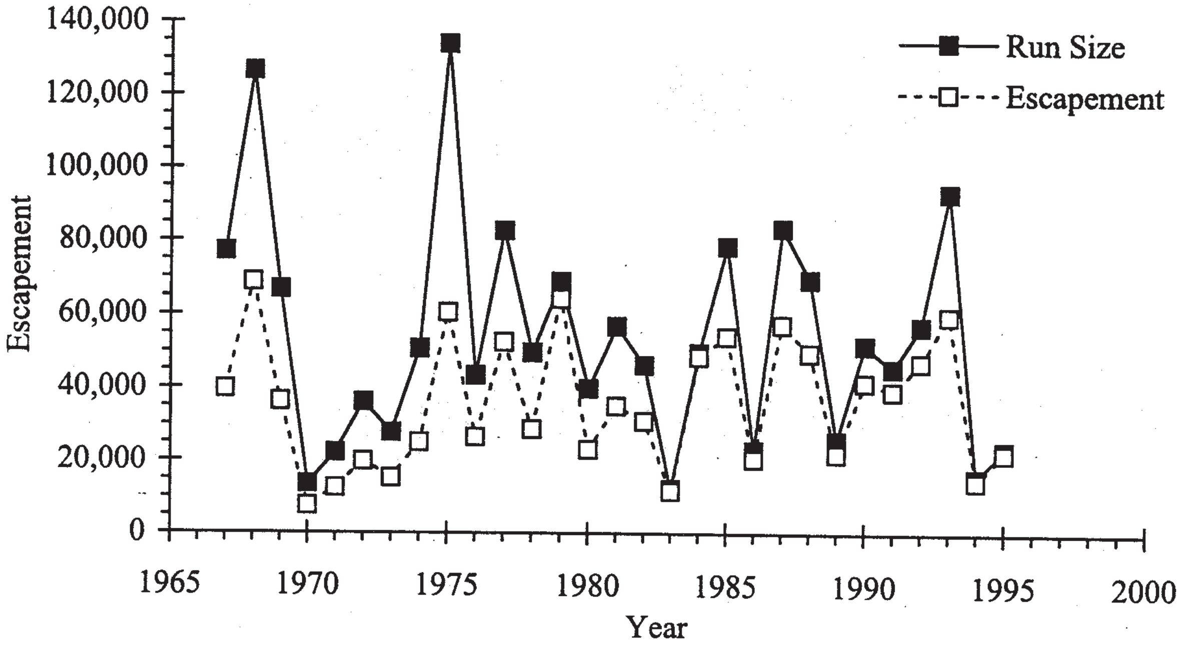


Figure 18. Estimated sockeye salmon run size and escapement to the Quinault River, based on spawner counts prior to the mid-1970s and hydroacoustic surveys in Quinault Lake afterwards. Data from WDF et al. (1993), QIN (1995c) and D. Boyer (Pers. commun., Quinault Fisheries Division, P.O. Box 189, Taholah, WA 98587, October 1996).

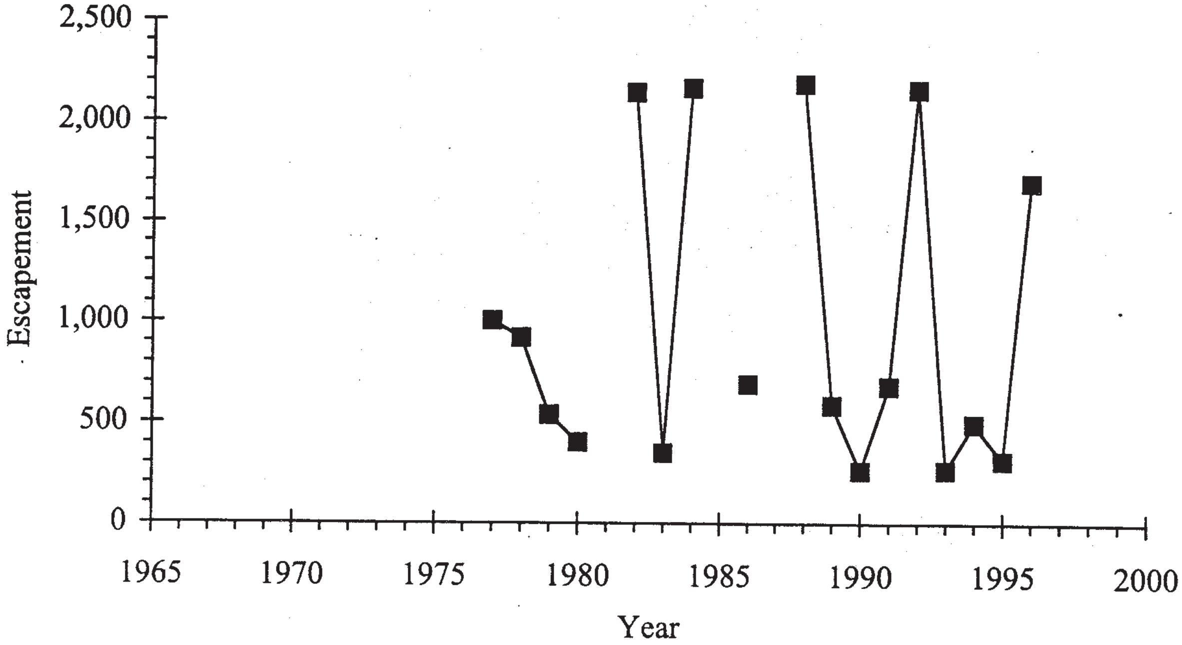


Figure 19. Estimated sockeye salmon escapement to the Ozette River, based on weir counts. Data from WDF et al. (1993), E. Currence (Pers. commun. October 1995), and D. Dailey (Pers. commun., Makah Fisheries Management, Makah Tribe, P.O. Box 115, Neah Bay, WA 98357, October 1996).

In previous assessments, Nehlsen et al. (1991) did not identify Quinault Lake sockeye salmon as at risk, and WDF et al. (1993) classified this stock as of native origin, wild production, and healthy status.

4) Ozette Lake

The major abundance data series for Ozette River sockeye salmon consists of escapement estimates derived from counts at a weir located at the outlet of Ozette Lake. Counting has occurred in most years since 1977 (Dlugokenski et al. 1981, WDF et al. 1993). The most recent (1992-1996) 5-year average annual escapement for this ESU was about 700 adults (see Appendix Table E-1). Historical estimates indicate run sizes of a few thousand sockeye salmon in 1926 (Rounsefell and Kelez 1938), with a peak recorded harvest of nearly 18,000 in 1949 (WDF 1974). Subsequently, commercial harvest declined steeply to only a few hundred fish in the mid-1960s and was ended in 1974. A small ceremonial and subsistence fishery continued until 1981 (Dlugokenski et al. 1981); there has been no direct fishery on this stock since 1982 (WDF et al. 1993). Assuming that Ozette River harvest consisted of sockeye salmon destined to spawn in this system, comparison of these estimates indicates that recent abundance is substantially below the historical abundance range for this ESU.

Three studies have been undertaken to evaluate habitat-related factors limiting production of sockeye salmon in Ozette Lake. The U.S. Fish and Wildlife Service conducted studies of the decline in this stock during the 1970s, culminating in a report describing limiting factors and outlining a restoration plan (Dlugokenski et al. 1981). This report noted that this population formerly spawned in tributaries but presently only uses the lakeshore, and that food supply, competition, and predation in the lake are probably not limiting, but that siltation has caused cementing of spawning gravels in tributaries. Dlugokenski et al. (1981) suspected that sedimentation, resulting primarily from logging and associated road building, coupled with log truck traffic on weak siltstone roadbeds, have led to decreased hatching success of sockeye salmon in tributary creeks and creek outwash fans in Ozette Lake. The authors concluded that “a combination of overfishing and habitat degradation have reduced the sockeye population to its current level of less than 1,000 fish” (p. 43).

More recently, Blum (1988) conducted an assessment of the same problems and concluded that “the absence of tributary spawners is the paramount problem explaining why sockeye runs have not increased following the cessation of terminal-area fishing in 1973.” He cited three main problems related to road-building and logging that limit spawning habitat: increased magnitude and frequency of peak flows, stream-bed scouring, and degraded water quality. He also noted that “the logging of the watershed was so extensive that stream spawning and rearing conditions are still questionable, despite having 35 years to recover” (p. 1). Finally, Beauchamp et al. (1995) examined patterns of prey, predator, and competitor abundance in Ozette Lake as potential limiting factors for juvenile production of sockeye salmon and kokanee. They concluded that competition is unlikely to limit production but that predation could be a limiting factor; however, data on piscivore abundance were lacking, so the authors could not evaluate predation impact accurately.

A recent National Park Service Technical Report (Jacobs et al. 1996) reported the conclusions of a review panel concerning the status and management of sockeye salmon in Ozette Lake. The panel was unanimous in expressing great concern about the future of this population, but was unable to identify a single set of factors contributing to the population decline. The panel concluded that declines were likely the result of a combination of factors, possibly including introduced species, predation, loss of tributary populations, decline in quality of beach-spawning habitat, temporarily unfavorable oceanic conditions, excessive historical harvests, and introduced diseases. They felt that intra- and inter-specific competition was unlikely as a contributing factor.

Harvest of sockeye salmon in the Ozette River fluctuated considerably over time (Fig. 19), which would indicate similar fluctuations in spawner abundance if harvest rates were fairly constant. Based on the full weir-count series (1977-1995), abundance has decreased by an average of about 3% per year; for the 1986-1995 period the decrease averaged 10% per year. However, in recent years the stock has exhibited dominance by a single brood cycle returning every 4 years (1984, 1988, 1992, 1996), and this dominant cycle has remained stable at between 1,700 and 2,200 adults; declines are apparent only in the smaller returns during off-cycle years (Fig. 19).

Artificial propagation has not been extensive in this basin, but many of the releases have been non-indigenous stocks (see “Artificial Propagation” section). Genetic effects of these introductions are unknown. Recent hatchery production in Ozette Lake has been primarily from local stock, with the exception of 120,000 Quinault Lake sockeye salmon juveniles released in 1983. The release of 14,398 kokanee/sockeye salmon hybrids in 1991-1992 (MFMD 1995, NRC 1995) may have had deleterious effects on genetic integrity of the ESU because Ozette Lake kokanee are genetically dissimilar to Ozette Lake sockeye salmon (see above “Genetics” section).

In previous assessments, Nehlsen et al. (1991) identified Ozette sockeye salmon as at moderate risk of extinction, citing logging and overfishing in the 1940s and 1950s as major causes of the decline. WDF et al. (1993) classified this stock as of native origin, wild production, and depressed status.

5) Baker River

The major abundance data series for Baker River sockeye salmon consists of escapement estimates derived from counts of adults arriving at a trap below Lower Baker Dam beginning in 1926 (Fig. 20). The most recent 5-year average annual escapement for this ESU was about 2,700 adults (see Appendix Table E-1). Historical estimates indicate escapements averaging 20,000 near the turn of the century, with a pre-dam low of 5,000 in 1916 (Rounsefell and Kelez 1938), although WDFW data suggest that the 20,000 figure is a

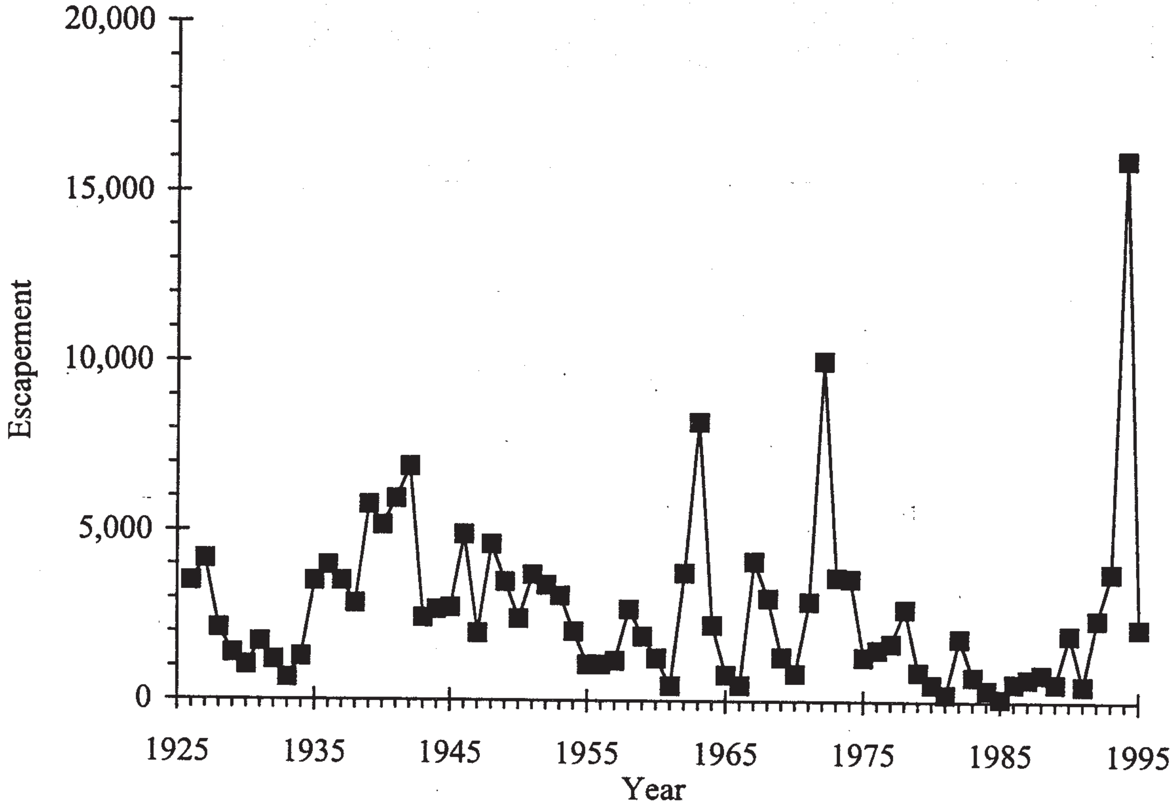


Figure 20. Estimated sockeye salmon escapement to the Baker River, based on trap counts. Data from CIS database (O'Connor et al. 1993), WDF et al. 1993, and J. Ames (Pers. commun., WDFW, 600 Capitol Way N., Olympia, WA 98501-1091, March 1995 and October 1996).

peak value, not an average (Sprague 1996a). Comparison of these estimates indicates that recent average abundance is probably near the lower end of the historical abundance range for this ESU, although escapement in 1994 (16,000 fish) was near the turn-of-the-century average.

Currently, spawning is restricted to artificial spawning "beaches" at the upper end of Baker Lake (in operation since 1957) and just below Upper Baker Dam (beach constructed in 1990). Spawning on the beaches is natural, and fry are released to rear in Baker Lake. Before 1925, sockeye salmon had free access to Baker Lake and its tributaries. Lower Baker Dam (constructed 1925) blocked access to this area, but passage structures were provided. Upper Baker Dam was completed in 1959 and increased the size of Baker Lake, inundating most natural spawning habitat; this was mitigated by construction of artificial spawning beaches. In most years, all returning adults are trapped below Lower Baker Dam and transported to the artificial beaches, with no spawning occurring in natural habitat (WDF et al. 1993). The only recent exception to this was in 1994, when the large number of returning adults exceeded artificial habitat capacity, and excess spawners were allowed to enter Baker Lake and its tributaries (J. Ames[58]). At the time of this report, no quantitative reports regarding offspring resulting from this spawning "experiment" are available (WDFW 1996).

The artificial nature of spawning habitat, use of net-pens for juvenile rearing, and reliance on artificial upstream and downstream transportation poses a certain degree of risk to the ESU. These human interventions in the life-cycle have undoubtedly changed selective pressures on the population from those under which it evolved its presumably unique characteristics, and thus pose some risk to the long-term evolutionary potential of the ESU. There have been continuing potential problems with siltation at the newer (lower) spawning beach (WDF et al. 1993), and recent proposals to close the two upper beaches in favor of production at the lower beach would thus be likely to increase risk of spawning failure in some years. The future use of the upper beaches is uncertain (WDFW 1996). Problems with operations of downstream smolt bypass systems have been documented, and there may be limitations to juvenile sockeye production due to inadequate lake productivity and interactions with other salmonids (WDF et al. 1993). IHN has also been a recent problem for this stock (G. Sprague[59]).

While stock abundance has fluctuated considerably over time (recent escapements ranging from a low of about 100 in 1985 to 16,000 in 1994), the long-term trend has been relatively flat. For the full data series (1926-1995), abundance has decreased by an average of about 2% per year; for the 1986-1995 period, abundance increased by about 32% per year.

---

[58] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., April 1995.

[59] G. Sprague, Habitat Program, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., 15 March 1995.

Artificial production in this ESU began in 1896 with a state hatchery on Baker Lake; hatchery efforts at Baker Lake ended in 1933, by which time the hatchery was being operated by the U.S. Bureau of Fisheries (see "Artificial Propagation" section, WDF et al. 1993). Current propagation efforts rely primarily on the spawning beaches and net-pen rearing. Lake Whatcom kokanee were recently introduced to Lake Shannon (Knutzen 1995). Genetic consequences of these releases and rearing programs are unknown, but there is some risk of genetic change resulting from unnatural selective pressures.

In previous assessments, Nehlsen et al. (1991) identified Baker River sockeye salmon as at high risk of extinction, and WDF et al. (1993) classified this stock as of native origin, artificial production, and critical status.

6) Lake Pleasant

Although no recent complete escapement estimates are available for this stock, we recently have received some spawner-survey data for the period 1987 to 1996 (Mosley 1995, Tierney 1997). Peak spawner counts ranged from a low of 90 (1991–a year with limited sampling) to highs above 2,000 (1987 and 1992). Abundance fluctuated widely during this period, with a slight negative trend overall.

Complete counts at a trapping station on Lake Creek in the early 1960s showed escapements of sockeye salmon ranging from 763 to 1,485 fish, and 65,000 sockeye salmon smolts were reported to have outmigrated in 1958 (Crutchfield et al. 1965). This stock supports small sport and tribal commercial fisheries, with probably fewer than 100 fish caught per year in each fishery (WDF et al. 1993). Sockeye salmon from Grandy Creek stock were released in 1933 and 1937; no sockeye salmon have been introduced since then (see "Artificial Propagation" section above).

In previous assessments, Nehlsen et al. (1991) did not identify Lake Pleasant sockeye salmon as at risk, and WDF et al. (1993) classified this stock as of native origin, wild production, and unknown status.

Analysis of Biological Information for Provisional ESU

Big Bear Creek

Abundance data for Big Bear Creek sockeye salmon are derived from spawner surveys conducted by WDFW from 1982 to the present (WDF et al. 1993, J. Ames[60]). The most recent (1991-1995) 5-year average annual escapement for this unit was about 11,400 adults

---

[60] J. Ames, Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091. Pers. commun., October 1996.

(see Appendix Table E-1). No historical estimates are available, but comparing habitat areas in these basins with other sockeye salmon populations suggests that current production is probably a substantial proportion of freshwater habitat capacity. Habitat in this basin is subject to effects of urbanization.

Stock abundance has fluctuated considerably over time, with recent escapements ranging from a low of 1,800 in 1989 to 39,700 in 1994. There has been little overall trend in this unit; for the full data series (1982-1995), abundance has decreased by an average of about 7% per year; for the 1986-1995 period, abundance decreased approximately 4% per year. 1995 escapement was the second lowest on record, but 1994 was the highest.

Releases of non-native sockeye salmon in this area have occurred on Big Bear and North Creek (tributaries of the Sammamish River), using Grandy Creek stock from the Skagit River and Cultus Lake stock from British Columbia, respectively (see Appendix Table D-2). There have been extensive introductions of kokanee in this area, a substantial proportion of which were from Lake Whatcom. Genetic interactions of these kokanee with sockeye salmon are unknown.

In previous assessments, Nehlsen et al. (1991) did not identify this stock as at risk, and WDF et al. (1993) classified this stock as of unknown origin, wild production, and depressed status.

Analysis of Biological Information for Other Population Units

While the units discussed below are not presently considered to constitute ESUs, we briefly examined available information regarding population status and extinction risk. Three other sockeye salmon stocks (Cedar River, Issaquah Creek, and Lake Washington beach spawners) are apparently introduced from outside the Lake Washington drainage and have not been included in a recognized ESU at this time (see above “Discussion and conclusions on ESU Determinations” section).

Riverine-Spawning Sockeye Salmon

Beyond WDFW Salmon Spawning Ground Survey Data (Egan 1977, 1995, 1997) and anecdotal reports (see above section “Information Specific to Sockeye Salmon Populations Under Review”) of small numbers of sockeye salmon observed regularly spawning in some Puget Sound and coastal Washington rivers with no access to lake rearing habitat, we have no information on overall abundance or trends for these stocks.

Deschutes River, Oregon

Counts of sockeye salmon adults reaching Pelton Dam on the Deschutes River have been made during most years since the mid-1950s (Fig. 21). The most recent (1990-1994)

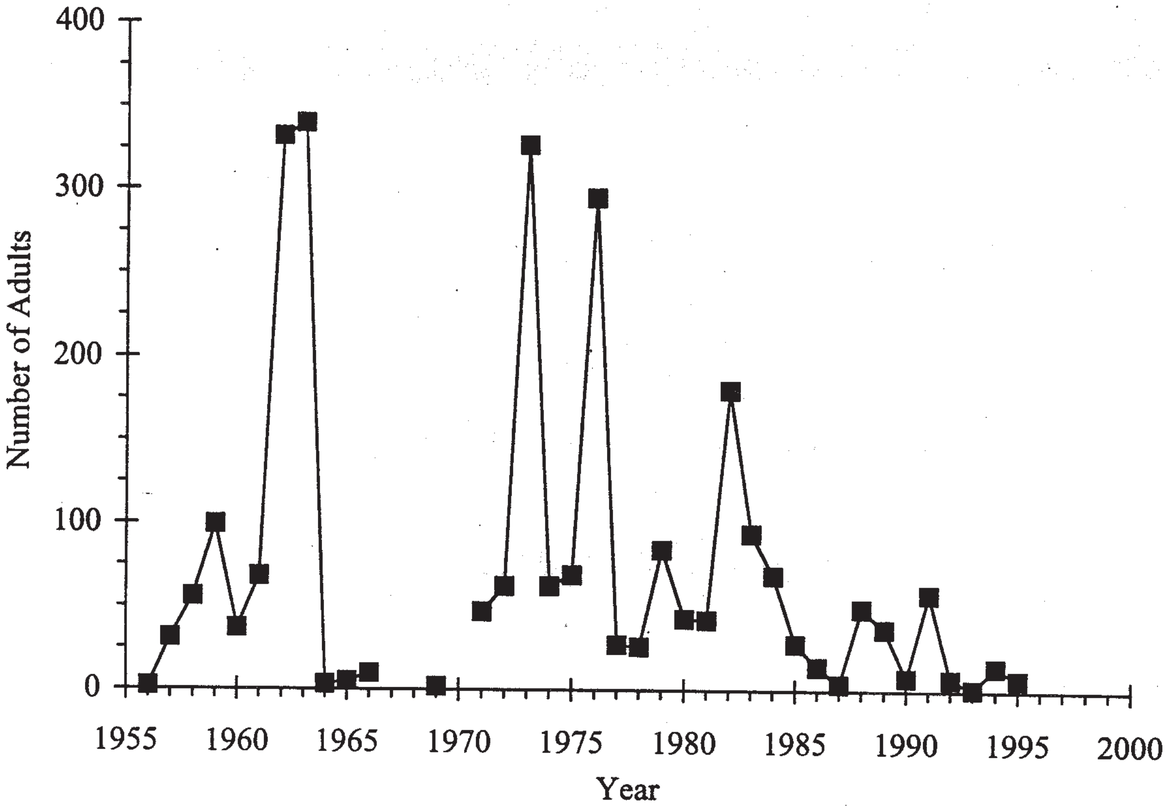


Figure 21. Estimated sockeye salmon adult returns to Pelton Trap on the Deschutes River, Oregon. Data from CIS database (O'Connor et al. 1993), Fish Commission of Oregon (1967), and S. Lewis (Portland General Electric, Pers. commun. October 1996).

5-year average annual escapement was only 9 adults (see Appendix Table E-1). No accurate estimates of historical abundance are available for this unit, but a substantial run is known to have spawned in Suttle Lake prior to construction of a dam in the 1930s, and is believed to have continued to spawn in the Metolius River after that time (CBFWA 1990, Olsen et al. 1994, ODFW 1995a). Since construction of Pelton Dam, abundance has reached peaks of about 300 fish in several years (1962, 1963, 1973, 1976–Fish Commission of Oregon 1967, O'Connor et al. 1993). We have made no evaluation of abundance of kokanee in the Deschutes River basin, which may be part of the same evolutionary unit as sockeye salmon in this basin. Sockeye salmon derived from the GCFMP were introduced into Suttle Lake and the Metolius River between 1937 and 1961 (see "Artificial Propagation" section) (see Appendix Table D-3).

Sockeye salmon stock abundance has fluctuated considerably over time (recent escapements ranging from a low of 1 in 1993 to 340 in 1963), but there has been a substantial decline over the years for which data are available. For the full data series (1957-1994), abundance decreased by an average of about 3% per year; for the 1985-1994 period, abundance declined by about 13% per year. Nehlsen et al. (1991) identified Deschutes River sockeye salmon as at high risk of extinction.

Conclusions: Risk Assessment

The BRT has concluded that if recent conditions continue into the future, one ESU (Ozette Lake) is likely to become endangered, and four ESUs (Okanogan River, Lake Wenatchee, Quinault Lake, and Baker River) and one provisional ESU (Big Bear Creek) are not presently in significant danger of becoming extinct or endangered. For the sixth ESU (Lake Pleasant), there was insufficient information to reach a conclusion regarding risk of extinction.

Conclusions: Risk Assessment

Consideration was also given to the status of two other population units for which ESU status has not been determined. For one of these (riverine sockeye salmon) there was insufficient information to reach any conclusions regarding risk of extinction. For the other unit (Deschutes River sockeye salmon), the BRT concluded that the anadromous component is clearly in danger of extinction if not already extinct.

The following paragraphs summarize the conclusions for each ESU or other population unit, and major considerations leading to these conclusions are summarized in Tables 5 and 6.

These conclusions are tempered by uncertainties in specific critical information. For several units, there are kokanee (either native or introduced) populations using the same water bodies as sockeye salmon; potential interbreeding and ecological interactions could affect population dynamics and (in the case of non-native kokanee) genetic integrity of the sockeye salmon populations. With few exceptions, adult abundance data do not represent direct

Table 5. Summary of risk considerations for U.S. sockeye salmon by evolutionarily significant unit (ESU).

Risk Category	**Okanogan River**	**Lake Wenatchee**	**Quinault Lake**	**Ozette Lake**	**Baker River**
Abundance (Recent 5-yr geometric mean)	Escapement 12,000.	Escapement 16,000.	Run size 46,000, escapement 37,000.	Escapement 600.	Escapement 2,700.
Numbers relative to historical abundance and carrying capacity	Probably near historic average abundance. Habitat problems on spawning grounds and in migration corridor.	Probably near historic average abundance. Habitat problems in migration corridor.	Below historic run size (50,000-500,000 in early 1900s). Severe habitat degradation in upper river early 1900s, continuing.	Recent runs clearly below historical (ca. 1950) catches. Capacity unknown. Habitat has been degraded by logging.	Except in 1994, recent abundance below historical levels. Little or no natural spawning habitat remaining.
Trends in abundance and production	Long-term trend flat with fluctuations, recent trend steeply downward. Some recent net-pen production.	Long-term trend slightly upward, recent trend slightly downward. Some net-pen production.	Long-term trend slightly upward, recent trend downward. Some hatchery production.	Long-term and recent trends downward. Some hatchery production.	Long-term trend slightly downward with fluctuations. Recent 5-year trend steeply upward. Some recent net-pen production.
Variability factors	None identified.	None identified.	None identified.	None identified.	None identified.
Threats to genetic integrity	Historic interbreeding with other ESUs during Grand Coulee Fish Maintenance Program (GCFMP).	Possible effects of interbreeding with non-indigenous kokanee; historic interbreeding with other ESUs during GCFMP.	Possible effects of past and present hatchery production.	Possible effects of present hatchery production and recent program interbreeding sockeye salmon with kokanee.	Stock essentially of native origin. Potential selection due to artificial habitat conditions.
Recent events	None identified.	None identified.	None identified.	None identified.	None identified.
Other Factors	None identified.	None identified.	None identified.	None identified.	Vulnerability to water quality problems and IHN. Dependence on human intervention.

Table 6. Preliminary summary of risk considerations for U.S. sockeye salmon stock units of undetermined evolutionarily significant unit (ESU) status.

Risk Category	**Lake Washington/ Sammamish River Tributaries**	**Lake Pleasant**	**Riverine Spawning**	**Deschutes River, OR**
Absolute numbers (Recent 5-yr geometric mean)	Escapement 20,000.	Escapement several hundred to few thousand.	Unknown.	Escapement 9.
Numbers relative to historical abundance and carrying capacity	No historical records. Capacity unknown. Habitat subject to urbanization.	Unknown.	Unknown.	Historical escapement (Suttle Lake) in 1000s. Sockeye salmon currently blocked from native habitat.
Trends in abundance and production	Recent trend slightly upward.	Unknown.	Unknown.	Trend strongly downward. Native sockeye salmon extinct or nearly so.
Variability factors	None identified.	None identified.	None identified.	None identified.
Threats to genetic integrity	None identified.	None identified.	None identified.	None identified.
Recent events	None identified.	None identified.	None identified.	None identified.
Other Factors	None identified.	None identified.	None identified.	Interactions with kokanee in upper river.

counts of adults destined to a single spawning area, so estimates of total population abundance and trends in abundance must be interpreted with some caution.

ESUs

ESU 1) Okanogan River

The BRT had several concerns about the overall health of this ESU. Low abundance, downward trends and wide fluctuations in abundance, land use practices, and variable ocean productivity were perceived as resulting in low to moderate or increasing risk for the ESU. Other major concerns regarding health of this ESU were restriction and channelization of spawning habitat in Canada, hydrosystem impediments to migration, and water temperature problems in the lower Okanogan River. Positive indicators for the ESU were escapement above 10,000, which is probably a substantial fraction of historical abundance, and the limited amount of recent hatchery production within the ESU. Recent changes in hydrosystem management (increases in flow and spill in the mainstem Columbia River) and harvest management (restrictions in commercial harvest to protect Snake River sockeye salmon) were regarded as beneficial to the status of this ESU. The BRT concluded unanimously that the Okanogan River sockeye salmon ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future. However, the very low returns in the 3 most recent years suggest that the status of this ESU bears close monitoring and its status should be reconsidered if abundance remains low.

ESU 2) Lake Wenatchee

The BRT had several concerns about the overall health of this ESU. Low abundance, downward trends and wide fluctuations in abundance, and variable ocean productivity were perceived as resulting in low to moderate risk for the ESU. Other major concerns regarding the health of this ESU were the effects of hatchery production, hydrosystem impediments to migration, and potential interbreeding with nonnative kokanee on genetic integrity of the unit. Positive indicators for the ESU were escapement above 10,000, and the limited amount of recent hatchery production within the ESU. Recent changes in hydrosystem management (increases in flow and spill in the mainstem Columbia River) and harvest management (restrictions in commercial harvest to protect Snake River sockeye salmon) were regarded as beneficial to the status of this ESU. The majority of the BRT concluded that the Lake Wenatchee sockeye salmon ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future. A minority concluded that this ESU is likely to become endangered in the foreseeable future, largely on the basis of extremely low abundance in the last 3 years. In any case, the very low returns in the 3 most recent years suggest that the status of this ESU bears close monitoring and should be reconsidered if abundance remains low.

ESU 3) Quinault Lake

All risk factors were perceived as very low or low for this ESU. However, the BRT had two concerns about the overall health of this ESU. The ESU is presently near the lower end of its historical abundance range, a fact that may be largely attributed to severe habitat degradation in the upper river, which contributes to poor spawning habitat quality and possible impacts on juvenile rearing habitat in Quinault Lake. The influence of hatchery production on genetic integrity is also a potential concern for the ESU. On the positive side, the BRT noted that recent escapement averaged above 30,000, harvest management has been responsive to stock status, and recent restrictions in logging to protect terrestrial species should have a beneficial effect on habitat conditions. The BRT concluded unanimously that the Quinault Lake sockeye salmon ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future.

ESU 4) Ozette Lake

Perceived risks ranged from low to moderate for genetic integrity and variable ocean productivity, from low to moderate and increasing for downward trends and population fluctuations, and from moderate to increasing for abundance considerations. Current escapements averaging below 1,000 adults per year imply a moderate degree of risk from small-population genetic and demographic variability, with little room for further declines before abundances would be critically low. Other concerns include siltation of beach spawning habitat, very low abundance compared to harvest in the 1950s, and potential genetic effects of present hatchery production and past interbreeding with genetically dissimilar kokanee. The BRT concluded that the Ozette Lake sockeye salmon ESU is not presently in danger of extinction, but if present conditions continue into the future, it is likely to become so in the foreseeable future.

ESU 5) Baker River

The BRT had several concerns about the overall health of this ESU, focusing on high fluctuations in abundance, lack of natural spawning habitat, and the vulnerability of spawning beaches to water quality problems. Large fluctuations in abundance were a substantial concern. It is also likely that this stock would go extinct if present human intervention were halted, and problems related to that intervention pose some risk to the population. In particular, the BRT concluded that the proposed change in management to concentrate spawning in a single spawning beach could substantially increase risk to the population. There was considerable disagreement regarding the risks associated with several factors for this ESU. For example, the assessment of perceived risk for abundance and habitat capacity ranged among BRT members from very low to high, and classifications for risks related to water quality and disease also had wide ranges. The majority of the BRT concluded that the Baker sockeye salmon ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future if present conditions continue. A minority concluded that this ESU is likely to become endangered in the foreseeable future, largely on the basis of lack of natural spawning habitat and the vulnerability of the entire population to problems in artificial habitats.

ESU 6) Lake Pleasant

Although escapement monitoring data are sparse, escapements (represented by peak spawner counts) in the late 1980s, and 1990s appear roughly comparable to habitat capacity for this small lake (peak spawner counts for the 1990s were not available at the time the BRT met). Some concerns were expressed regarding potential urbanization of habitat and effects of sport harvest during the migration delay in the Sol Duc River. It was noted that recent restrictions in logging to protect terrestrial species should have a beneficial effect on habitat conditions, although little or no old growth forest is present in the watershed. The majority of the BRT concluded that there was insufficient information to adequately assess extinction risk for the Lake Pleasant ESU, although a minority concluded that the ESU is not presently in danger of extinction nor likely to become so in the foreseeable future.

Provisional ESU

Big Bear Creek

The BRT had several concerns about the health of this provisional ESU and felt that the extreme fluctuations in recent abundances and potential effects of urbanization in the watershed suggest that the status of this populations bears close monitoring. Recent average abundance has been relatively high, with escapement between 10,000 and 20,000. Recent development of a county growth management plan was seen as a possible benefit to freshwater habitat for this population. The majority of the BRT concluded that the Big Bear Creek sockeye salmon provisional ESU is not presently in danger of extinction, nor is it likely to become endangered in the foreseeable future if present conditions continue. A minority concluded that this provisional ESU is likely to become endangered in the foreseeable future, while a second minority felt that information was insufficient to adequately assess extinction risk.

Other Population Units

Riverine-spawning sockeye salmon

There was insufficient information to reach any conclusion regarding the status of this unit.

Deschutes River, Oregon

The BRT concluded that if anadromous sockeye salmon recently seen in the lower Deschutes River are remnants of the historic Deschutes River ESU, the ESU clearly is in danger of extinction due to extremely low population abundance. If there is an ESU that includes sockeye salmon and native kokanee above Round Butte Dam, further evaluation of the kokanee stock and its relationship to the sockeye salmon would need to be completed before any conclusions regarding extinction risk could be made. If these sockeye salmon originated from stocks outside the Deschutes River Basin, then they are not subject to protection under the ESA.

CITATIONS

Ajwani, S. 1956. A review of Lake Washington watershed, historical, biological, and limnological. Master's Thesis, Univ. Washington, Seattle, WA, 148 p.

Allen, R. L., and T. K. Meekin. 1973. Columbia River sockeye salmon study, 1972 progress report. Wash. Dep. Fish., 61 p.

Allen, R. L., and T. K. Meekin. 1980. Columbia River sockeye salmon study, 1971-1974. Wash. Dep. Fish. Prog. Rep. 120, 75 p.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 66, 151 p.

Allendorf, F. W., and N. Ryman. 1987. Genetic management of hatchery stocks. *In* N. Ryman and F. Utter (editors), Population genetics & fishery management, p. 141-159. Univ. Washington Press, Seattle.

Altukhov, Yu. P., A. Yu. Novoselskaya, E. A. Salmenkova, G. D. Ryabova, A. A. Goncharova, S. M. Konovalov, V. E. Ilyin, A. G. Shevlyakov, and Yu. I. Novelselsky. 1983. Factors of differentiation and integration of genetical structure of a native system of *Oncorhynchus nerka* Walb. (Pisces) subpopulations in Lake Azabachye (Kamchatka). [In Russ., Engl. Summ.] Zh. Obshch. Biol. 44:316-331.

Altukhov, Yu. P., E. A. Salmenkova, G. D. Ryabova, S. M. Konovalov, and A. I. Pudovkin. 1975. Stationary distributions of the frequencies of lactate dehygrogenase and phosphoglucomutase genes in a system of subpopulations of a local fish stock of *Oncorhynchus nerka* Walb. I. Stability of a stock over generations with simultaneous variability of the component subpopulations. Sov. Genet. 11:447-454.

Altukhov, Yu. P., and N. V. Varnavskaya. 1983. Adaptive genetic structure and its relationship to intrapopulational sex, age, and growth rate differentiation in sockeye, *Oncorhynchus nerka* (Walb.). Sov. Genet. 19:614-624.

Aro, K. V., and G. C. Broadhead. 1950. Differences between egg counts of sockeye salmon at Lakelse and Babine lakes. Fish. Res. Board Can. Pac. Prog. Rep. 82:17-19.

Aro, K. V., and M. P. Shepard. 1967. Salmon of the North Pacific Ocean -- Part IV. Spawning populations of North Pacific salmon. 5. Pacific salmon in Canada. Int. North Pac. Fish. Comm. Bull. 23:225-322.

Atkinson, C. E. 1976. Salmon aquaculture in Japan, the Koreas, and the USSR. *In* D. H. Rosenberg (editor), Proceedings of the conference on salmon aquaculture and the Alaska fishing community, p. 79-154. Alsk. Sea Grant Rep. 76-2.

Atkinson, C. E., J. H. Rose, and O. T. Duncan. 1967. Salmon of the North Pacific Ocean -- Part IV. Spawning populations of North Pacific salmon. 4. Pacific salmon in the United States. Int. North Pac. Fish. Comm. Bull. 23:43-223.

Bagenal, T. B. 1978. Aspects of fish fecundity. *In* S. D. Gerking (editor), Ecology of freshwater fish production, p. 75-101. Blackwell Scientific Publications, Oxford.

Bailey, R. E., and L. Margolis. 1987. Comparison of parasite fauna of juvenile sockeye salmon (*Oncorhynchus nerka*) from southern British Columbian and Washington State lakes. Can. J. Zool. 65:420-431.

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946-71. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-671, 103 p.

Bakun, A. 1975. Daily and weekly upwelling indices, west coast of North America, 1967-73. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-693, 114 p.

Barnaby, J. T. 1946. Letter to Dr. R. Van Cleve from J. T. Barnaby, dated 6 May 1946. *In* "Transplanting adult Quinault bluebacks", File 1380.1-1, Pacific Salmon Commission. (Available from Librarian, Pacific Salmon Commission, Suite 600 - 1155 Robson Street, Vancouver, B.C., Canada V6E 1B9.)

Barraclough, W. E., and D. Robinson. 1972. The fertilization of Great Central Lake. III. Effect on juvenile sockeye salmon. Fish. Bull., U.S. 70:37-48.

Bartlett, G. 1967. The story of Wallowa Lake. Published by Grace Bartlett, 14 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Beacham, T. D. 1982. Fecundity of coho salmon (*Oncorhynchus kisutch*) and chum salmon (*O. keta*) in the northeast Pacific Ocean. Can. J. Zool. 60:1463-1469.

Beacham, T. D., and C. B. Murray. 1989. Variation in developmental biology of sockeye salmon (*Oncorhynchus nerka*) and chinook salmon (*O. tshawytscha*) in British Columbia. Can. J. Zool. 67:2081-2089.

Beacham, T. D., and C. B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). J. Fish Biol. 42:485-508.

Beacham, T. D., R. E. Withler, and C. C. Wood. 1995. Stock identification of sockeye salmon by means of minisatellite DNA variation. N. Am. J. Fish. Manage. 15:249-265.

Beamish, R. J., and D. R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Can. J. Fish. Aquat. Sci. 50:1002-1016.

Beamish, R. J., C. M. Neville, and A. J. Cass. 1997. Production of Fraser River sockeye salmon (*Oncorhynchus nerka*) in relation to decadal-scale changes in the climate and the ocean. Can. J. Fish. Aquat. Sci. 54:950-968.

Beauchamp, D. A. 1995. Riverine predation on sockeye salmon fry migrating to Lake Washington. N. Am. J. Fish. Manage. 15:358-365.

Beauchamp, D. A., M. G. LaRiviere, and G. L. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Ozette, Washington. N. Am. J. Fish. Manage. 15:193-207.

Bendire, C. 1881. Notes on Salmonidae of the Upper Columbia. Proc. U. S. Natl. Mus. 6:81-87.

Berggren, T. J. 1974. Seasonal changes in the abundance, biomass, production, distribution, and feeding of the 1971 year class of sockeye salmon in Lake Sammamish. Master’s Thesis, Univ. Washington, Seattle, WA, 80 p.

Bickham, J. W., C. C. Wood, and J. C. Patton. 1995. Biogeographic implications of cytochrome *b* sequences and allozymes in sockeye (*Oncorhynchus nerka*). J. Hered. 86:140-144.

Bilton, H. T. 1970. Maternal influences on the age at maturity of Skeena River sockeye salmon (*Oncorhynchus nerka*). Fish. Res. Board Can. Tech. Rep. 167:1-20.

Birtwell, I. K., M. D. Nassichuk, and H. Buene. 1987. Underyearling sockeye salmon (*Oncorhynchus nerka*) in the estuary of the Fraser River. Can. Spec. Publ. Fish. Aquat. Sci. 96:25-35.

Bjornn, T. C., D. R. Craddock, and D. R. Corley. 1968. Migration and survival of Redfish Lake, Idaho, sockeye salmon, *Oncorhynchus nerka*. Trans. Am. Fish. Soc. 97(4):360-373.

Blackbourn, D. J. 1987. Sea surface temperature and pre-season prediction of return timing in Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:296-306.

Blackett, R. F. 1979. Establishment of sockeye (*Oncorhynchus nerka*) and chinook (*O. tshawytscha*) salmon runs at Frazer Lake, Kodiak, Island, Alaska. J. Fish. Res. Board Can. 36:1265-1277.

Blair, G. R., D. E. Rogers, and T. P. Quinn. 1993. Variation in life history characteristics and morphology of sockeye salmon in the Kvichak River system, Bristol Bay, Alaska. Trans. Am. Fish. Soc. 122:550-559.

Blum, J. P. 1984. Management strategies for restoration and rehabilitation of sockeye salmon (*Oncorhynchus nerka*) in Lake Ozette, Washington. *In* J. M. Walton and D. B. Houston (editors), Proceedings of the Olympic wild fish conference, p. 55-62. Fisheries Technology Program, Peninsula College, Port Angeles, WA.

Blum, J. P. 1988. Assessment of factors affecting sockeye salmon (*Oncorhynchus nerka*) production in Ozette Lake, WA. Master's Thesis, Univ. Washington, Seattle, WA, 107 p.

Boomer, R. 1995. Letter to R. Gustafson, NMFS, from R. Boomer, Project Leader, Western Washington Fishery Resource Office, Fish and Wildlife Service, re. Quilcene National Fish Hatchery Log Books, 1920-1958, dated 11 May 1995. 1 p. plus attachment. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Bortleson, G. C., and N. P. Dion. 1979. Preferred and observed conditions for sockeye salmon in Ozette Lake and its tributaries, Clallam County, Washington. U.S. Geol. Surv. Water-Res. Investigations 78-64, 61 p.

Bortleson, G. C., N. P. Dion, J. B. McConnell, and L. M. Nelson. 1976. Reconnaissance data on lakes in Washington. Vol. 1, Clallam, Island, Jefferson, San Juan, Skagit, and Whatcom Counties. Water-Supply Bulletin 43, 248 p.

Bower, S. M., and L. Margolis. 1984. Detection of infection and susceptibility of different Pacific salmon stocks (*Oncorhynchus* spp.) to the haemoflagellate *Cryptobia salmositica*. J. Parasitol. 70(2):273-278.

Bowler, B. 1990. Additional information on the status of Snake River sockeye salmon. Report submitted to ESA Administrative Record for sockeye salmon, December 1990. Idaho Department of Fish and Game, Boise, 23 p.

Brannon, E. L. 1972a. Mechanisms controlling migration of sockeye salmon fry. Ph.D. Thesis, Univ. Washington, Seattle, WA, 156 p.

Brannon, E. L. 1972b. Mechanisms controlling migration of sockeye salmon fry. Int. Pac. Salmon Fish. Comm. Bull. 21:1-86.

Brannon, E. L. 1987. Mechanisms stabilizing salmonid fry emergence timing. Can. Spec. Publ. Fish. Aquat. Sci. 96:120-124.

Brannon, E. L. 1996. Review of preliminary work product "Preliminary conclusions of the review of the status of sockeye salmon (*Oncorhynchus nerka*) from Washington and Oregon under the U. S. Endangered Species Act," and "Supplemental information regarding proposed sockeye salmon ESUs for Washington and Oregon," dated 19 July 1996, 17 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Brannon, E., A. Setter, T. Welsh, R. Danner, K. Collins, M. Casten, G. Thorgaard, K. Adams, and S. Cummings. 1994. Genetic analysis of *Oncorhynchus nerka*: life history and genetic analysis of Redfish Lake *Oncorhynchus nerka*. Completion report. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 90-93, Contract No. DE-BI79-90BP12885, Portland, OR, 48 p.

Brenner, R., S. Hennig, A. Holt, and V. Ridge-Cooney. 1990. Quality of local lakes and streams: 1988-1989 status report. Water Resources Section, Municipality of Metropolitan Seattle, Publication 167, 297 p. plus 6 appendices.

Britton, E. W., A. J. Leaney-East, C. I. Manzon, and D. E. Marshall. 1982. Catalogue of salmon streams and spawning escapements of Statistical Area 5. Can. Data Rep. Fish. Aquat. Sci., No. 320, 250 p.

Brix, R., and R. Kolb. 1971. Catch and effort data for Washington coastal Indian fisheries. Wash. Dep. Fish., Olympia, WA, 22 p.

Brown, B. 1982. Mountain in the clouds: A search for the wild salmon. Simon and Schuster, New York, 239 p.

Brunson, R. B., G. B. Castle, and R. Pirtle. 1952. Studies of sockeye salmon (*Oncorhynchus nerka*) from Flathead Lake, Montana. Proc. Montana Acad. Sci. 12:35-43.

Brusca, R. C., and B. R. Wallerstein. 1979. Zoogeographic patterns of idoteid isopods in the Northeast Pacific, with a review of shallow water zoogeography of the area. Bull. Biol. Soc. Wash. 3:67-105.

Bryant, F. G., and Z. E. Parkhurst. 1950. Survey of the Columbia River and its tributaries-4. Area III, Washington streams from the Klickitat and Snake Rivers to Grand Coulee Dam on the Columbia and its tributaries above Grand Coulee Dam. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 37, 108 p.

Bryant, M. D. 1976. Lake Washington sockeye salmon: biological production and simulated harvest by three fisheries. Ph.D. Thesis, Univ. Washington, Seattle, WA, 159 p.

Buckley, R. 1965. Incidence of beach spawning sockeye salmon in Lake Washington and Lake Sammamish. Wash. Dep. Fish., Annual Report, 1964, 28 p.

Budy, P., C. Luecke, W. A. Wurtsbaugh, and H. P. Gross. 1995. Limnology of Sawtooth Valley lakes with respect to potential growth of juvenile Snake River sockeye salmon. Northwest Sci. 69(2):133-150.

Buerge, D. M. 1985. Requiem for a river. The Weekly, Seattle's News magazine. October 16-22:33-49.

Buerge, D. M. 1989. Renton, where the water took wing. Windsor Publ., Chatsworth, California, 135 p.

Bugaev, V. F. 1984. Method for identification of sockeye salmon, *Oncorhynchus nerka* (Salmonidae), of different spawning populations in the Kamchatka River Basin. J. Ichthyol. 24(2):47-53.

Bugaev, V. F. 1987. Scale patterns and biology of juvenile sockeye salmon (*Oncorhynchus nerka*) in the Kamchatka River. Can. Spec. Publ. Fish. Aquat. Sci. 96:36-43.

Bugaev, V. F. 1992. Age structure of sockeye salmon, *Oncorhynchus nerka*, and methods for its study. J. Ichthyol. 32(8):1-19.

Burch, J. B. 1989. North American freshwater snails. Malacological Publications, Hamburg, Michigan, 365 p.

Burgner, R. L. 1991. Life history of sockeye salmon *Oncorhynchus nerka*. *In* C. Groot and L. Margolis (editors), Pacific salmon life histories, p. 3-117. Univ. British Columbia Press, Vancouver, B.C., Canada.

Burke, J. 1996. Letter to Dr. M. Schiewe, NMFS, from J. Burke, Deputy Director, Division of Sport Fish, Alaska Department of Fish and Game, dated 11 July 1996. 2 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street,Portland, OR 97232.)

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish. Wildl. Serv., Fish. Bull. 52:95-110.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of West Coast Steelhead from Washington, Idaho, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261 p.

Butler, V. L. 1987. Chapter 10, Fish remains. *In* URS Corp., The Duwamish No. 1 site: 1986 data recovery, p. 10-1 to 10-37. METRO, Municipality of Metropolitan Seattle, Renton effluent transfer system, Contact No. CW/F2-82, task 48.08. URS Corp., Seattle, WA.

Butler, V. L. 1990. Fish remains from the Black River sites (45-KI-59 and 45-KI-51-D). Archaeology in Washington 2:49-65.

Caughley, G. 1994. Directions in conservation biology. J. Anim. Ecol. 63:215-244.

Cavalli-Sforza, L. L., and A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. Evolution 21:550-570.

Cedarholm, C. J., L. C. Lestelle, B. G. Edie, D. J. Martin, J. V. Tagart, and E. O. Salo. 1978. The effects of landslide siltation on the salmon and trout resources of Stequaleho Creek and the main Clearwater River, Jefferson County, Washington, 1972-1975. Final report - Part II. Fish. Res. Inst., Univ. Washington, Seattle, WA, FRI-UW-7804, 53 p.

Chakraborty, R. 1980. Gene-diversity analysis in nested subdivided populations. Genetics 96:721-726.

Chamberlain, F. M. 1907. Some observations on salmon and trout in Alaska. Report of the Commissioner of Fisheries for the fiscal year 1906 and special papers, Bur. Fish. Doc. No. 627, 112 p plus 5 figures, Government Printing Office, Washington, D.C.

Chapman, D., C. Peven, A. Giorgi, T. Hillman, F. Utter, M. Hill, J. Stevenson, and M. Miller. 1995. Status of sockeye salmon in the Mid-Columbia region. Don Chapman Consultants, Inc., 245 p. plus 129 figs., 26 tables, and 1 appendix.

Chapman, D., W. S. Platts, D. Park, and M. Hill. 1990. Status of Snake River sockeye salmon. Don Chapman Consultants, Inc., Final Report for Pacific Northwest Utilities Conference Committee, 90 p.

Chapman, W. M. 1941. Observations on the migration of salmonid fishes in the Upper Columbia River. Copeia 1941(4):240-242.

Chapman, W. M. 1943. The spawning of chinook salmon in the main Columbia River. Copeia 1943(3):138.

Chatters, J. C. 1988. Tualdad Altu (45KI49), a 4th century village on the Black River, King County, Washington. First City Equities, Seattle, WA, 140 p.

Chrzastowski, M. 1983. Historical changes to Lake Washington and route of the Lake Washington Ship Canal, King County, Washington. Water Res. Invest Open-File Rep. 81-1182, Map plus 9 p. text.

Clarke, A. H. 1981. The Freshwater Molluscs of Canada. National Museum of Natural Sciences, National Museums of Canada, Ottawa, 446 p.

Clutter, R. I., and L. E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Int. Pac. Salmon Fish. Comm. Bull. 9, 159 p.

Cobb, J. N. 1911. The salmon fisheries of the Pacific coast. Report of the Commissioner of Fisheries for the Fiscal Year 1910 and Special Papers, 180 p.

Cobb, J. N. 1914. The species of Pacific salmon and the runs. Pac. Fisherman Yearbook 1914, 12(2):31-33.

Cobb, J. N. 1927. Preliminary report of fishway work. Trans. Am. Fish. Soc. 57:181-201.

Cobb, J. N. 1930. Pacific salmon fisheries, 4th edition. Bureau of Fisheries, Washington, D.C. 704 p.

Columbia Basin Fish and Wildlife Authority (CBFWA). 1990. Integrated system plan for salmon and steelhead production in the Columbia River Basin. Columbia Basin System Planning, 449 p. plus 40 subbasin volumes.

Cook, F. R. 1984. Introduction to Canadian amphibians and reptiles. National Museum of Natural Sciences, National Museums of Canada, Ottawa, 200 p.

Corsaletti, L. T. 1981. A river forgotten. The Seattle Times, March 18, 1981, South Times p. G1.

Cox, S. P., and S. G. Hinch. 1997. Changes in size at maturity of Fraser River sockeye salmon (*Oncorhynchus nerka*) (1952-1993) and associations with temperature. Can. J. Fish. Aquat. Sci. 54:1159-1167.

Craddock, D. R., and R. L. Major. 1958. The spawning escapement of Columbia River blueback salmon (*Oncorhynchus nerka*) - 1958. Bur. of Commer. Fish., Seattle, WA, 10 p. plus figures and tables.

Craddock, D. R., and R. L. Major. 1959. The spawning escapement of Columbia River blueback salmon (*Oncorhynchus nerka*) - 1959. Bur. of Commer. Fish., Seattle, WA, 13 p.

Craig, J. A., and A. J. Suomela. 1941. Time of appearance of the runs of salmon and steelhead trout native to the Wenatchee, Entiat, Methow and Okanogan rivers. Unpubl. manuscr., U.S. Fish Wildl. Serv., 35 p.

Craig, J. K. 1995. Genetic divergence in spawning color of sympatric forms of sockeye salmon (*Oncorhynchus nerka*): investigation of an unknown form. Master's Thesis, Univ. Washington, Seattle, WA, 105 p.

Craig, P. C. 1985. Identification of sockeye salmon (*Oncorhynchus nerka*) stocks in the Stikine River based on egg size measurements. Can. J. Fish. Aquat. Sci. 42:1696-1701.

Cramer, S. P. 1990. The feasibility for reintroducing sockeye and coho salmon in the Grande Ronde River and coho and chum salmon in the Walla Walla River. Progress Report prepared for Nez Perce Tribe, Umatilla Confederated Tribes, Warm Springs Confederated Tribes, and Oregon Department of Fish and Wildlife by S. P. Cramer and Associates, Gresham, OR, 132 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Crawford, B. A. 1979. The origin and history of trout brood stocks of the Washington Department of Game. Wash. State Game Dep., Fish. Res. Rep. 76 p.

Crawford, J. M. 1907. Some plain truths relative to propagation. Pac. Fisherman 5(3):9-11.

Crozier, G. F. 1969. Tissue carotenoids in prespawning and spawning sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 27(5):973-975.

Crutchfield, J. A., K. B. Kral, and L. A. Phinney. 1965. An economic evaluation of Washington State Department of Fisheries' controlled natural-rearing program for coho salmon (*Oncorhynchus kisutch*). Submitted to U.S. Fish Wildl. Serv. by Wash. Dep. Fish. Res. Division under Contract #14-17-0007-246, 152 p.

Curtright, S. 1979. The Quinault blueback. Quinault Dept. Natural Resources Economic Development Newsletter, May 1979:4-5.

Dall, W. H. 1905. Land and freshwater mollusks of Alaska and adjoining regions. Harriman Alsk. Expedition 13:1-171.

Danner, G. R. 1994. Behavioral, physiological and genetic differences among anadromous and resident *Oncorhynchus nerka* populations. Master's Thesis, Univ. Idaho, Boise, ID, 107 p.

Davidson, F. A. 1953. Historical notes on development of Yakima River Basin. Manuscript report, 21 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Davidson, F. A. 1966. Population trends in the blueback and Upper Columbia River fall chinook salmon. Grant County PUD, Ephrata, WA, 36 p. plus figures and tables.

Davidson, F. A., and J. T. Barnaby. 1936. Survey of Quinault river system and its runs of sockeye salmon. Unpublished manuscript, Bureau of Fisheries, 17 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Dawson, J. J. 1972. Determination of seasonal distribution of juvenile sockeye salmon in Lake Washington by means of acoustics. Master's Thesis, Univ. Washington, Seattle, WA. 112 p.

Dawson, J. J., R. E. Thorne, and J. J. Traynor. 1973. Acoustic surveys of Lake Wenatchee and Lake Osoyoos in 1973. Final Report, Service Contr. 526, to Wash. Dep. Fish., by Fish. Res. Inst., Coll. of Fish., Univ. Washington, Seattle, WA, 18 p.

Denman, K. L., D. L. Mackas, H. J. Freeland, M. J. Austin, and S. H. Hill. 1981. Persistent upwelling and mesoscale zones of high productivity off the west coast of Vancouver Island, Canada. *In* F. A. Richards (editor), Coastal upwelling, p. 514-521. American Geophysical Union, Washington, D.C.

Dion, N. P., G. C. Bortleson, J. B. McConnell, and J. K. Innes. 1976a. Data on selected lakes in Washington, Part 5. Water-Supply Bulletin 42, Part 5, 125 p.

Dion, N. P., G. C. Bortleson, J. B. McConnell, and J. K. Innes. 1976b. Reconnaissance data on lakes in Washington, Vol. 5, Chelan, Ferry, Klickitat, Okanogon, and Yakima counties. Water-Supply Bulletin 43, Part 5, 264 p.

Dlugokenski, C. E., W. H. Bradshaw, and S. R. Hager. 1981. An investigation of the limiting factors to Lake Ozette sockeye salmon production and a plan for their restoration. U.S. Fish Wildl. Serv., Fisheries Assistance Office, Olympia, WA, 52 p.

Doble, B. D., and D. M. Eggers. 1978. Diel feeding chronology, rate of gastric evacuation, daily ration, and prey selectivity in Lake Washington juvenile sockeye salmon (*Oncorhynchus nerka*). Trans. Am. Fish. Soc. 107:36-45.

Donaldson, L. R. 1980. Salmon ranching in Washington State. *In* J. E. Thorpe (ed.) Salmon ranching, p. 29-45. Academic Press, New York.

Easterbrook, D. J., and D. A. Rahm. 1970. Landforms of Washington, the geologic environment. Union Printing Co., Bellingham, WA, 156 p.

Edie, B. G. 1975. A census of the juvenile salmonids of the Clearwater River Basin, Jefferson County, Washington, in relation to logging. Master's Thesis, Univ. Washington, Seattle, WA, 86 p.

Edmondson, W. T. 1977a. Section VI - Washington. Lake Washington. *In* Seyb, L. and K. Randolph (eds.) North American project — A study of U. S. water bodies, p. 288-300. U.S. Environmental Protection Agency, Environmental Research Laboratory - Corvallis, EPA-600/3-77-086.

Edmondson, W. T. 1977b. Trophic equilibrium of Lake Washington. U.S. Environmental Protection Agency, Ecological Research Series, EPA-6000/3-77-087, 35 p.

Edmondson, W. T., and S. E. B. Abella. 1988. Unplanned biomanipulation in Lake Washington. Limnologica 19:73-79.

Edmondson, W. T., and J. T. Lehman. 1981. The effect of changes in the nutrient income on the condition of Lake Washington. Limnol. Oceanogr. 26:1-29.

Edmondson, W. T., and A. H. Litt. 1982. *Daphnia* in Lake Washington. Limnol. Oceanogr. 27:272-293.

Egan, R. 1977. Salmon spawning ground data report. State of Wash. Dep. Fish. Prog. Rep. 17, 346 p.

Egan, R. 1995. Letter to R. Gustafson, NMFS, from R. Egan, WDFW, re. Sockeye Salmon Spawning Ground Survey Data, dated 28 June 1995. 1 p. plus 33 p. computer printout. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Egan, R. 1997. Letter to R. Gustafson, NMFS, from R. Egan, WDFW, re. Sockeye Salmon Spawning Ground Survey Data, dated 10 January 1997. 1 p. plus 9 p. computer printout. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Eggers, D. M. 1978. Limnetic feeding behavior of juvenile sockeye salmon in Lake Washington and predator avoidance. Limnol. Oceanogr. 23:1114-1125.

Eggers, D. M., and D. E. Rogers. 1987. The cycle of runs of sockeye salmon (*Oncorhynchus nerka*) to the Kvichak River, Bristol Bay, Alaska: cyclic dominance or depensatory fishing? Can. Spec. Publ. Fish. Aquat. Sci. 96:343-366.

Egorova, T. V. 1970. Reproduction and development of sockeye in the basin of Ozernaya River. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 73:39-53. [Fish. Res. Board Can. Transl. Ser. No. 2619]

Eiler, J. H., B. D. Nelson, R. F. Bradshaw, J. R. Greiner, and J. M. Lorenz. 1988. Distribution, stock composition, and location and habitat type of spawning areas used by sockeye salmon on the Taku River. NWAFC Processed Rep. 88-24, 44 p.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Trans. Am. Fish. Soc. 121(6):701-708.

Emmett, R. L., and M. H. Schiewe (eds.). 1997. Estuarine and ocean survival of northeastern Pacific salmon. Proceedings of the workshop, March 20-22, 1996, Newport, OR. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-29, 313 p.

Emmett, R. L., S. L. Stone, S. A. Hinton, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: species life history summaries. ELMR Rep. No. 8 NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 329 p.

Evermann, B. W. 1895. A preliminary report upon salmon investigations in Idaho in 1894. U.S. Fish Comm., Bull. 15:253-284.

Evermann, B. W. 1896. A report upon salmon investigations in the headwaters of the Columbia River, in the state of Idaho, in 1895, together with notes upon the fishes observed in that state in 1894 and 1895. U.S. Fish Comm., Bull. 16:151-202.

Evermann, B. W., and E. L. Goldsborough. 1907. The fishes of Alaska. U.S. Bur. Fish., Bull. 26:219-360, 144 figs.

Evermann, B. W., and H. B. Latimer. 1910. On a collection of fishes from the Olympic Peninsula, together with notes on other west coast species. Proc. Biol. Soc. Wash. 23:131-140.

Evermann, B. W., and S. E. Meek. 1898. A report upon salmon investigations in the Columbia River Basin and elsewhere on the Pacific Coast in 1896. U.S. Fish Comm., Bull. 17:15-84.

Evermann, B. W., and J. T. Scovell. 1896. Recent investigations concerning the redfish, *Oncorhynchus nerka*, at its spawning grounds in Idaho. Proc. Indiana Acad. Sci. 1895:131-134.

Fagen, R., and W. W. Smoker. 1989. How large - capacity hatcheries can alter interannual variability of salmon production. Fish. Res. 8:1-11.

Farley, A. L. 1979. Atlas of British Columbia. Univ. British Columbia Press, Vancouver, B.C., 136 p.

Fish Commission of Oregon. 1967. A report on and recommendations concerning passage of fish at Pelton and Round Butte Dams. Fish Comm. Oreg., Res. Division, Portland, OR.

Fish and Wildlife Technical Committee (FWTC). 1970. Nooksack-Sumas Basins. *In* Comprehensive study of water and related resources, Puget Sound and adjacent waters, Appendix XI, Fish and Wildlife, p. 4.1-4.32. Puget Sound Task Force, Pacific Northwest River Basins Commission, Vancouver, WA.

Fish Passage Center. 1996. Fish Passage Center Weekly Report 96-30, Fish Passage Center, Portland, OR, 10 p.

Fish, F. F., and M. G. Hanavan. 1948. A report on the Grand Coulee Fish-Maintenance Project 1939-1947. U.S. Fish Wildl. Serv. Spec. Sci. Rep. 55, 61 p.

Foerster, R. E. 1937. The relation of temperature to the seaward migration of young sockeye salmon (*Oncorhynchus nerka*). J. Biol. Board Can. 3(5):421-438.

Foerster, R. E. 1944. The relation of lake population density to size of young sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 6(3):267-280.

Foerster, R. E. 1947. Experiment to develop sea-run from land-locked sockeye salmon *(Oncorhynchus nerka kennerlyi*). J. Fish. Res. Board Can. 7(2):88-93.

Foerster, R. E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bull. Fish. Res. Board Can. 162, 422 p.

Foerster, R. E., and A. L. Pritchard. 1941. Observations on the relation of egg content to total length and weight in sockeye salmon (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*). Trans. R. Soc. Can. Sect. V, Ser. 3, 35:51-60.

Folsom, W., D. Altman, A. Manuar, F. Nielsen, T. Revord, E. Sanborn, and M. Wildman. 1992. World salmon culture. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-3, Silver Spring, Maryland, 323 p.

Foote, C. J., and P. A. Larkin. 1988. The role of male choice in the assortative mating of anadromous and non-anadromous sockeye salmon (*Oncorhynchus nerka*). Behaviour 106(1-2):43-61.

Foote, C. J., I. Mayer, C. C. Wood, W. C. Clarke, and J. Blackburn. 1994. On the developmental pathway to nonanadromy in sockeye salmon, *Oncorhynchus nerka*. Can. J. Zool. 72:397-405.

Foote, C. J., C. C. Wood, C. Clarke, and J. Blackburn. 1992. Circannual cycle of seawater adaptability in *Oncorhynchus nerka*: Genetic differences between sympatric sockeye salmon and kokanee. Can. J. Fish. Aquat. Sci. 49:99-109.

Foote, C. J., C. C. Wood, and R. E. Withler. 1989. Biochemical genetic comparison of sockeye salmon and kokanee, the anadromous and nonanadromous forms of *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. 46:149-158.

Forrester, C. R. 1987. Distribution and abundance of sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:2-10.

Forstall, R. L. (editor). 1969. The international atlas. Rand McNally, Chicago, 223 p.

Foskett, D. R. 1958. The Rivers Inlet sockeye salmon. J. Fish. Res. Board Can. 15(5):867-889.

Foy, M. G., K. K. English, C. R. Steward, J. Big Eagle, and C. Huntington. 1995a. Sockeye salmon catch, escapement, and historical abundance data. A report prepared for U.S. Dep. Commer., Natl. Mar. Fish. Serv., Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Foy, M. G., K. K. English, C. R. Steward, J. Big Eagle and C. Huntington. 1995b. Marine commercial and sport catch databases with information on salmon and steelhead. Report by Big Eagle and Associates and LGL Limited for U.S. Dep. Comm., Natl. Mar. Fish. Serv., 45 p. plus appendices. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Fredericks, J. P., M. A. Maiolie, and S. Elam. 1995. Kokanee impacts assessment and monitoring on Lake Pend Oreille, Idaho - Chapter 1. Kokanee impacts assessment and monitoring on Dworshak Reservoir, Idaho - Chapter 2. Annual Progress Report: January - December 1994. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 94-035, Contract No. 94BII2917, 87BI35167. Portland, OR, 61 p.

French, R., H. Bilton, M. Osako, and A. Hartt. 1976. Distribution and origin of sockeye salmon (*Oncorhynchus nerka*) in offshore waters of the North Pacific Ocean. Int. North Pac. Fish. Comm. Bull. 34, 113 p.

French, R. R., and R. J. Wahle. 1954. The distribution of salmon above Rock Island Dam as observed from stream surveys during the spawning season of 1954. U.S. Fish Wildl. Serv., Seattle, WA, 17 p.

French, R. R., and R. J. Wahle. 1959. Biology of chinook salmon and blueback salmon and steelhead in the Wenatchee River system. U.S. Fish Wildl. Serv. Spec. Sci. Rep. 304, 17 p.

French, R. R., and R. J. Wahle. 1960. Salmon runs - Upper Columbia River, 1956-57. U.S. Fish Wildl. Serv. Spec. Sci. Rep. 364, 15 p.

French, R. R., and R. J. Wahle. 1965. Salmon escapements above Rock Island Dam, 1954-60. U. S. Fish Wildl. Serv. Spec. Sci. Rep. 493, 18 p.

Fryer, J. K. 1995. Columbia Basin sockeye salmon: Causes of their past decline, factors contributing to their present low abundance, and future outlook. Ph.D. Thesis, Univ. Washington, Seattle, WA, 274 p.

Fryer, J. K., and M. Schwartzberg. 1993. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 1992. Columbia River Inter-Tribal Fish Commission, Tech. Rep. 93-2, 35 p.

Fryer, J. K., and M. Schwartzberg. 1994. Identification of Columbia Basin sockeye salmon stocks using scale pattern analyses in 1993. Columbia River Inter-Tribal Fish Commission, Tech. Rep. 94-2, 39 p.

Fulton, L. A. 1966. Palmer Lake study, 1966. Bur. Commer. Fish., Fish-Passage Res. Program, 8 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Fulton, L. A. 1970. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River basin -- past and present. Spec. Sci. Rep. -- Fisheries 618, 37 p. Natl. Mar. Fish. Serv., Washington, D.C.

Fulton, L. A., and R. E. Pearson. 1981. Transplantation and homing experiments on salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, in the Columbia River system: fish of the 1939-1944 broods. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC 12, 97 p.

Gangmark, H. A., and L. A. Fulton. 1952. Status of Columbia blueback salmon runs, 1951. U. S. Fish Wildl. Serv. Spec. Sci. Rep. 74, 29 p.

Gard, R., B. Drucker, and R. Fagen. 1987. Differentiation of subpopulations of sockeye salmon (*Oncorhynchus nerka*), Karluk River System, Alaska. Can. Spec. Publ. Fish. Aquat. Sci. 96:408-418.

Gilbert, C. H. 1914. Contributions to the life history of the sockeye salmon. (No. 1) *In* Report of the British Columbia Commissioner of Fisheries, 1914, p. R53-R78. Province of British Columbia, Victoria, B.C., Canada.

Gilbert, C. H. 1918. Contributions to the life history of the sockeye salmon (No. 4). *In* Report of the British Columbia Commissioner of Fisheries, 1917, p. 33-80. Province of British Columbia, Victoria, B.C., Canada.

Gilbert, C. H. 1919. Contributions to the life history of the sockeye salmon (No. 5). *In* Report of the British Columbia Commissioner of Fisheries, 1918, p. 26-52. Province of British Columbia, Victoria, B.C., Canada.

Gilhousen, P. 1960. Migratory behavior of adult Fraser River sockeye. Int. Pac. Salmon Fish. Comm. Prog. Rep. 7, 72 p.

Gilhousen, P. 1990. Prespawning mortalities of sockeye salmon in the Fraser River system and possible casual factors. Int. Pac. Salmon Fish. Comm. Bull. 27, 62 p.

Gilpin, M. E., and M. E. Soulé. 1986. Minimum viable populations: Processes of species extinction. *In* M. E. Soulé (editor), Conservation biology: The science of scarcity and diversity, p. 19-34. Sinauer, Sunderland, MA.

Godfrey, H. 1958. A comparison of sockeye salmon catches at Rivers Inlet and Skeena River, B. C., with particular reference to age at maturity. J. Fish. Res. Board Can. 15:331-354.

Godin, J. G. J. 1982. Migrations of salmonid fishes during early life history phases: Daily and annual timing. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 22-50. School of Fisheries, Univ. Washington, Seattle, WA.

Goldstein, L. S. 1982. Little Bear Creek stream resource inventory. Tech. Rep. WR-82-4. METRO Water Quality Division, Municipality of Metropolitan Seattle, 51 p. plus appendices.

Goodlad, J. C., T. W. Gjernes, and E. L. Brannon. 1974. Factors affecting sockeye salmon (*Oncorhynchus nerka*) growth in four lakes of the Fraser River system. J. Fish. Res. Board Can. 31:871-892.

Grant, W. S., G. B. Milner, P. Krasnowski, and F. M. Utter. 1980. Use of biochemical genetic variants for identification of sockeye salmon (*Oncorhynchus nerka*) stocks in Cook Inlet, Alaska. Can. J. Fish. Aquat. Sci. 37:1236-1247.

Graynoth, E. 1995. Spawning migrations and reproduction of landlocked sockeye salmon (*Oncorhynchus nerka*) in the Waitaka catchment, New Zealand. N. Z. J. Mar. Freshwater Res. 29:257-269.

Groot, C., and K. Cooke. 1987. Are the migrations of juvenile and adult Fraser River sockeye salmon (*Oncorhynchus nerka*) in near-shore waters related? Can. Spec. Publ. Fish. Aquat. Sci. 96:53-60.

Gross, H. P., W. A. Wurtsbaugh, C. Luecke, and P. Budy. 1993. Nutrient limitation of phytoplankton in oligotrophic lakes of the Sawtooth Valley, Idaho. *In* C. Luecke and W. Wurtsbaugh (editors), Part II: Limnological and fisheries investigations of Sawtooth Valley lakes with respect to potential rehabilitation of endangered Snake River sockeye salmon, p. 29-52. BPA Report DOE/BP-22548-1.

Gunsolus, R. T., and G. J. Eicher. 1962. Evaluation of the fish passage facilities at the Pelton project on the Deschutes River in Oregon. Fish Comm. Oregon and Portland General Electric Co., 133 p.

Guthrie, C. M., III, J. H. Helle, P. Aebersold, G. A. Winans, and A. J. Gharrett. 1994. Preliminary report on the genetic diversity of sockeye salmon populations from southeast Alaska and northern British Columbia. Alsk. Fish. Sc. Center Proc. Rep. 94-03, 109 p.

Hall, C. A. 1964. Shallow-water marine climates and molluscan provinces. Ecology 45(2):226-234.

Hallock, R. J., and D. H. Fry, Jr. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game 53(1):5-22.

Halupka, K. C., J. K. Troyer, M. F. Wilson, M. B. Bryant, and F. H. Everest. 1993. Identification of unique and sensitive sockeye salmon stocks of Southeast Alaska (Draft Manuscript). For. Sc. Lab., Pac. N. W. Res. Stat., U.S. Dep. Agr., 235 p.

Hämäläinen, A. H. E. 1978. Effects of instream flow levels on sockeye salmon fry production in the Cedar River, Washington. Master's Thesis, Univ. Washington, Seattle, WA, 90 p.

Hamilton, J. A. R., and F. J. Andrew. 1954. An investigation of the effect of Baker Dam on downstream-migrant salmon. Int. Pac. Salmon Fish. Comm. Bull. 6:1-73.

Hamilton, J. A. R., and L. Rothfus. 1963. A summary report on Lake Merwin investigations. Wash. Dept. Fish., Olympia, WA, 40 p.

Hammond, J. P. 1886. Fish in Puget Sound. U.S. Fish Comm., Bull. 6:95-196.

Hanamura, N. 1966. Salmon of the North Pacific Ocean -- Part III. A review of the life history of North Pacific salmon: Sockeye salmon in the far east. Int. North Pac. Fish. Comm. Bull. 18:1-27.

Hanamura, N. 1967. Salmon of the North Pacific Ocean -- Part IV. Spawning populations of North Pacific salmon. 1. Sockeye salmon in the Far East. Int. North Pac. Fish. Comm. Bull. 23:1-7.

Hanson, A.J., and H. D. Smith. 1967. Mate selection in a population of sockeye salmon (*Oncorhynchus nerka*) of mixed age-groups. J. Fish. Res. Board Can. 24(9):1955-1977.

Hanson, J. M., and W. C. Leggett. 1982. Empirical prediction of fish biomass and yield. Can. J. Fish. Aquat. Sci. 39:257-263.

Hard, J. J., R. P. Jones, M. R. Delarm, and R. S. Waples. 1992. Pacific salmon and artificial propagation under the Endangered Species Act. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWFSC-2, 56 p.

Hartman, W. L. and R. L. Burgner. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. J. Fish. Res. Board. Can. 29:699-715.

Hartman, W. L., and C. Y. Conkle. 1960. Fecundity of red salmon at Brooks and Karluk lakes, Alaska. U.S. Fish. Wildl. Serv., Fish. Bull. 61:53-60.

Hartman, W. L., W. R. Heard, and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. J. Fish. Res. Board Can. 24(10):2069-2099.

Hartt, A. C. 1980. Juvenile salmonids in the oceanic ecosystem - The critical first summer. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 25-57. Oregon State Univ. Press, Corvallis, OR.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Int. North Pac. Fish. Comm. Bull. 46, 105 p.

Hassemer, P. F., S. W. Kiefer, and C. E. Petrosky. 1996. Idaho's salmon: can we count every last one? *In* D. J. Stouder, P. A. Bisson, and R. J. Naiman (editors), Pacific salmon and their ecosystems, status and future options, p. 113-125. Chapman & Hall, New York.

Hatch, D. R., A. Wand, and M. Schwartzberg. 1992. Wenatchee River salmon escapement estimates using video tape technology in 1991. Columbia River Inter-Tribal Fish Commission, Tech. Rep. 92-3. 28 p.

Hayden, B. P., and R. Dolan. 1976. Coastal marine fauna and marine climates of the Americas. J. Biogeogr. 3:71-81.

Healey, M. C. 1986. Optimum size and age at maturity in Pacific salmon and effects of size-selective fisheries. *In* D. J. Meerburg (editor), Salmonid age at maturity, p. 39-52. Can. Spec. Publ. Fish. Aquat. Sci. 89.

Healey, M. C. 1987. The adaptive significance of age and size at maturity in female sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:110-117.

Heg, R. T. 1953. Further observations on Lake Pleasant. *In* Smoker, W. A., H. M. Jensen, R. T. Heg, J. W. Fitzgerald, R. W. Williams, W. Bayliff, W. Rees, and D. R. Johnson. Progress Report, Puget Sound Investigations, December 1952 to February 1953. Wash. Dept. Fish. Wildl., Olympia, p. 10-12.

Heifitz, J., S. W. Johnson, K V. Koski, and M. L. Murphy. 1989. Migration timing, size, and salinity tolerance of sea-type sockeye salmon (*Oncorhynchus nerka*) in an Alaska estuary. Can. J. Fish. Aquat. Sci. 46:633-637.

Heiser, D. 1969. Fecundity of Cedar River sockeye salmon (*Oncorhynchus nerka*) 1968, 1969. Unpubl. manuscr., Wash. Dep. Fish. 7 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Helle, J. H., and M. S. Hoffman. 1995. Size decline and older age at maturity of two chum salmon (*Oncorhynchus keta*) stocks in western North America. Can. Spec. Publ. Fish. Aquat. Sci. No. 121, 245-260.

Henderson, H. F., R. A. Ryder, and A. W. Kudhongania. 1973. Assessing fishery potentials of lakes and reservoirs. J. Fish. Res. Board. Can. 30:2000-2009.

Henderson, J. 1929. The non-marine Mollusca of Oregon and Washington. Univ. Colorado Studies. 17(2):47-190.

Henderson, J. 1936. The non-marine Mollusca of Oregon and Washington -- supplement. Univ. Colorado Studies. 23(4):251-280.

Hendry, A. P. 1995. Sockeye salmon (*Oncorhynchus nerka*) in Lake Washington: An investigation of ancestral origins, population differentiation and local adaptation. Master's Thesis, Univ. Washington, Seattle, WA, 159 p.

Hendry, A. P., and T. P. Quinn. 1997. Variation in adult life history and morphology among Lake Washington sockeye salmon (*Oncorhynchus nerka*) populations, in relation to habitat features and ancestral affinities. Can. J. Fish. Aquat. Sci. 54:75-84.

Hendry, A. P., T. P. Quinn, and F. M. Utter. 1996. Genetic evidence for the persistence and divergence of native and introduced sockeye salmon (*Oncorhynchus nerka*) within Lake Washington, Washington. Can. J. Fish. Aquat. Sci. 53:823-832.

Henshaw, F. F., E. C. La Rue, and G. C. Stevens. 1913. Surface water supply of the United States, 1910. Part XII. North Pacific coast. U.S. Geol. Survey Water Supply Paper 292, 685 p.

Hershberger, W. K., J. Seeb, and P. Aebersold. 1982. Genetic analysis of the sockeye salmon (*Oncorhynchus nerka*) returning to Lake Ozette. Final report to Makah Tribe, 30 November 1982, 9 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Hill, P. M. 1984. A detailed listing of the liberations of salmon into the open waters of the State of Washington during 1983. Wash. Dep. Fish. Prog. Rep. No. 210, 369 p.

Hinch, S. G., M. G. Healey, R. E. Diewert, and M. A. Henderson. 1995a. Climate change and ocean energetics of Fraser River sockeye (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. No. 121, 439-445.

Hinch, S. G., M. G. Healey, R. E. Diewert, K. A. Thomson, R. Hourston, M. A. Henderson, and F. Juanes. 1995b. Potential effects of climate change on marine growth and survival of Fraser River sockeye salmon. Can. J. Fish. Aquat. Sci. 52:2651-2659.

Hiss, J. M., and R. C. Wunderlich. 1994. Status of kokanee salmon (*Oncorhynchus nerka*) in the Lake Sutherland basin and prospects for sockeye salmon restoration. U.S. Fish Wildl. Serv., 51 p.

Hodgins, H. O., W. E. Ames, and F. M. Utter. 1969. Variants of lactate dehydrogenase isozymes in sera of sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board. Can. 26:15-19.

Hoines, L. 1995. Washington state statistical report 1991. Wash. Dep. Fish Wildl., Olympia, WA, 32 p.

Houston, D. B. 1983. Anadromous fish in Olympic National Park: A status report. Natl. Park Serv. Pacific Northwest Region, 72 p.

Houston, D. B. 1984. Anadromous fish in Olympic National Park: Status and management considerations. *In* J. M. Walton and D. B. Houston (editors), Proceedings of the Olympic wild fish conference, p. 97-111. Peninsula College, Fisheries Technology Program, Port Angeles, WA.

Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, and D. Ortmann. 1985. Stock assessment of Columbia River anadromous salmonids, Volume I: Chinook, coho, chum and sockeye salmon stock summaries. Final report to Bonneville Power Administration, Contract DE-A179-84BP12737, Project No. 83-335, 558 p.

Huntington, C., W. Nehlsen, and J. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. Fisheries 21(3):6-14.

Hyatt, K. D., D. Rutherford, T. Gjernes, P. Rankin, and T. Cone. 1984. Lake enrichment program: Juvenile sockeye unit survey guidelines. Can. Man. Rep. Fish. Aquat. Sci. 1796, 84 p.

Hyatt, K. D., and J. G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka*) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42:320-331.

Hydrosphere Data Products, Inc. 1993. Hydrodata Regional CD-ROMs: U.S. Geological Survey Daily values, Vols. West 1, West 2. (Available from Hydrosphere Data Products Inc., 1002 Walnut, Suite 200, Boulder, CO 80302.)

Idaho Department of Fish and Game (IDFG). 1996. Letter to R. Gustafson, NMFS, from D. A. Cannamela, IDFG, re. Comments on "Preliminary conclusions of the review of the status of sockeye salmon (*Oncorhynchus nerka*) from Washington and Oregon under the U. S. Endangered Species Act," dated 11 July 1996. 1 p. plus attachment. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Ingram, W. M. 1948. The larger freshwater clams of California, Oregon, and Washington. J. Entomol. Zool. 40(4):72-92.

International Pacific Salmon Fisheries Commission (IPSFC). 1972. Proposed program for restoration and extension of the sockeye and pink salmon stocks of the Fraser River. New Westminster, B.C., Canada, 91 p.

Ivankov, V. N., and V. L. Andreyev. 1969. Fecundity of Pacific salmon (genus *Oncorhynchus* spp.). Vopr. Ikthiol. 9:80-89. [Engl. Transl. Problems in Ichthyology, Am. Fish. Soc. 9:59-66]

Jacobs, R., G. Larson, J. Meyer, N. Currence, and J. Hinton. 1996. The sockeye salmon *Oncorhynchus nerka* population in Lake Ozette, Washington, USA. Tech. Rep. NPS/CCSOSU/NRTR-96/04, 140 p. (Available from Denver Service Center, Technical Information Center, P. O. Box 25287, Denver, CO 80225-0287.)

James, M. C., and O. L. Meehean. 1944. Propagation and distribution of food fishes, calendar year 1942. U.S. Fish Wildl. Serv. Statistical Digest 9, 27 p.

James, M. C., and O. L. Meehean. 1945. Propagation and distribution of food fishes, calendar year 1943. U.S. Fish Wildl. Serv. Statistical Digest 12, 25 p.

Johnson, R. L. 1977. A management program for the Quinault sockeye salmon (*Oncorhynchus nerka*, Walbaum) fishery. Master's Thesis, Univ. Washington, Seattle, 58 p.

Johnson, R. S. 1914. The distribution of fish and fish eggs during the fiscal year 1913. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1913, Bur. of Fish. Doc. 794, 122 p.

Johnson, R. S. 1915. The distribution of fish and fish eggs during the fiscal year 1914. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1914, Bur. of Fish. Doc. 808, 114 p.

Johnson, R. S. 1916. The distribution of fish and fish eggs during the fiscal year 1915. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1915, Bur. of Fish. Doc. 828, 138 p.

Johnson, W. E., and C. Groot. 1963. Observations on the migration of young sockeye salmon (*Oncorhynchus nerka*) through a large, complex lake system. J. Fish. Res. Board Can. 20:919-938.

Jordan, D. S., and B. W. Evermann. 1896. The fishes of North and Middle America. U.S. Natl. Mus. Bull. 47(Part 1), 954 p.

Jordan, D. S., and C. H. Gilbert. 1881a. Notes on the fishes of the Pacific coast of the United States. Proc. U.S. Natl. Mus. 4:29-70.

Jordan, D. S., and C. H. Gilbert. 1881b. Observations on the salmon of the Pacific. Am. Nat. 15(3):177-186.

Kaeriyama, M., S. Urawa, and T. Suzuki. 1992. Anadromous sockeye salmon (*Oncorhynchus nerka*) derived from nonanadromous kokanees: Life history in Lake Toro. Sci. Rep. Hokkaido Salmon Hatchery 46:157-174.

Kemmerich, J. 1939. Letter to Dr. R. E. Foerster from J. Kemmerich, dated 21 June 1939 and titled, “Subject: Ozette Lake Sockeye Salmon Work.” *In* Miscellaneous sockeye runs to streams in Washington, File 1510.1-1, Pacific Salmon Commission Library. 1 p. plus 4 p. attachment. (Available from Librarian, Pacific Salmon Commission, Suite 600-1155 Robson Street, Vancouver, B.C., Canada V6E 1B9.)

Kemmerich, J. 1945. A review of the artificial propagation and transplantation of the sockeye salmon of the Puget Sound area in the state of Washington conducted by the federal government from 1896 to 1945. Unpubl. manusc., 76 p. plus tables. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Kershaw, T. R. 1902. Thirteenth annual report of the state fish commissioner to the governor of the State of Washington. Metropolitan Press, Seattle, 92 p.

Killick, S. R. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning and death. Int. Pac. Salmon Fish. Comm. Bull. 7:1- 95.

Killick, S. R., and W. A. Clemens. 1963. The age, sex ratio and size of Fraser River sockeye salmon 1915 to 1960. Int. Pac. Salmon Fish. Comm. Bull. 14:1-140.

Kimsey, J. B. 1951. Notes on kokanee spawning in Donner Lake, California. Calif. Fish Game 37:273-279.

Kirpichnikov, V. S., and I. M. Ivanova. 1977. Variation in the frequencies of the alleles of the lactate dehydrogenase and phosphoglucomutase loci in local populations, different age groups, and successive generations of sockeye salmon (*Oncorhynchus nerka*). Sov. Genet. 13:791-799.

Kirpichnikov, V. S., G. A. Muske, A. D. Scholl-Engberts, V. M. Chernov, and S. N. Borchsenius. 1990. Genetic structure and allele frequency dynamics in the sockeye salmon population of Lake Dalneye, Kamchatka. Aquaculture 84:13-25.

Kline, P., and J. Younk. 1995. Research and recovery of Snake River sockeye salmon. Annual report 1994. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 91-72, Contract No. DE-BI79-91BP21065, Portland, OR, 47 p.

Kloempken, K. 1996. Letter to R. Gustafson, NMFS, from K. Kloempken, WDFW, re. information request on kokanee planting records, dated 4 November 1996. 3 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Knapp, G., and T. Johnson. 1995. The Russian salmon industry, an initial review. Div. of Trade & Development, Alsk. Dep. Commerce and Economic Development, Juneau, AK, 62 p. (Available from Alaska Division of Trade and Development, P. O. Box 110804, Juneau, AK 99801.)

Knutzen, D. 1995. Letter to R. Gustafson, NMFS, from D. Knutzen, WDFW, re. Historical kokanee planting records for Lake Wenatchee, Lake Pleasant, Lake Ozette, Lake Shannon, and Baker Lake from 1981-1994, dated 17 July 1995. 1 p. plus attachment. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Kobayashi, T. 1980. Salmon propagation in Japan. *In* J. E. Thorpe (ed.) Salmon ranching, p. 91-107. Academic Press, New York.

Kolb, R. 1971. A review of Lake Washington sockeye (*Oncorhynchus nerka*) age and racial characteristics as determined by scale analysis. Suppl. Prog. Rep. Mar. Fish. Invest., Wash. Dep. Fish., p. 1-9.

Konkel, G. W., and J. D. McIntyre. 1987. Trends in spawning populations of Pacific anadromous salmonids. U.S. Fish Wildl. Serv. Tech. Rep. 9, 25 p.

Konovalov, S. M. 1975. Differentiation of local populations of sockeye salmon *Oncorhynchus nerka* (Walbaum). Univ. Wash. Publ. Fish. New Ser. 6, 290 p. [Translated by L.V. Sagen]

Konovalov, S. M. 1980. U. S. S. R.: Salmon ranching in the Pacific. *In* J. E. Thorpe (ed.) Salmon ranching, p. 63-89. Academic Press, New York.

Koo, T. S. Y. 1962. Age designation in salmon. *In* T. S. Y. Koo (editor), Studies of Alaska red salmon, p. 41-48. Univ. Washington Press, Seattle, WA.

Kostow, K. 1996a. Memorandum to R. Gustafson (NMFS) from K. Kostow (ODFW), dated 19 March 1996 and titled, "Subject: ODFW *O. nerka* hatchery records in Wallowa and Metolius subbasins," 18 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Kostow, K. 1996b. The status of salmon and steelhead in Oregon. *In* D. J. Stouder, P. A. Bisson, and R. J. Naiman (editors), Pacific salmon and their ecosystems, status and future options, p. 145-178. Chapman & Hall, New York.

Krogius, F. V. 1958. O stroenii cheshui kamchatskoi krasnoi raznykh lokalnykh stad. *In* Materialy po biologii moskovo perioda zhizni dalnevostochnykh lososei, p. 52-63. [On scale pattern of Kamchatka sockeye of different populations.] VNIRO, Moscow. (Translated by R. E. Foerster, Fish. Res. Board Can. Transl. Ser. No. 181, 1958.)

Kyle, G. B., J. P. Koenings, and B. M. Barrett. 1988. Density-dependant, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island, Alaska. Can. J. Fish. Aquat. Sci. 45:856-867.

Landry, M. R., J. R. Postel, W. K. Peterson, and J. Newman. 1989. Broad-scale distributional patterns of hydrographic variables on the Washington/Oregon shelf. *In* M. R. Landry and B. M. Hickey (editors), Coastal oceanography of Washington and Oregon, p. 1-40. Elsevier, New York.

Langness, O. P. 1991. Summer chinook salmon spawning ground surveys of the Methow and Okanogan River Basins in 1990. Confederated Tribes of the Colville Reservation, Fish and Wildlife Dep., Rep. to Chelan County PUD, 87 p.

LaRiviere, M. G. 1990. 1989 Lake Ozette sockeye smolt outmigration. Progress report, Makah Fisheries Management 90-2, 7 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

LaRiviere, M. G. 1991. The Lake Ozette sockeye salmon enhancement program. Makah Fisheries Management Department, Unpubl. rep., 9 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Larson, S. B. 1975. Dig the ditch: The history of the Lake Washington Ship Canal. King County Arts Commission, King County Department of Public Works, Seattle, 48 p.

Lawson, P. W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries 18(8):6-10.

Leach, G. C. 1920. The distribution of fish and fish eggs during the fiscal year 1919. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1919. Bur. Fish. Doc. 878, 76 p.

Leach, G. C. 1922. Propagation and distribution of food fishes, 1921. Appendix IX to the Report of the U.S. Commissioner of Fisheries for 1921. Bur. Fish. Doc. 912, 94 p.

Leach, G. C. 1923. Propagation and distribution of food fishes, 1922. Appendix XVII to the Report of the U.S. Commissioner of Fisheries for 1922. Bur. Fish. Doc. 941, 116 p.

Leach, G. C. 1924. Propagation and distribution of food fishes, fiscal year 1923. Appendix XIII to the Report of the U.S. Commissioner of Fisheries for 1923. Bur. Fish. Doc. 964, 108 p.

Leach, G. C. 1925. Propagation and distribution of food fishes, fiscal year 1924. Appendix V to the Report of the U.S. Commissioner of Fisheries for 1924, p. 361-440. Bur. Fish. Doc. 978.

Leach, G. C. 1926. Propagation and distribution of food fishes, fiscal year 1925. Appendix V to the Report of the U. S. Commissioner of Fisheries for 1925, p. 439-500. Bur. Fish. Doc. 999.

Leach, G. C. 1927. Propagation and distribution of food fishes, fiscal year 1926. Appendix VI to the Report of the U. S. Commissioner of Fisheries for 1926, p. 323-384. Bur. Fish. Doc. 1011.

Leach, G. C. 1928. Propagation and distribution of food fishes, fiscal year 1927. Appendix VIII to the Report of the U.S. Commissioner of Fisheries for 1927, p. 683-736. Bur. Fish. Doc. 1033.

Leach, G. C. 1929. Propagation and distribution of food fishes, fiscal year 1928. Appendix VIII to the Report of the Commissioner of Fisheries for 1928, p. 339-399. Bur. Fish. Doc. 1049.

Leach, G. C. 1930. Propagation and distribution of food fishes, fiscal year 1929. Appendix XII to Report of the Commissioner of Fisheries for the fiscal year 1929, p. 759-823. Bur. Fish. Doc. 1070.

Leach, G. C. 1931. Propagation and distribution of food fishes, fiscal year 1930. Appendix XVI to Report of the Commissioner of Fisheries for the fiscal year 1930, p. 1123-1191. Bur. Fish. Doc. 1098.

Leach, G. C. 1932. Propagation and distribution of food fishes, fiscal year 1931. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1931, p. 627-690.

Leach, G. C. 1933. Propagation and distribution of food fishes, fiscal year 1932. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1932, p. 531-569.

Leach, G. C. 1934. Propagation and distribution of food fishes, fiscal year 1933. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1933, p. 451-484.

Leach, G. C., and M. C. James. 1934. Propagation and distribution of food fishes, fiscal year 1934. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1934, p. 385-417.

Leach, G. C., and M. C. James. 1936. Propagation and distribution of food fishes, fiscal year 1935. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1935, p. 401-427. Administrative Rep. No. 22.

Leach, G. C., and M. C. James. 1937. Propagation and distribution of food fishes, fiscal year 1936. Appendix III to Report of the Commissioner of Fisheries for the fiscal year 1936, p. 349-379. Administrative Rep. No. 25.

Leach, G. C., and M. C. James. 1938. Propagation and distribution of food fishes, fiscal year 1937. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1937, p. 461-492. Administrative Rep. No. 33.

Leach, G. C., M. C. James, and E. J. Douglass. 1939. Propagation and distribution of food fishes, fiscal year 1938. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1938, p. 461-494. Administrative Rep. No. 34.

Leach, G. C., M. C. James, and E. J. Douglass. 1940. Propagation and distribution of food fishes, fiscal year 1939. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1939, p. 555-598. Administrative Rep. No. 38.

Leach, G. C., M. C. James, and E. J. Douglass. 1941. Propagation and distribution of food fishes, fiscal year 1940. Appendix IV to Report of the Commissioner of Fisheries for the fiscal year 1940, p. 555-603. Administrative Rep. No. 42.

Leach, G. C., M. C. James, and E. J. Douglass. 1942. Propagation and distribution of food fishes, fiscal year 1941. U.S. Fish Wildl. Serv. Statistical Digest No. 3, 25 p.

Leach, G. C., M. C. James, and E. J. Douglass. 1943. Propagation and distribution of food fishes, calendar year 1941. U.S. Fish Wildl. Serv. Statistical Digest No. 6, 26 p.

Leonard, W. P., H. A. Brown, L. L. Jones, K. R. McAllister, and R. M. Storm. 1993. Amphibians of Washington and Oregon. Seattle Audubon Society, Seattle, WA, 168 p.

Lestelle, L. and L. Workman. 1990. Proposed sockeye hatchery. Quinault Natural Resources 13(1):6-7.

Levings, C. D., D. E. Boyle, and T. R. Whitehouse. 1995. Distribution and feeding of juvenile Pacific salmon in freshwater tidal creeks of the lower Fraser River, British Columbia. Fish. Manage. Ecol. 2:299-308.

Levy, D. A. 1987. Review of the ecological significance of diel vertical migrations by juvenile sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:44-52.

Lewis, S. L. 1972. Life history and ecology of kokanee in Odell Lake. Job Progress Rep., Project No. F-71-R-8, Oregon State Game Commission, Portland, OR, 71 p.

Linley, T. J. 1993. Patterns of life history variation among sockeye salmon (*Oncorhynchus nerka*) in the Fraser River, British Columbia. Ph.D. Thesis, Univ. Washington, Seattle, WA, 162 p.

Lorenz, J. M., and J. H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Trans. Am. Fish. Soc. 118:495-502.

Major, R. L., and D. R. Craddock. 1962. Influence of early maturing females on reproductive potential of Columbia River blueback salmon (*Oncorhynchus nerka*). U.S. Fish Wildl. Serv., Fish. Bull. 61:429-437.

Major, R. L, and R. L. Mighell. 1966. Influence of Rocky Reach Dam and the temperature of the Okanogan River on the upstream migration of sockeye salmon. U.S. Fish. Wildl. Serv., Fish. Bull. 66(1):131-147.

Makah Fisheries Management Department (MFMD). 1995. Ozette sockeye BY 1994. Data sheets containing length, sex, and age of sockeye salmon utilized in 1994 Ozette Lake Makah Hatchery program. 3 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Makah Fisheries Management Department (MFMD). No date. Ozette sockeye. (Prepared for 1992-93 Washington State Salmon and Steelhead Stock Inventory). 2 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Manzer, J. I., and I. Miki. 1985. Fecundity and egg retention of some sockeye salmon (*Oncorhynchus nerka*) stocks in British Columbia. Can. J. Fish. Aquat. Sci. 43:1643-1655.

Manzer, J. I., M. Wright, I. Miki, and K. D. Hyatt. 1984. Abundance, upstream migration, age-composition and fecundity of Hobiton Lake adult sockeye salmon (*Oncorhynchus nerka*), 1982. Can. Tech. Rep. Fish. Aquat. Sci. 1262, 57 p.

Margolis, L. 1963. Parasites as indicators of the geographical origin of sockeye salmon, *Oncorhynchus nerka* (Walbaum), occurring in the North Pacific Ocean and adjacent seas. Int. North Pac. Fish. Comm. Bull. 11:31-56

Margolis, L., F. C. Cleaver, Y. Fukuda, and H. Godfrey. 1966. Salmon of the North Pacific Ocean — Part VI. Sockeye salmon in offshore waters. Int. North Pac. Fish. Comm. Bull. 20:70 p.

Marshall, D. E., R. F. Brown, G. A. Buxton, V. D. Chahley, and D. G. Demontier. 1978. Preliminary catalogue of salmon streams and spawning escapements of statistical area 2E (Queen Charlotte Islands). Fish. Mar. Serv. Data Rep. 72, 346 p.

Martz, M., F. Goetz, J. Dillon, and T. Shaw. 1996. Early lake life distribution of sockeye salmon in Lake Washington [Abstract]. *In* Western Division American Fisheries Society, 1996 Annual Meeting Program and Abstracts July 14-18, 1996.

McCart, P. J. 1970. A polymorphic population of *Oncorhynchus nerka* at Babine Lake, B. C. involving anadromous (sockeye) and non-anadromous (kokanee) forms. Ph.D. Thesis, Univ. British Columbia, Vancouver, B.C., 135 p.

McGee, J. A., and K. Truscott. 1982. Juvenile salmonid monitoring Okanogan River and Wells Dam forebay April-May 1982. Douglas County PUD, East Wenatchee, WA.

McGee, J. A., R. Rulifson, C. Heath, and R. F. Leland. 1983. Juvenile salmon monitoring Methow River, Okanogan River and Wells Dam forebay April-May 1983. Douglas County PUD, East Wenatchee, WA.

McHenry, M. L., D. C. Morrill, and E. Currence. 1994. Spawning gravel quality, watershed characteristics and early life history survival of coho salmon and steelhead in five north Olympic Peninsula watersheds. Lower Elwha S'Klallam Tribe and Makah Tribe, Port Angeles and Neah Bay, WA, 59 p. plus appendix

McKee, B. 1972. Cascadia. The geologic evolution of the Pacific Northwest. McGraw-Hill Book Co., New York, 394 p. [Reprinted 1992 by TechBooks, Fairfax, VA.]

McKinnell, S. 1995. Age-specific effects of sockeye abundance on adult body size of selected British Columbia sockeye stocks. Can. J. Fish. Aquat. Sci. 52:1050-1063.

McPhail, J. D., and C. C. Lindsey. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia system and rivers north to the Stikine). *In* C. H. Hocutt and E. O. Wiley (editors), Zoogeography of North American freshwater fishes, p. 615-637. Wiley Interscience Publications, New York.

McPherson, S. A., and A. J. McGregor. 1986. Abundance, age, sex and size of sockeye salmon (*Oncorhynchus nerka* Walbaum) catches and escapements in southeastern Alaska in 1985. Alsk. Dep. Fish Game Tech. Data Rep. 188, 122 p.

Mesner, N., and J. Davis. 1984. Water quality in nearshore Lake Sammamish King County, Washington: 1983 baseline monitoring report. Tech Rep. WR-85-1, Municipality of Metropolitan Seattle, Water Quality Division, Seattle, WA, 59 p.

Miller, J. D., L. K. Brannian, and B. A. Cross. 1994. Sonar enumeration of Pacific salmon into Nushagak River and evaluation of species composition estimates, 1992. Alsk. Dep. Fish Game Tech. Fish. Rep. 94-06, 75 p.

Miller, R. J., and E. L. Brannon. 1982. The origin and development of life history patterns in Pacific salmonids. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 296-309. School of Fisheries, Univ. Washington, Seattle, WA.

Miller, W. H., T. C. Coley, H. L. Burge, and T. T. Kisanuki. 1990. Analysis of salmon and steelhead supplementation: emphasis on unpublished reports and present programs. Part 1. Report submitted to U. S. Department of Energy, Bonneville Power Administration, Project No. 88-100, 46 p. plus appendices.

Millimann, R. E., and S. E. Knapp. 1970. Biology of *Nanophyetus salminicola* and "salmon poisoning" disease. Advances in Parasitology, B. Dawes (ed.), Academic Press, London, 8:1-41.

Milner, A. M., and R. G. Bailey. 1989. Salmonid colonization of new streams in Glacier Bay National Park, Alaska. Aquacult. Fish. Manage. 20:179-192.

Minckley, W. L., D. A. Hendrickson, and C. E. Bond. 1986. Geography of western North American freshwater fishes: Description and relationships to intracontinental tectonism. *In* C. H. Hocutt and E. O. Wiley (editors), Zoogeography of North American freshwater fishes, p. 519-613. Wiley Interscience Publications, New York.

Mitchell, S. 1980. The fish passage issue at Enloe Dam, an assessment. Wash. Dep. Ecol., State Water Program, Olympia, WA, 15 p.

Moberly, S. A., and R. Lium. 1977. Japan salmon hatchery review. Alsk. Dep. Fish Game, Juneau, AK, 124 p.

Moles, A., P. Rounds, and C. Kondzela. 1990. Use of the brain parasite *Mysobolus neurobius* in separating mixed stocks of sockeye salmon. Am. Fish. Soc. Symp. 7:224-231.

Monaco, M. E., T. A. Lowery, and R. L. Emmett. 1992. Assemblages of U.S. west coast estuaries based on the distribution of fishes. J. Biogeogr. 19:251-267.

Mosley, R. A. 1995. Letter to R. Gustafson, NMFS, from R. A. Mosley, WDFW, re. Lake Pleasant sockeye spawner data, dated 7 November 1995. 1 p. plus attachment. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Moser, J. F. 1899. The salmon and salmon fisheries of Alaska. Report of the Operations of the United States Fish Commission Steamer Albatross for the year ending June 30, 1898. U.S. Government Printing Office, Washington, D.C, 178 p.

Mud Mountain Dam Fish Haul Report (MMDFHR). Seattle District, WA. U. S. Army Corps of Engineers, 1996—. (Available through Online Internet database at http://www.nps.usace.army.mil/fish/mmdfish.htm)

Mullan, J. W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880's-1982: A review and synthesis. U.S. Fish Wildl. Serv. Biol. Rep. 86(12), 135 p.

Murphy, M.L., K V. Koski, J. M. Lorenz, and J. F. Thedinga. 1988. Migrations of juvenile salmon in the Taku River, Southeast Alaska. NWAFC Processed Rep. 88-31, 39 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, Southeast Alaska. Can. J. Fish. Aquat. Sci. 46:1677-1685.

Murphy, M. L., J. M. Lorenz, and K V. Koski. 1991. Population estimates of juvenile salmon downstream migrants in the Taku River, Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC 203, 27 p.

National Marine Fisheries Service (NMFS). 1991. Notice of policy: Policy on applying the definition of species under the Endangered Species Act to Pacific salmon. Federal Register [Docket 910248-1255, 20 November 1991] 56(224):58612-58618.

National Marine Fisheries Service (NMFS). 1993. Interim policy on artificial propagation of Pacific salmon under the Endangered Species Act. Federal Register [Docket 921186-2286, 5 April 1993] 58(63):17573-17576.

National Marine Fisheries Service (NMFS). 1994. Listing endangered and threatened species and designating critical habitat: Initiation of status reviews for pink salmon, chum salmon, sockeye salmon, chinook salmon, and sea-run cutthroat trout populations in Washington, Oregon, Idaho, and California. Federal Register [I.D. 081694D, 12 September 1994] 59(175):46808-46810.

National Marine Fisheries Service (NMFS). 1996. Factors for decline: A supplement to the Notice of determination for West Coast Steelhead under the Endangered Species Act. NMFS Protected Species Branch, Portland, OR, 82 p. plus appendices.

National Park Service (NPS). 1995. Final environmental impact statement: Elwha River ecosystem restoration, Olympic National Park, Washington. U.S. Dep. Interior, Denver, CO, 674 p. (Available from United States Department of the Interior, National Park Service, Denver Service Center-DSC-TWE, P.O. Box 25287, Denver, CO, 80225-0287.)

Natural Resources Consultants (NRC). 1995. Artificial propagation of anadromous Pacific salmonids: west coast sockeye salmon. Electronic database submitted to Coastal Zone and Estuarine Studies Division, Northwest Fisheries Science Center, Natl. Mar. Fish. Serv. Contract No. 50ABNF400128, 1.8 MB.

Natural Resource Council Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (NRCC). 1996. Upstream: Salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C., 452 p.

Nehlsen, W. 1995. Historical salmon and steelhead runs of the upper Deschutes River basin and their environments. Report to Portland General Electric Company, Portland, OR, 65 p. plus references and appendices. (Available from Portland General Electric Company, Hydro Licensing Department, Attn: Marty May, 3WTCBR04, 121 SW Salmon St., Portland, OR 97204.)

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Nei, M. 1978. Estimation of average heterozygosity and genetic distance from a small number of individuals. Genetics 89:583-590.

Nelson, J. S. 1968. Variation in gillraker number in North American kokanee, *Oncorhynchus nerka*. J. Fish. Res. Board Can. 25(2):415-420.

Nielson, R. S. 1950. Survey of the Columbia River and its tributaries - Part V. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 38, 41 p.

Northcote, T. G., and P. A. Larkin. 1956. Indices of productivity in British Columbia lakes. J. Fish. Res. Board Can. 13(4):515-540.

Oakley, A. L., and T. E. Kruse. 1963. Occurrence of a sockeye salmon stray in an Oregon coastal river. Oreg. Fish. Comm. Res. Briefs 9(1):68.

O’Connor, D., R. Tomsinski, S. Allen, and D. Reece. 1993. Columbia River Coordinated Information System data catalog. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. 12 p. plus appendices.

Oglesby, R. T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. J. Fish. Res. Board Can. 34:2271-2279.

Ogura, M., Y. Ishida, and S. Ito. 1991. Growth variation of coho salmon *Oncorhynchus kisutch* in the Western North Pacific. Nippon Suisan Gakkaishi 57:1089-1093.

Olsen, E. A., P. M. P. Beamesderfer, M. L. McLean, and E. S. Tinus. 1994. Salmon and steelhead stock summaries for the Deschutes River Basin: An interim report. Oreg. Dep. Fish Wildl., Portland, 136 p.

O’Malley, H. 1917. The distribution of fish and fish eggs during the fiscal year 1916. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1916. Bur. of Fish. Doc. 837, 111 p.

O’Malley, H. 1918. The distribution of fish and fish eggs during the fiscal year 1917. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1917. Bur. of Fish. Doc. 846, 99 p.

O’Malley, H. 1919. The distribution of fish and fish eggs during the fiscal year 1918. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1918. Bur. of Fish. Doc. 863, 82 p.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Ann. Assoc. Am. Geogr. 77(1):118-125.

Omernik, J. M., and A. L. Gallant. 1986. Ecoregions of the Pacific Northwest. U.S. Environ. Protec. Agen. Rep. EPA/600/3-86/033, 39 p.

Oregon Department of Fish and Wildlife (ODFW). 1995a. Biennial report on the status of wild fish in Oregon. Oregon Dep. Fish Wildl., Portland. 217 pp. plus 1 appendix.

Oregon Department of Fish and Wildlife (ODFW). 1995b. Oregon Game Commission Stocking Records, Watersheds 3-6. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Orrell, R. F. 1969. Baker project sockeye artificial spawning beaches annual report 1967-1968 season. Puget Sound Power and Light Co., Contract No. D-33347, Wash. Dep. Fish., Olympia, WA, 14 p.

Ostergaard, E. 1996. 1995 status report: Abundance of spawning kokanee in the Sammamish River Basin. Addendum to 1994 status report. King County Surface Water Management Division. 22 p. plus 5 appendices. (Available from King County Surface Water Management Division, 700 Fifth Ave., Suite 2200, Seattle, WA 98104.)

Ostergaard, E., C. Young, and K. Ludwa. 1995. Abundance of spawning kokanee in the Sammamish River Basin. 1994 status report. King County Surface Water Management Division. 194 p. (Available from King County Surface Water Management Division, 700 Fifth Ave., Suite 2200, Seattle, WA 98104.)

Pacific Fisherman. 1905a. The propagation of sockeye salmon in Puget Sound: Other notes of hatchery operation. Pac. Fisherman 3(9):15-16.

Pacific Fisherman. 1905b. News items from fisheries districts: Puget Sound. Pac. Fisherman 3(9):31.

Pacific Fisherman. 1906. News items from the fisheries districts, Puget Sound, marked sockeye for river. Pac. Fisherman 4(5):16.

Pacific Fisherman. 1915a. Will propagate sockeyes in the Samish Hatchery. Pac. Fisherman 13(4):28.

Pacific Fisherman. 1915b. Hatching sockeyes in the Samish River. Pac. Fisherman 13(9):26.

Pacific Fisherman. 1916. Deming to again aid state in Samish Hatchery. Pac. Fisherman 14(4):22.

Pacific Fisherman. 1918. Sockeyes for Samish Hatchery. Pac. Fisherman 16(7):35.

Pacific Fishery Management Council (PFMC). 1995. Vital habitat concerns. Pacific Fishery Management Council, Portland, OR, 19 p. plus appendices.

Pahlke, K. A. 1989. Length conversion equations for sockeye, chinook, chum and coho salmon in southeast Alaska. Alsk. Dep. Fish Game Fish. Res. Bull., 89-02, 15 p.

Pahlke, K. A., and R. R. Riffe. 1988. Compilation of catch, escapement, age, sex, and size data for salmon returns to the Yakutat area in 1986. Alsk. Dep. Fish Game Tech. Data Rep. 224, 151 p.

Paragamian, V. L., V. L. Ellis, and S. Andersen. 1993. Kokanee stock status and contribution of Cabinet Gorge Hatchery, Lake Pend Oreille, Idaho, Annual Progress Report for FY 1991. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 85-339, Contract No. DE-A179-85BP22493, Portland, OR, 73 p.

Parkhurst, Z. E. 1950a. Survey of the Columbia River and its tributaries - Part VI. Area V-Snake River system from the mouth through the Grande Ronde River. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 39, 58 p.

Parkhurst, Z. E. 1950b. Survey of the Columbia River and its tributaries - Part VII. Area VI-Snake River system from above the Grande Ronde River through the Payette River. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 40, 95 p.

Pauley, G. B., R. Risher, and G. L. Thomas. 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) - sockeye salmon. U.S. Fish Wildl. Serv., Biol. Rep. 82(11.116). U.S. Army Corps of Engineers, TR EL-82-4, 22 p.

Pearcy, W. G. 1992. Ocean ecology of North Pacific salmonids. Washington Sea Grant Prog., distributed by Univ. Washington Press, Seattle, WA, 179 p.

Peterman, R. M. 1984. Density-dependent growth in early ocean life of sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 41:1825-1829.

Peterman, R. M. 1985. Patterns of interannual variation in age at maturity of sockeye salmon (*Oncorhynchus nerka*) in Alaska and British Columbia. Can. J. Fish. Aquat. Sci. 42:1595-1607.

Peven, C. M. 1987. Downstream migration timing of two stocks of sockeye salmon on the Mid-Columbia River. Northwest Sci. 61(3):186-190.

Pfeifer, B. 1978. Evaluation of the natural reproduction of kokanee (*Oncorhynchus nerka* Walbaum) in Lake Stevens, Washington, as related to the lake limnology and basin. Master's Thesis, Univ. Washington, Seattle, WA, 328 p.

Pfeifer, B. 1992. Fisheries investigations of Lakes Washington and Sammamish — 1980-1990. Part V. Wild cutthroat and kokanee in Lakes Washington and Sammamish (draft document). Wash. Dep. Game. 210 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Phinney, L. A., and P. Bucknell. 1975. A catalog of Washington streams and salmon utilization, Vol. 2: Coastal region. R. W. Williams (editor), Wash. Dep. of Fish., Olympia, WA. 477 p. plus appendices.

Poe, P. H., and O. A. Mathisen. 1981. Distances from sea and elevation of important sockeye salmon spawning grounds. Univ. Wash. Fish. Res. Inst. Circular No. 81-1, 23 p.

Pratt, D. C., and E. D. Jewell. 1972. The 1971 Lake Washington sockeye tagging study final report. Wash. Dep. Fish., Olympia, WA. 34 p.

Professional Resource Organization-salmon (PRO-Salmon). 1994. Petition for a rule to list nine Puget Sound salmon populations as threatened or endangered under the Endangered Species Act and to designate critical habitat. Petition to the U.S. National Marine Fisheries Service, March 1994, 86 p.

Quinault Indian Nation (QIN). 1981. 1981 preseason management report for spring and summer fisheries on the Quinault and Queets Rivers. Harvest Management Section, Quinault Fisheries Division, 82 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quinault Indian Nation (QIN). 1995a. Computer disk submitted by Quinault Indian Nation (computer files titled “sizenage.txt” and “blueback.zip”) containing data on sockeye salmon collected in in-river fishery on Quinault and Queets Rivers (species, river, date, statistical week, sex, weight, length, freshwater age, saltwater age from 1971 to 1993). (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quinault Indian Nation (QIN). 1995b. Artificial propagation records submitted to the Administrative Record for sockeye salmon. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quinault Indian Nation (QIN). 1995c. Draft preseason management report for spring and summer fisheries in the Quinault River for 1995. Harvest Management Section, Quinault Fisheries Division, Taholah, WA, 11 p.

Quinn, T.P. 1980. Evidence for celestial and magnetic compass orientation in lake migrating sockeye salmon fry. J. Comp. Physiol. 137:243-248.

Quinn, T.P. 1981. Compass orientation of juvenile sockeye salmon (*Oncorhynchus nerka*). Ph.D. Thesis, Univ. Washington, Seattle, WA, 89 p.

Quinn, T.P. 1985. Homing and evolution of sockeye salmon (*Oncorhynchus nerka*). *In* M. A. Rankin (editor), Migration: Mechanisms and adaptive significance. Contrib. Mar. Sci. (Suppl.) 27:353-366.

Quinn, T.P., and D. J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology 77:1151-1162.

Quinn, T. P., A. P. Hendry, and L. A. Wetzel. 1995. The influence of life history trade-offs and the size of incubation gravels on egg size variation in sockeye salmon (*Oncorhynchus nerka*). Oikos 74:425-438.

Quinn, T. P., C. C. Wood, L. Margolis, B. E. Riddell, and K. D. Hyatt. 1987. Homing in wild sockeye salmon (*Oncorhynchus nerka*) populations as inferred from differences in parasite prevalence and allozyme allele frequencies. Can. J. Fish. Aquat. Sci. 44:1963-1971.

Quistorff, E. 1954a. Notes on stream observations - Baker River: September 9-12, 1954. Wash. Dep. Fish., Olympia, WA, 7 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quistorff, E. 1954b. Notes on stream observations - Baker River: September 17-22, 1954. Wash. Dep. Fish., Olympia, WA, 5 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quistorff, E. 1954c. Notes on stream observations - Baker River: September 28 - October 2, 1954. Wash. Dep. Fish., Olympia, WA, 8 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quistorff, E. 1955. A preliminary report on the Puget Sound Power and Light Company, Baker River fisheries survey project September, 1954 - December, 1954. Puget Sound Power and Light and Wash. Dep. Fish., Olympia, WA, 5 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quistorff, E. 1959. Sockeye spawning beach, Baker Lake: The problem confronted and accomplishments to date, 1959. Wash. Dep. Fish., Olympia, WA, 8 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Quistorff, E. 1966. Floating salmon smolt collectors at Baker River dams. Wash. Dep. Fish. Fish. Res. Pap. 2(4):39-52.

Raleigh, R. F. 1967. Genetic control in the lakeward migrations of sockeye salmon (*Oncorhynchus nerka*) fry. J. Fish. Res. Board Can. 24:2613-2622.

Rathbun, R. 1900. A review of the fisheries in the contiguous waters of the state of Washington and British Columbia. Report of the Commissioner for the year ending June 30, 1899, U. S. Comm. Fish and Fisheries 25:251-350.

Ravenel, W. de C. 1901. Report on the propagation and distribution of food-fishes. Report of the Commissioner for the year ending June 30, 1900, U. S. Comm. Fish and Fisheries 26:25-118.

Ravenel, W. de C. 1902. Report on the propagation and distribution of food-fishes. Report of the Commissioner for the year ending June 30, 1901, U. S. Comm. Fish and Fisheries 27:21-110.

Rawson, D. S. 1952. Mean depth and the fish production of large lakes. Ecology 33(4):513-521.

Regenthal, A. F. 1955. Report on the test of a ski-jump spillway. Wash. Dep. Fish., Olympia, WA. 8 p.

Rensel, J. 1995. Water quality and sockeye salmon rearing in Lake Osoyoos during 1994. Draft Report of Rensel Associates, Arlington, WA. to Douglas County PUD, East Wenatchee, WA. (As quoted by Chapman et al. 1995).

Rice, S. D., R. E. Thomas, and A. Moles. 1994. Physiological and growth differences in three stocks of underyearling sockeye salmon (*Oncorhynchus nerka*) on early entry into seawater. Can. J. Fish. Aquat. Sci. 51:974-980.

Ricker, W. E. 1937. Physical and chemical characteristics of Cultus Lake, British Columbia. J. Biol. Board Can. 3(4):363-402.

Ricker, W. E. 1938. “Residual” and kokanee salmon in Cultus Lake. J. Fish. Res. Board Can. 4(3):192-218.

Ricker, W. E. 1940. On the origin of kokanee, a fresh-water type of sockeye salmon. Trans. R. Soc. Can., Ser. 3, 34(5):121-135.

Ricker, W. E. 1950. Cyclic dominance among the Fraser River sockeye. Ecology 31:6-26.

Ricker, W. E. 1959. Additional observations concerning residual sockeye and kokanee (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 16(6):897-902.

Ricker, W. E. 1966. Salmon of the North Pacific Ocean - Part III. A review of the life history of North Pacific salmon. 4. Sockeye salmon in British Columbia. Int. North Pac. Fish. Comm. Bull. 18:59-70.

Ricker, W. E. 1972. Hereditary and environmental factors affecting certain salmonid populations. *In* R.C. Simon and P.S. Larkin (editors), The stock concept in Pacific salmon, p. 19-160. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C., Canada.

Ricker, W. E. 1982. Size and age of British Columbia sockeye salmon (*Oncorhynchus nerka*) in relation to environmental factors and the fishery. Can. Tech. Rep. Fish. Aquat. Sci. 1115, 117 p.

Ricker, W. E. 1995. Trends in the average size of Pacific salmon in Canadian catches. Can. Spec. Publ. Fish. Aquat. Sci. No. 121, 593-602.

Ricker, W. E. 1997. Cycles of abundance among Fraser River sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 54:950-968.

Riggs, L. A. 1990. Principles for genetic conservation and production quality. Report to Northwest Power Planning Council, Portland, OR.

Robertson, A. 1922. Further proof of the parent stream theory. Trans. Am. Fish. Soc. 51:87-90.

Robison, B. D. 1995. Genetic relationships between maternal lineages of sympatric anadromous and resident forms of *Oncorhynchus nerka* determined through PCR RFLP analysis of mtDNA. Master's Thesis, Univ. Idaho, Boise, ID, 53 p.

Rogers, D. E. 1980. Density-dependent growth of Bristol Bay sockeye salmon. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 267-283. Oregon State Univ. Press, Corvallis.

Rogers, D. E. 1987. The regulation of age at maturity in Wood River sockeye salmon (*Oncorhynchus nerka*). Can. Spec. Publ. Fish. Aquat. Sci. 96:78-89.

Rogers, D. E., and G. T. Ruggerone. 1993. Factors affecting marine growth of Bristol Bay sockeye salmon. Fish. Res. (Bethesda) 18:89-103.

Rohlf, F. J. 1993. NTSYS-pc. Numerical taxonomy and multivariate analysis system. Exeter Software, Setauket, N.Y. (Software program).

Roppel, P. 1982. Alaska's salmon hatcheries 1891-1991. Alaska Historical Commission Studies in History 20, Natl. Mar. Fish. Serv., Portland, OR, 299 p.

Roukhlov, F. N. 1982. The role of salmon production and the perspectives of its development in the Sakhalin Region. *In* B. R. Metcalfe and R. A. Neve (editors), Proceedings of the North Pacific aquaculture symposium, August 18-21, 1980, Anchorage, AK, p. 99-103. Alaska Sea Grant Program, Univ. Alaska, Fairbanks. Publ. 82-2.

Rounsefell, G. A. 1957. Fecundity of North American Salmonidae. U.S. Fish. Wildl. Serv., Fish. Bull. 57:451-468.

Rounsefell, G. A. 1958a. Anadromy in North American Salmonidae. U.S. Fish. Wildl. Serv., Fish. Bull. 58:171-185.

Rounsefell, G. A. 1958b. Factors causing decline in sockeye salmon of Karluk River, Alaska. U.S. Fish. Wildl. Serv., Fish. Bull. 58:83-169.

Rounsefell, G. A., and G. B. Kelez. 1938. The salmon and salmon fisheries of Swiftsure Bank, Puget Sound, and the Fraser River. U.S. Bur. Fish., Bull. 49:693-823.

Royal, L. A., and A. Seymour. 1940. Building new salmon runs, Puget Sound sockeye salmon plantings show varying degrees of success. Prog. Fish - Cult. (Memo I-131) 52:7 p.

Ruggles, C. P. 1966. Juvenile sockeye studies in Owikeno Lake, British Columbia. Can. Fish. Cult. 36:3-21.

Russell, R. B., D. L. Bill, and W. A. Bucher. 1989. Salmon spawning ground surveys in the Bristol Bay area, 1988. Alsk. Dep. Fish Game Regional Information Rep., 2K88-14.

Rutherford, D. T., C. C. Wood, and J. R. Candy. 1988. Stock assessments and biological investigations of kokanee (*Oncorhynchus nerka*) in Cowichan Lake, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 1995, 35 p.

Rutherford, D. T., C. C. Wood, K. D. Hyatt, L. Margolis, T. E. McDonald, B. E. Ridell, and R. E. Withler. 1992. Biological characteristics of coastal populations of sockeye salmon (*Oncorhynchus nerka*) in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1849, 47 p.

Rutherford, D. T., C. C. Wood, A. L. Jantz, and D. R. Southgate. 1994. Biological characteristics of Nass River sockeye salmon and their utility for stock composition analysis of test fisheries. Can. Tech. Rep. Fish. Aquat. Sci. 1988, 65 p.

Rutter, C. 1904. Natural history of the quinnat salmon. A report of investigations in the Sacramento River, 1896-1901. U.S. Fish. Comm., Bull. 22:65-141.

Ryder, R. A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94:214-218.

Schaefer, M. B. 1950. A study of the spawning populations of sockeye salmon in the Harrison River system, with special reference to the problem of enumeration by means of marked members. Ph.D. Thesis, Univ. Washington, Seattle, WA, 383 p.

Schaefer, M. B. 1951. A study of the spawning populations of sockeye salmon in the Harrison River system, with special reference to the problem of enumeration by means of marked members. Int. Pac. Salmon Fish. Comm. Bull. 4, 207 p.

Scheffer, V. B., and R. J. Robinson. 1939. A limnological study of Lake Washington. Ecol. Monogr. 9:95-143.

Schultz, L. P., and A. C. DeLacy. 1935-1936. The fishes of the American northwest. A catalogue of the fishes of Washington and Oregon, with distributional records and a bibliography. J. Pan-Pacific Res. Inst. 10:365-380 and Mid. Pac. Mag. 48:63-78, 127-142, 211-226, 275-290.

Schultz, L. P., and Students. 1935. The breeding activities of the little redfish, a landlocked form of the sockeye salmon, *Oncorhynchus nerka*. Journ. Pan-Pacific Res. Inst. 10:67-77.

Scofield, N. B. 1916. The humpback and dog salmon taken in San Lorenzo River. Calif. Dep. Fish Game Fish Bull. 2(1):41.

Scott, D. 1984. Origin of the New Zealand sockeye salmon, *Oncorhynchus nerka* (Walbaum). J. Roy. Soc. N. Z. 14:245-249.

Seale, A. 1895. List of fresh-water fishes collected in the vicinity of Seattle, Washington, by Edwin C. Starks. Proc. Calif. Acad. Sci., Ser. 2, 5(2):852-854.

Seeb, J., and L. Wishard. 1977. Lake Washington sockeye study, p. 26-36. *In* J. Seeb and L. Wishard, The use of biochemical genetics in the management of Pacific salmon stocks: genetic marking and mixed fishery analysis. Final Rep., Wash. Dep. Fish., Serv. Contr. No. 792.

Seiler, D., and L. E. Kishimoto. 1996. Annual report 1995 Cedar River sockeye salmon fry production evaluation program. Wash. Dep. Fish Wildl., Olympia, WA, 9 p. plus figures and tables.

Semko, R. S. 1954. Zapasy zapadnokamchatskikh lososei i ikh promyslovoe ispolzovanie. Isvestiia Ttikhookeanskovo Nauchno-issledovatelskovo Instituta Rybnovo Khoziaistvai. [The stocks of West Kamchatka salmon and their commercial utilization] Okeanografii (Vladisvostok) 41:3-109. (Transl. by R. E. Foerster, Fish. Res. Board Can. Transl. Ser. No. 30, 1960.)

Shaklee, J. B., J. Ames, and L. LaVoy. 1996. Genetic diversity units and major ancestral lineages for sockeye salmon in Washington. Chapter E (Tech. Rep. RAD 95-02/96) *In* C. Busack and J. B. Shaklee (editors), Genetic diversity units and major ancestral lineages of salmonid fishes in Washington, Tech Rep. RAD 95-02. Wash. Dep. Fish Wildl., Olympia, Wash., 37 p. plus figures and appendices.

Shaklee, J. B., D. C. Klaybor, S. Young, and B. A. White. 1991. Genetic stock structure of odd-year pink salmon, *Oncorhynchus gorbuscha* (Walbaum), from Washington and British Columbia and potential mixed-stock fisheries applications. J. Fish. Biol. 39(A):21-34.

Sharr, S., C. Peckham, and G. Carpenter. 1988. Catch and escapement statistics for Copper River, Bering River, and Prince William Sound, 1986. Alsk. Dep. Fish Game Tech. Fish. Rep. 88-17, 254 p.

Shepard, B. G., and B. A. Inkster. 1995. Sockeye and kokanee fry migration study Okanagan River above Osoyoos Lake, 1994. Ministry of Environm., Lands, and Parks, Okanagan Fish. Sect., Fish. Project Rep. OK-18, Penticton, B.C., Canada. (As cited by Chapman et al. 1995)

Shepard, M. P., C. D. Shepard, and A. W. Argue. 1985. Historic statistics of salmon production around the Pacific Rim. Can. Manuscr. Rep. Fish. Aquat. Sci. 1819, 297 p.

Simon, R. C., J. D. McIntyre, and A. R. Hemingsen. 1986. Family size and effective population size in a hatchery stock of coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 43:2434-2442.

Slaney, T. L., K. D. Hyatt, T. G. Northcote, and R. J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21:20-35.

Slauson, M. C. 1976. Renton - from coal to jets. Renton Historical Society, Renton, WA. 183 p.

Smith, M. W. 1940. The Puyallup - Nisqually. Columbia Univ. Press, New York, 336 p.

Smith, R. L. 1983. Physical features of coastal upwelling systems. Wash. Sea Grant Tech. Rep. WSG 83-2, Wash. Sea Grant, Seattle, 34 p.

Smirnov, A. I. 1975. The biology, reproduction and development of the Pacific salmon. Izd. Mosk. Univ., p. 1-355. [Fish. Res. Board Can. Transl. Ser. No. 3816, 1976]

Smoker, W. A., H. M. Jensen, R. T. Pressey, R. T. Heg, and J. W. Fitzgerald. 1952. Special fresh water surveys, Lake Pleasant and Upper and Lower Lake Creeks, Clallam County. *In* Puget Sound Investigations, April 1952 to June 1952. Wash. Dept. Fish. Wildl., Olympia, WA, p. 18-23.

Sneath, P. H. A., and R. R. Sokal. 1973. Numerical taxonomy. W. H. Freeman & Co., San Francisco, CA, 573 p.

Sneva, J. 1997. Final Lake Pleasant sockeye age estimates, 1994-1996, submitted to NMFS, by J, Sneva, Washington Department of Fish and Wildlife, 5 May 1997. 5 p. and Additional Lake Pleasant sockeye spawner age data, submitted to NMFS, by J, Sneva, Washington Department of Fish and Wildlife, 5 June 1997. 1 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. 2nd ed. W. H. Freeman & Co., San Francisco, CA, 859 p.

Sprague, G. 1996a. Baker sockeye terminal runsize. Histogram, footnotes, and data tables sent to Dr. M. Schiewe, NMFS, from G. Sprague, Washington Department of Fish and Wildlife, dated 6 June 1996. 6 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Sprague, G. 1996b. Data tables and unpublished reports on Baker Lake sockeye salmon submitted to NMFS, by G. Sprague, Washington Department of Fish and Wildlife, 17 December 1996. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Stanford, L. M. 1942. Preliminary studies in the biology of the Snake River. Ph.D. Thesis, Univ. Washington, Seattle, WA, 119 p.

Steer, G. J., and K. D. Hyatt. 1987. Use of a run timing model to provide in-season estimates of sockeye salmon (*Oncorhynchus nerka*) returns to Barkley Sound, 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1557, 39 p.

Stickney, A. E., and L. McDonald. 1977. Squak Slough 1870-1920. Early days on the Sammamish River Woodinville-Bothell-Kenmore. Friends of the Bothell Library, Bothell, WA. 266 p.

Stober, Q. J., and A. H. Hämäläinen. 1979. Cedar River sockeye salmon fry emigration. Univ. Wash. Fish. Res. Inst. FRI-UW-7917. 52 p.

Stober, Q. J., and A. H. Hämäläinen. 1980. Cedar River sockeye salmon production. Univ. Wash. Fish. Res. Inst. FRI-UW-8016. 59 p.

Stockner, J. G. 1987. Lake fertilization: The enrichment cycle and lake sockeye salmon (*Oncorhynchus nerka*) production. Can. Spec. Publ. Fish. Aquat. Sci. 96:198-215.

Stockner, J. G., and T. G. Northcote. 1974. Recent limnological studies of Okanagan Basin lakes and their contribution to comprehensive water resource planning. J. Fish. Res. Board Can. 31:955-976.

Stockner, J. G., and K. S. Shortreed. 1978. Limnological survey of 35 sockeye salmon (*Oncorhynchus nerka*) nursery lakes in British Columbia and the Yukon Territory. Fish. Mar. Serv. Tech. Rep. 827, 47 p.

Stockner, J. G., and K. S. Shortreed. 1979. Limnological studies of 13 sockeye salmon (*Oncorhynchus nerka*) nursery lakes in British Columbia, Canada. Fish. Mar. Serv. Tech. Rep. 865, 125 p.

Stockner, J. G., and K. S. Shortreed. 1983. A comparative limnological survey of 19 sockeye salmon (*Oncorhynchus nerka*) nursery lakes in the Fraser River system, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1190, 63 p.

Stockner, J. G., K. S. Shortreed, E. A. MacIsaac, and B. Nidle. 1993. The limnology of Kitlope Lake: A cold, glacially-turbid sockeye salmon (*Oncorhynchus nerka*) nursery lake. Can. Tech. Rep. Fish. Aquat. Sci. No. 1909, 35 p.

Storm, J. M., D. Chance, J. Harp, K. Harp, L. Lestelle, S. C. Sotomish, and L. Workman. 1990. Land of the Quinault. P. K. Capoeman (editor), Published by Quinault Indian Nation, Taholah, WA, 316 p.

Swan, G. A., L. K. Timmee, R. N. Iwamoto, L. C. Stuehrenberg, E. E. Hockersmith, B. L. Iverson, and B. P. Sandford. 1994. Wells Dam radio-telemetry study, 1992. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Sci. Cent., Seattle, WA, 70 p.

Swofford, D. L., and R. B. Selander. 1981. BIOSYS-1: a FORTRAN program for the comprehensive analysis of electrophoretic data in population genetics and systematics. J. Hered. 72:282-283.

Taft, A. C. 1937. A red salmon (*Oncorhynchus nerka*) taken in the Klamath River. Calif. Fish Game 23(2):178.

Taylor, E. B. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

Taylor, E. B., and C. J. Foote. 1991. Critical swimming velocities of juvenile sockeye salmon and kokanee, the anadromous and non-anadromous forms of *Oncorhynchus nerka* (Walbaum). J. Fish Biol. 38:407-419.

Taylor, E. B., C. J. Foote, and C. C. Wood. 1996. Molecular genetic evidence for parallel life history evolution within a Pacific salmon (sockeye salmon and kokanee, *Oncorhynchus nerka*). Evolution 50:401-416.

Technical Advisory Committee (TAC). 1991. Sockeye. *In* Columbia River fish management plan: 1991 All species review. Technical Advisory Committee, *U.S. v. Oregon*. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Srv., 525 N.E. Oregon Street, Portland, OR 97232.)

Technical Advisory Committee (TAC). 1994. Biological assessment of the impacts of anticipated 1995 winter, spring, and summer season Columbia River and tributary fisheries on listed Snake River salmon species under the Endangered Species Act. U.S. v. Oregon Technical Advisory Committee, Portland, Oregon. (Available from Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N.E. Oregon Street, Portland, OR 97232.)

Teuscher, D, and D. Taki. 1996. Snake River sockeye salmon habitat and limnological research, Annual Report 1995. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 91-71, Contract No. DE-B179-91BP22548. Portland, OR, 135 p. plus figure and tables.

Teuscher, D., D. Taki, W. A. Wurtsbaugh, C. Luecke, P. Budy, H. P. Gross, and G. Steinhart. 1994. Snake River salmon habitat and limnological research annual report: 1993. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 91-71, Contract No. DE-BI79-91BP22548, Portland, OR, 133 p. plus appendices.

Teuscher, D, D. Taki, W. Wurtsbaugh, C. Luecke, P. Budy, and G. Steinhart. 1995. Snake River sockeye salmon habitat and limnological research, Annual Report 1994. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 91-71, Contract No. DE-B179-91BP22548, Portland, OR, 85 p. plus figures and tables.

Thompson, G. G. 1991. Determining minimum viable populations under the Endangered Species Act. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-198, 78 p.

Thompson, R. B., and D. F. Tufts. 1967. Predation by Dolly Varden and northern squawfish on hatchery-reared sockeye salmon in Lake Wenatchee, Washington. Trans. Am. Fish. Soc. 96:424-427.

Thompson, R. E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56, 291 p.

Thomson, B. L., S. K. Bachen, and R.D. Goruk. 1988. An historical overview of the Owikeno Lake (Rivers Inlet, Statistical Area 9) fall sockeye salmon escapement surveys 1971-1987. Can. Data Rep. Fish. Aquat. Sci. 711, 69 p. plus appendices.

Thomson, B. L., and R.D. Goruk. 1988. An historical overview of the Docee River enumeration program 1963-1987. Can. Data Rep. Fish. Aquat. Sci. 702, 8 p. plus appendices.

Thorgaard, G. H., P. Spruell, S. A. Cummings, A. S. Peek, and E. L. Brannon. 1995. Mixed DNA fingerprint analysis differentiates sockeye salmon populations. *In* J. L. Nielsen (editor), Evolution and the aquatic ecosystem: defining unique units in population conservation. Am. Fish. Soc. Symp. 17:295-303.

Tierney, E. 1997. Letter to R. Gustafson, NMFS, from E. Tierney, Quileute Natural Resources, re. Lake Pleasant sockeye survey data, dated 8 April 1997. 1 p. plus attachment. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Titcomb, J. W. 1904. Report on the propagation and distribution of food-fishes. Report of the Commissioner for the year ending June 30, 1902, U. S. Comm. Fish and Fisheries 28:22-110.

Titcomb, J. W. 1905. Report on the propagation and distribution of food fishes. Report of the Commissioner for the year ending June 30, 1903, U. S. Comm. Fish and Fisheries 29:29-74.

Toner, R. C. 1960. Appendix A: A study of some of the factors associated with the reestablishment of blueback salmon (*Oncorhynchus nerka*) into the upper Wallowa River system. *In* Thompson, R. N. and J. B. Haas (editors), Environmental survey report pertaining to salmon and steelhead in certain rivers of eastern Oregon and the Willamette River and its tributaries. Part 1. Survey reports of eastern Oregon rivers, p. A1-A46. Oreg. Fish Comm., Res. Division, Clackamas, OR.

Tschaplinksi, P. J., and K. D. Hyatt. 1990. Abundance, migration timing, and biological characteristics of sockeye salmon (*Oncorhynchus nerka*) returning to Henderson Lake, Vancouver Island during 1988. Can. Tech. Rep. Fish. Aquat. Sci. 1758, 82 p.

Tschaplinksi, P. J., and K. D. Hyatt. 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (*Oncorhynchus nerka*) returning to Henderson Lake, Vancouver Island during 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1798, 101 p.

Tufts, D. F., and D. R. Craddock. 1963. Spawning escapement of Columbia River sockeye salmon (*Oncorhynchus nerka*), 1962. U.S. Fish and Wildl. Serv. Processed Rep., Seattle, WA, 17 p.

Tyler, R. W., and T. E. Wright. 1974. A method of enumerating blueback salmon smolts from Quinault Lake and biological parameters of the 1974 outmigration. Final report to Quinault Tribal Council, Fisheries Research Institute, Univ. Washington, FRI-UW-74-14. 29 p.

U.S. Bureau of Fisheries (USBF). 1905-1921. Reports of the U.S. Commissioner of Fisheries for the fiscal years 1904-1920. Washington, D.C., various pages.

U.S. Bureau of Fisheries (USBF). 1906. The propagation and distribution of food fishes during 1905. Bur. of Fish. Doc. 602, 64 p.

U.S. Bureau of Fisheries (USBF). 1907. The distribution of food fishes during the fiscal year 1906. Bur. of Fish. Doc. 613, 78 p.

U.S. Bureau of Fisheries (USBF). 1909. The distribution of fish and fish eggs during the fiscal year 1908. Bur. of Fish. Doc. 644, 93 p.

U.S. Bureau of Fisheries (USBF). 1910. The distribution of fish and fish eggs during the fiscal year 1909. Bur. of Fish. Doc. No. 728, 103 p.

U.S. Bureau of Fisheries (USBF). 1911. The distribution of fish and fish eggs during the fiscal year 1910. Bur. of Fish. Doc. 740, 112 p.

U.S. Bureau of Fisheries (USBF). 1913. The distribution of fish and fish eggs during the fiscal year 1912. Bur. of Fish. Doc. 770, 108 p.

U.S. Bureau of Sport Fisheries and Wildlife (USBSFW). 1971. Sockeye fishery investigations on the Quinault River system. U.S. Dep. Interior, Bur. Sport Fish. Wildl., Division Fish. Services, Spec. Rep., Tumwater, WA, 5 p. plus figures and tables.

U.S. Department of Commerce (USDOC). 1968. Weather atlas of the United States (Originally titled: Climate atlas of the United States). [1975 reprint of 1968 edition published by U.S. Environmental Data Service and Gale Research Co., Detroit, MI, 262 p.]

U.S. Environmental Protection Agency (USEPA). 1974. The relationships of phosphorus and nitrogen to the trophic state of Northeast and North Central lakes and reservoirs. Working Paper No. 23. National Eutrophication Survey, Corvallis, OR.

Utter, F. 1995. Letter from F. Utter (Univ. of Washington, School of Fisheries) to C. Pevan (Chelan County PUD), re. Preliminary results of investigations of genetic variation in 1994 sockeye salmon collections from the Mid-Columbia River, dated 30 November 1995. 3 p. plus 3 tables and 1 fig. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Utter, F., P. Aebersold, J. Helle, and G. Winans. 1984. Genetic characterization of populations in the southeastern range of sockeye salmon. *In* J. M. Walton and D. B. Houston (editors), Proceedings of the Olympic wild fish conference, p. 17-31. Fisheries Technology Program, Peninsula College, Port Angeles, WA.

Utter, F. M., and H. O. Hodgins. 1970. Phosphoglucomutase polymorphism in sockeye salmon. Comp. Biochem. Physiol. 36:195-199.

Utter, F., G. Milner, G. Stahl, and D. Teel. 1989. Genetic population structure of chinook salmon, *Oncorhynchus tshawytscha*, in the Pacific Northwest. Fish. Bull., U.S. 87:239-264.

Valentine, J. W. 1966. Numerical analysis of marine molluscan ranges on the extratropical northeastern Pacific shelf. Limnol. Oceanogr. 11:198-211.

Varnavskaya, N. V. 1984. Distribution of lactic acid dehydrogenase and phosphoglucomutase gene frequencies in populations of Kamchatka sockeye salmon (*Oncorhynchus nerka* Walb.) preferring different types of spawning grounds. Sov. Genet. 20:81-87.

Varnavskaya, N. V., V. S. Varnavskii, I. I. Vetsler, and K. Yu. Nepomnyashchii. 1988. Features of spatial genetic differentiation of populations of blue-black salmon (*Oncorhynchus nerka* Walbaum) in lakes Nachiki, Dvukhyurtochnoe, Dal’nee and Blizhnee (Kamchatka). Sov. Genet. 24:505-512.

Varnavskaya, N. V., C. C. Wood, and R. J. Everett. 1994a. Genetic variation in sockeye salmon (*Oncorhynchus nerka*) populations of Asia and North America. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):132-146.

Varnavskaya, N. V., C. C. Wood, R. J. Everett, R. L. Wilmot, V. S. Varnavsky, V. V. Midanaya, and T. P. Quinn. 1994b. Genetic differentiation of subpopulations of sockeye salmon (*Oncorhynchus nerka*) within lakes of Alaska, British Columbia, and Kamchatka, Russia. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):147-157.

Velsen, F. P. J. 1980. Embryonic development in eggs of sockeye salmon, *Oncorhynchus nerka*. Can. Spec. Publ. Fish. Aquat. Sci. 49:1-19.

Vernon, E. H. 1957. Morphometric comparison of three races of kokanee (*Oncorhynchus nerka*) within a large British Columbia Lake. J. Fish. Res. Board Can. 14(4):573-598.

Waknitz, F. W., G. M. Mathews, T. Wainwright, and G.A. Winans. 1995. Status review for mid-Columbia River summer chinook salmon. NOAA Tech. Memo. NMFS-NWFSC-22, 80 p.

Waltemyer, D. L. 1994. Age, sex and size composition of chinook, sockeye, coho, and chum salmon returning to Upper Cook Inlet, Alaska in 1991. Alsk. Dep. Fish Game Tech. Fish. Rep. 94-11, 95 p.

Wampler, P. L. 1980. Instream flow requirements of the lower North Fork, South Fork and mainstem Skokomish River. U.S. Fish Wildl. Serv., Fisheries Assistance Office, Olympia, WA, 54 p.

Waples, R. S. 1991a. Pacific salmon, *Oncorhynchus* spp., and the definition of “species” under the Endangered Species Act. Mar. Fish. Rev. 53(3):11-22.

Waples, R. S. 1991b. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. 48(Suppl. 1):124-133.

Waples, R. S., P. B. Aebersold, and G. A. Winans. In press. Population genetic structure and life-history variability in *Oncorhynchus nerka* from the Snake River Basin. Final report of research. U.S. Dep. Energy, Bonneville Power Administration, Proj. No. 93-066, Contract No. DE-A179-93BP05326.

Waples, R. S., O. W. Johnson, and R. P. Jones, Jr. 1991. Status review for Snake River sockeye salmon. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-195, 23 p.

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

Ward, F. J. 1952. Egg counts as a means of identifying the races of Fraser River sockeye salmon. Bachelor’s Thesis, Dep. of Zool., Univ. British Columbia, Vancouver, B. C., 48 p.

Ward, F. J., and P. A. Larkin. 1964. Cyclic dominance in Adams River sockeye salmon. Int. Pac. Salmon Fish. Comm. Prog. Rep. 11, 116 p.

Ward, H. B. 1929. Further studies on the influence of a power dam in modifying conditions affecting the migration of the salmon. Proc. Nat. Acad. Sci. 15:56-62.

Ward, H. B. 1930. Some responses of sockeye salmon to environmental influence during fresh-water migration. Ann. Mag. Nat. Hist. (10) 6:18-36.

Ward, H. B. 1932. The origin of the landlocked habit in salmon. Proc. Nat. Acad. Sci. 18:569-580.

Warner, E. 1996. Lake Washington sockeye smolt lengths. E-mail to R. Gustafson, NMFS, from E. Warner, Muckleshoot Indian Tribe, dated 22 January 1997. 1 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Warner, E. 1997. Letter to R. Gustafson, NMFS, from E. Warner, Muckleshoot Indian Tribe Fisheries Department, re. Muckleshoot Indian Tribe comments on the draft sockeye status review, dated 30 January 1997. 3 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Washington Department of Fish and Wildlife (WDFW). 1996. Letter to M. Schiewe, NMFS, from R. Lincoln, Assistant Director, Fish Management Program, Washington Department of Fish and Wildlife, dated 12 July 1996. 3 p. plus appendix. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Washington Department of Fisheries (WDF). 1973. Review draft. Fisheries resources in southwest Washington. Southwest Washington river basins study. Wash. Dep. Ecol., Olympia, WA, 151 p.

Washington Department of Fisheries (WDF). 1974. 1974 fisheries statistical report, p. 108-110. State Printing Plant, Olympia, WA.

Washington Department of Fisheries (WDF), Washington Department of Game (WDG), and United States Bureau of Fisheries (USBF). 1938. A report on the preliminary investigations into the possible methods of preserving the Columbia River salmon and steelhead at the Grand Coulee Dam. Wash. Dep. Fish, Olympia, WA, 120 p.

Washington Department of Fisheries (WDF), Washington Department of Wildlife (WDW), and Western Washington Treaty Indian Tribes (WWTIT). 1993. 1992 Washington State salmon and steelhead stock inventory (SASSI). Wash. Dep. Fish Wildl., Olympia, WA, 212 p. plus 5 regional volumes.

Washington Department of Fisheries and Game (WDFG). 1916a. Twenty-forth and twenty-fifth annual reports of State Fish Commissioner to the Governor of the State of Washington April 1, 1913, to March 31, 1915. Wash. Dep. Fish. Game, Olympia, WA, 171 p.

Washington Department of Fisheries and Game (WDFG). 1916b. First and second annual reports of the chief game warden to the Governor of the State of Washington June 12, 1913 to February 28, 1915. Wash. Dep. Fish. Game, Olympia, WA, 58 p.

Washington Department of Fisheries and Game (WDFG). 1917. Twenty-sixth and twenty-seventh annual reports of State Fish Commissioner to the Governor of the State of Washington April 1, 1915, to March 31, 1917. Wash. Dep. Fish. Game, Olympia, WA, 196 p.

Washington Department of Fisheries and Game (WDFG). 1918. Third and fourth annual reports of the state game warden to the Governor of the State of Washington March 1, 1915 to February 28, 1917. Wash. Dep. Fish. Game, Olympia, WA, 78 p.

Washington Department of Fisheries and Game (WDFG). 1919. Fifth and sixth annual reports of the state game warden to the Governor of the State of Washington March 1, 1917 to February 28, 1919. Wash. Dep. Fish. Game, Olympia, WA, 99 p.

Washington Department of Fisheries and Game (WDFG). 1920. Twenty-eighth and twenty-ninth annual reports of State Fish Commissioner to the Governor of the State of Washington April 1, 1917, to March 31, 1919. Wash. Dep. Fish. Game, Olympia, WA, 174 p.

Washington Department of Fisheries and Game (WDFG). 1921a. Seventh and eighth annual reports of the state game warden to the Governor of the State of Washington March 1, 1919 to February 28, 1921. Wash. Dep. Fish. Game, Olympia, WA, 143 p.

Washington Department of Fisheries and Game (WDFG). 1921b. Thirtieth and thirty-first annual reports of State Fish Commissioner to the Governor of the State of Washington April 1, 1919, to March 31, 1921. Wash. Dep. Fish. Game, Olympia, WA, 302 p.

Washington Department of Fisheries and Game (WDFG). 1923. First biennial report 1921-1922. Wash. Dep. Fish. Game, Olympia, WA, 174 p.

Washington Department of Fisheries and Game (WDFG). 1924. Thirty-second and thirty-third annual reports of State Supervisor of Fisheries for the period from April 1, 1921, to March 31, 1923. Wash. Dep. Fish. Game, Olympia, WA, 114 p.

Washington Department of Fisheries and Game (WDFG). 1928. Thirty-sixth and thirty-seventh annual reports of State Department of Fisheries and Game, Division of Fisheries, for the period from April 1, 1925, to March 31, 1927. Wash. Dep. Fish. Game, Olympia, WA, 218 p.

Washington Department of Fisheries and Game (WDFG). 1930. Thirty-eighth and thirty-ninth annual reports of State Department of Fisheries and Game, Division of Fisheries, for the period from April 1, 1927, to March 31, 1929. Wash. Dep. Fish. Game, Olympia, WA, 121 p.

Washington Department of Fisheries and Game (WDFG). 1932. Fortieth and forty-first annual reports of State Department of Fisheries and Game, Division of Fisheries, for the period from April 1, 1929, to March 31, 1931. Wash. Dep. Fish. Game, Olympia, WA, 150 p.

Wayne, W. W. 1961. Fish handling facilities for Baker River Project. J. Power Division, Proc. Amer. Soc. Civil Engineers 87(PO3):23-54.

Weitkamp, D., and J. Neuner. 1981. Juvenile salmonid monitoring Methow River, Okanogan River and Wells Dam forebay. Doc. No. 82-0113-001D2, review draft prepared for Douglas County PUD, East Wenatchee, WA.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-24, 258 p.

Welch, E. B., T. Wiederholm, D. E. Spyridakis, and C. A. Rook. 1977. Nutrient loading and trophic state of Lake Sammamish, Washington. *In* Seyb, L. and K. Randolph (eds.) North American project — A study of U. S. water bodies, p. 301-320. U.S. Environmental Protection Agency, Environmental Research Laboratory - Corvallis, EPA-600/3-77-086.

Wendler, H. O., and G. Deschamps. 1955. The salmon fisheries of Washington's coastal rivers and harbors. Wash. Dep. of Fish., Olympia, WA. 33 p. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Westley, R. E. 1966. Limnological study of Merwin, Upper Baker, and Lower Baker Reservoirs. Res. Division, Wash. Dep. Fish., Summary Rep. Olympia, WA, 206 p.

Wilcock, J. A. 1993. Salmon catch and escapement statistics for Copper River, Bering River, and Prince William Sound, 1989. Alsk. Dep. Fish Game Tech. Fish. Rep. 93-07, 152 p.

Wilcox, W. A. 1898. Notes on the fisheries of the Pacific coast in 1895. Report of the Commissioner for the year ending June 30, 1896, U. S. Comm. Fish and Fisheries 22:575-659.

Wilderness Society. 1993. The living landscape, Vol. 2: Pacific salmon and federal lands. Bolle Center for Forest Ecosystem Management, 87 p.

Williams, I. V. 1987. Attempts to re-establish sockeye salmon (*Oncorhynchus nerka*) populations in the Upper Adams River, British Columbia, 1949-1984. Can. Spec. Publ. Fish. Aquat. Sci. 96:235-242.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization, Vol. 1, Puget Sound region. Wash. Dep. Fish., Olympia, WA. 926 p.

Willoughby, C. 1889. Indians of the Quinaielt *(sic)* Agency, Washington Territory. Smithsonian Institution Annul Report of the Board of Regents for the year ending June 30, 1886, p. 267-282. U.S. Government Printing Office, Washington, D.C. (Available from West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division, Natl. Mar. Fish. Serv., 525 N. E. Oregon Street, Portland, OR 97232.)

Wilmot, R. L., and C. V. Burger. 1985. Genetic differences among populations of Alaskan sockeye salmon. Trans. Am. Fish. Soc. 114:236-243.

Winans, G. A., P. B. Aebersold, S. Urawa, and N. V. Varnavskaya. 1994. Determining continent of origin of chum salmon (*Oncorhynchus keta*) using genetic stock identification techniques: status of allozyme baseline in Asia. Can. J. Fish. Aquat. Sci. 51 (Suppl. 1):95-113.

Winans, G. A., P. A. Aebersold, and R. S. Waples. 1996. Allozyme variability of *Oncorhynchus nerka* in the Pacific Northwest, with special consideration to populations of Redfish Lake, Idaho. Trans. Am. Fish. Soc. 205:645-663.

Withler, R. E. 1985. *Ldh-4* allozyme variability in North American sockeye salmon (*Oncorhynchus nerka*) populations. Can. J. Zool. 63:2924-2932.

Withler, R. E. 1988. Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. Aquaculture 68:15-25.

Wolcott, E. E. 1961. Lakes of Washington, Vol. 1, Western Washington. Water Supply Bulletin No 14. Water Resources Division, Wash. Dep. Conservation, Olympia, WA, 618 p.

Wood, C. C. 1995. Life history variation and population structure in sockeye salmon. *In* J. L. Nielsen (editor), Evolution and the aquatic ecosystem: defining unique units in population conservation. Am. Fish. Soc. Symp. 17:195-216.

Wood, C. C., and C. J. Foote. 1990. Genetic differences in the early development and growth of sympatric sockeye salmon and kokanee (*Oncorhynchus nerka*), and their hybrids. Can. J. Fish. Aquat. Sci. 47:2250-2260.

Wood, C. C., and C. J. Foote. 1996. Evidence for sympatric genetic divergence of anadromous and non-anadromous morphs of sockeye salmon (*Oncorhynchus nerka*). Evolution 50:1265-1279.

Wood, C. C., N. B. Hargreaves, D. T. Rutherford, and B. T. Emmett. 1993. Downstream and early marine migratory behaviour of sockeye salmon (*Oncorhynchus nerka*) smolts entering Barkley Sound, Vancouver Island. Can. J. Fish. Aquat. Sci. 50:1329-1337.

Wood, C. C., G. T. Oliver, and Rutherford, D.T. 1988. Comparison of several biological markers used for stock identification of sockeye salmon (*Oncorhynchus nerka*) in northern British Columbia and southeast Alaska. Can. Tech. Rep. Fish. Aquat. Sci. 1624, 44 p.

Wood, C. C., B. E. Riddell, and D. T. Rutherford. 1987a. Alternative juvenile life histories of sockeye salmon (*Oncorhynchus nerka*) and their contribution to production in the Stikine River, northern British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 96:12-24.

Wood, C. C., B. E. Riddell, D. T. Rutherford, and K. L. Rutherford. 1987b. Variation in biological characters among sockeye salmon populations of the Stikine River with potential application for stock identification in mixed-stock fisheries. Can. Tech. Rep. Fish. Aquat. Sci. 1535, 61 p.

Wood, C. C., B. E. Riddell, D. T. Rutherford, and R. E. Withler. 1994. Biochemical genetic survey of sockeye salmon (*Oncorhynchus nerka*) in Canada. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):114-131.

Wood, C. C., D. T. Rutherford, and S. McKinnell. 1989. Identification of sockeye salmon (*Oncorhynchus nerka*) stocks in mixed-stock fisheries in British Columbia and Southeast Alaska using biological markers. Can. J. Fish. Aquat. Sci. 46:2108-2120.

Woodey, J. C. 1966. Sockeye salmon spawning grounds and adult returns in the Lake Washington watershed, 1965. Master’s Thesis, Univ. Washington, Seattle, WA, 101 p.

Woodey, J. C. 1972. Distribution, feeding, and growth of juvenile sockeye salmon in Lake Washington. Ph.D. Thesis, Univ. Washington, Seattle, WA, 174 p.

Wunderlich, R. C., B. D. Winter, and J. H. Meyer. 1994. Restoration of the Elwha River ecosystem. Fisheries 19(8):11-19.

Young, S. F. 1997. Data tables for sockeye salmon collected for genetic stock inventory, submitted to NMFS, 16 December 1996, 11 January 1997, 29 April 1997, and 23 May 1997 by S. F. Young, Washington Department of Fish and Wildlife, Olympia, WA, 8 p., 3 p., and 6 p.

Youngs, W. D., and D. G. Heimbuch. 1982. Another consideration of the morphoedaphic index. Trans. Am. Fish. Soc. 111:151-153.

Zhadin, V. I. 1965. Mollusks of fresh and brackish waters of the U.S.S.R. Keys to the fauna of the U.S.S.R., No. 46 [Transl. by A. Mercado]. Israel Program for Scientific Translations, Jerusalem, 368 p.

APPENDIX A - GLOSSARY

GLOSSARY

age

Age is based on counts and measurements of annual rings on scales or otoliths (a calcareous "earstone" found in the internal ear of fishes). Several notation styles have been developed to designate age (Koo 1962). In this review the European notation style is used. Freshwater age is generally separated from saltwater age by a period (.); for example, the age of a fish which spent 2 winters in fresh water (not counting the incubation period) and 2 years in saltwater would be represented as age 2.2.

allele

An **allele** is an alternate form of a **gene** (the basic unit of heredity passed from parent to offspring). By convention, the "**100 allele**" is the most common allele in a population and is the reference for the electrophoretic mobility of other alleles of the same gene. Other genetic terms used in this document include **allozymes** (alternate forms of an enzyme produced by different alleles and often detected by protein electrophoresis); **dendrogram** (a branching diagram, sometimes resembling a tree, that provides one way of visualizing similarities between different groups or samples); **gene locus** (pl. **loci**; the site on a chromosome where a gene is found); **genetic distance** (**D**) (a quantitative measure of genetic differences between a pair of samples); and **introgression** (introduction of genes from one population or species into another). *See also* **DNA** and **electrophoresis**.

artificial propagation

See **hatchery**.

Biological Review Team (BRT)

The team of scientists from National Marine Fisheries Service formed to conduct the status review.

DNA (deoxyribonucleic acid)

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

electrophoresis

Electrophoresis refers to the movement of charged particles in an electric field. It has proven to be a very useful analytical tool for biochemical characters because molecules can be separated on the basis of differences in size or net charge. **Protein electrophoresis**, which measures differences in the amino acid composition of proteins from different individuals, has been used for over two decades to study natural populations, including all species of anadromous Pacific salmonids. Because the amino acid sequence of proteins is coded for by DNA, data provided by protein electrophoresis provide insight into levels of genetic variability within populations and the extent of genetic differentiation between them. Genetic techniques that focus directly on variation in DNA also routinely use electrophoresis to separate fragments formed by cutting DNA with special enzymes (**restriction endonucleases**). *See also* **allele** and **DNA**.

epilimnion

The upper region of a thermally stratified lake, above the thermocline, and generally warm and well oxygenated.

escapement

The number of fish that survive to reach the spawning grounds or hatcheries. The escapement plus the number of fish removed by harvest form the **total run size**.

evolutionarily significant unit (ESU)

A “distinct” population of Pacific salmon, and hence a species, under the Endangered Species Act.

hatchery

Salmon hatcheries typically spawn adults in captivity and raise the resulting progeny in fresh water for release into the natural environment. In some cases, fertilized eggs are outplanted (usually in “hatch-boxes”), but it is more common to release **fry** (young juveniles) or **smolts** (juveniles that are physiologically prepared to undergo the migration into salt water). The fish are released either at the hatchery (**on-station release**) or away from the hatchery (**off-station release**). Releases may also be classified as **within basin** (occurring within the river basin in which the hatchery is located or the stock originated from) or **out-of-basin** (occurring in a river basin other than that in which the hatchery is located or the stock originated from).

The broodstock of some hatcheries is based on adults that return to the hatchery each year; others rely on fish or eggs from other hatcheries, or capture adults in the wild each year.

hypolimnion

The lower zone of a thermally stratified lake, below the thermocline, and usually depleted in oxygen during summer stagnation.

IHN

Infectious Hematopoietic Necrosis; a viral disease endemic to salmonid fishes of the Pacific Coast of North America that can cause high mortality in 3-week to 6-month-old fish.

.

jacks

Male salmon that return from the ocean to spawn one or more years before full-sized adults return. For sockeye salmon in Oregon, Washington, and southern British Columbia, jacks are 3 years old (age 1.1), having spent only one winter in the ocean, in contrast to more typical sockeye salmon that are age 1.2, 1.3, 2.2 or 2.3 on return.

jills

Female salmon that return from the ocean to spawn one or more years before full-sized adults return. For sockeye salmon in Oregon, Washington, and southern British Columbia, jills are 3 years old (age 1.1), having spent only one winter in the ocean, in contrast to more typical sockeye salmon that are age 1.2, 1.3, 2.2 or 2.3 on return.

kokanee

The self-perpetuating, nonanadromous form of *O. nerka* that occurs in balanced sex-ratio populations and whose parents, for several generations back, have spent their whole lives in fresh-water.

morphoedaphic index (MEI)

The most widely used index of potential fish production in lakes. A metric expression of the MEI is derived by dividing a lake's total dissolved solids (mg/L), or its conductivity, by its mean depth in meters.

polymorphic

Having more than one form (e.g., polymorphic gene loci have more than one allele).

principal component analysis (**PCA**)

A statistical technique that attempts to explain variation among several (*n*) variables in terms of a smaller number of composite independent factors called **principal components**. These principal components are represented by **eigenvectors**, or the perpendicular axes of central trend that pass through the clouds of points represented in *n*-dimensional space. The matrix of eigenvectors and the **matrix of correlations** of independent variables are used with linear algebra to calculate the equations describing the principal components that account for the greatest amount of the variation expressed in the original variables. Principal component one (**PC1**) is defined as a linear combination of the *n* variables that accounts for more of the variance in the data than any other linear combination of variables. Second (**PC2**) and subsequent components are defined as linear combinations that account for residual variance after the effect of the first (and subsequent) component(s) is removed from the data. PC values or "scores" are calculated for each individual and subjected to statistical analysis.

resident sockeye salmon

The progeny of anadromous sockeye salmon parents that spend their adult life in freshwater and are observed together with their anadromous siblings on the spawning grounds.

river kilometer (RKm)

Distance, in kilometers, from the mouth of the indicated river. Usually used to identify the location of a physical feature, such as a confluence, dam, waterfall, or spawning area.

smolt

verb- The physiological process that prepares a juvenile anadromous fish to survive the transition from fresh water to salt water.

noun- A juvenile anadromous fish that has smolted.

spawner surveys

Spawner surveys utilize counts of **redds** (nests dug by females in which they deposit their eggs) and fish carcasses to estimate spawner escapement and identify habitat being used by spawning fish. Annual surveys can be used to compare the relative magnitude of spawning activity between years. Surveys are conducted on a regular basis on **standard stream segments**, groups of which form a spawner **index**, and are occasionally conducted on **supplemental stream segments** (those that are not part of the standard surveying plan).

Strait of Georgia

The body of water separating the southern portion of Vancouver Island and the British Columbia mainland. The strait extends from Cortes Island and Desolation Sound in the north to the San Juan Islands in the south.

Strait of Juan de Fuca

The body of water separating the southern portion of Vancouver Island and the Olympic Peninsula in Washington. The strait extends from the Pacific Ocean east to the San Juan and Whidbey Islands.

thermocline

That layer of water in a lake in which the temperature changes 1^0C with each meter increase in depth.

west coast sockeye salmon

For the purposes of this document, west coast sockeye salmon are defined as sockeye salmon originating from fresh waters of Washington, Oregon, and British Columbia.

Appendix Table B-1. Physical and morphometric characteristics of selected sockeye salmon nursery lakes. Dashes indicate data were unavailable[a].

System and lake	Altitude (m)	Distance from sea (km)	Area (km^2)	Depth (m)		Volume (m^{3}x 10^6)	Drainage area (km^2)	Water residence time (yr)	Maximum surface temp. (°C)
				max.	mean				
Columbia River Basin									
Wenatchee	572	842	9.9	73	55	542	707	0.45	--
Osoyoos (Southern Basin)	--	--	11.0	--	11	125	--	--	--
Osoyoos (Middle Basin)	--	--	2.2	--	36	79	--	--	--
Osoyoos (Northern Basin)	--	--	10.0	63	15	154	--	--	>21
Osoyoos (Total)	278	986	23.0	63	14	397	8158	0.7	--
Redfish	1996	1448	6.2	91	44	270	108	5.4	18
Washington (Puget Sound)									
Washington	6	13	87.6	65	33	2900	1274	2.4	25
Sammamish	12	53	19.8	32	18	350	253	2.2	26
Baker Lake (natural lake)	201	92	3.0	35	--	--	--	--	--
Baker Lake (reservoir)	221 (full pool)	106	20.2	73	17	352	--	--	19
Washington (coastal)									
Quinault	56	54	15.1	76	--	--	707	--	--
Pleasant	98	44	2.0	15	10	20	23	--	--
Ozette	9	8	29.5	98	40	1183	201	--	21
Vancouver Island									
Nimpkish	20	--	37.2	--	152	--	1648	1.4	14
Woss	161	--	14.2	--	90	--	142	3.2	--
Queen Charlotte Islands									
Mathers	35	7	2.0	--	--	--	32	--	15
Skidegate	40	--	7.7	--	--	--	83	--	16
Yakoun	107	--	8.1	--	--	--	79	--	15
Mercer	30	--	0.8	--	--	--	43	--	14
Eden	52	--	6.5	--	--	--	73	--	15
Ian	35	--	17.2	--	--	--	243	--	16
Awun	45	--	6.1	--	--	--	70	--	16

Appendix Table B-1. Continued.

System and lake	Altitude (m)	Distance from sea (km)	Area (km^2)	Depth (m)		Volume ($m^3 x 10^6$)	Drainage area (km^2)	Water residence time (yr)	Maximum surface temp. (°C)
				max.	mean				
Mainland B.C. (coastal)									
Sakinaw	10	--	6.1	--	--	--	64	--	17
Heydon	20	--	9.3	--	--	--	51	--	15
Phillips	25	--	3.6	--	--	--	435	--	10
Owikeno	15	2	94.5	--	172	--	3621	2.0	--
Kitlope	15	10	11.9	140	86	--	858	0.7	16
Lowe	10	--	3.7	--	25	--	236	0.2	--
Fraser River									
Pitt	0	--	54	--	46	--	880	--	--
Harrison	10	129	218	--	151	--	8440	--	23
Cultus	41	88	6	42	32	201	83	--	22
Lillooet	196	274	35	--	62	--	5180	--	--
Seton	237	--	24	--	85	--	1040	--	--
Anderson	258	--	28	--	140	--	730	--	--
Little Shuswap	347	--	18	64	14	260	16200	--	--
Mara	347	--	19	--	18	--	5430	--	--
Shuswap	347	483	310	162	62	19,100	16200	--	--
Adams	407	--	138	--	169	--	3080	--	--
Momich	472	--	2	--	32	--	480	--	--
Stuart	678	977	360	--	20	--	14600	--	10
Fraser	670	965	55	31	13	724	6030	--	--
Trembleur	687	--	117	--	40	--	8750	--	8
Takla	692	--	260	--	107	--	6370	--	9
François	715	--	260	--	87	--	3600	--	--
Quesnel	725	--	270	--	158	--	5930	--	--
Bowron	945	--	10	--	16	--	460	--	--
Chilko	1172	644	200	366	108	21,600	2110	--	--
Taseko	1321	--	31	--	43	--	1550	--	--

[a] Sources: Ricker (1937), Scheffer and Robinson (1939), Wolcott (1961), Goodlad et al. (1974), Stockner and Northcote (1974), Bortleson et al. (1976), Dion et al. (1976a, b), Edmondson (1977a), Welch et al. (1977), Stockner and Shortreed (1978, 1979, 1983), Bortleson and Dion (1979), Poe and Mathisen (1981), Mesner and Davis (1984), Mullan (1986), Westley (1966), Brenner et al. (1990), Stockner et al. (1993), Gross et al. (1993), Teuscher et al. (1994), Budy et al. (1995).

Appendix Table B-2. Chemical and biological characterstics of selected sockeye salmon nursery lakes. Dashes indicate data were unavailable [a].

System and lake	Mean total phosphorus (µg/L)	Mean total nitrogen (µg/L)	Summer secchi depth (m)	Total dissolved solids (mg/L)	Chlorophyll (µg/L)	Morpho-edaphic index
Columbia River Basin						
Wenatchee	5	83	6.3	28	1.6	0.51
Osoyoos (Southern Basin)	27	154	3.2	168	--	14.74
Osoyoos (Middle Basin)	25	135	2.7	168	--	4.69
Osoyoos (Northern Basin)	22	65	2.5	168	--	10.91
Osoyoos (Total)	--	--	3.3	168	23.0	--
Redfish	8.3	51	11.9-13.5	--	0.4-0.6	0.17
Washington (Puget Sound)						
Washington	16-26	--	1.1-5.5	75	2.3-3.2	2.27
Sammamish	21-26	266	1.0-8.1	73	2.4-5.3	4.06
Baker Lake	--	--	--	--	--	--
Washington (coastal)						
Quinault	--	--	--	--	--	--
Pleasant	9	--	4.0	--	--	--
Ozette	5-7	60-150	2.1-3.8	--	3.5	--
Vancouver Island						
Sproat	1.2	--	--	37	0.5	--
Kennedy	1.3	--	--	26	1.6	--
Nimpkish	0.7-3.4	25.2-28.7	7.0	26	0.8	--
Woss	1.0-2.8	--	--	17-30	1.3	--
Queen Charlotte Islands						
Mathers	0.5	50.7	5.5	--	--	--
Skidegate	0.8	61.8	2.5-3.0	--	--	--
Yakoun	1.0	27.2	4.0	29	3.0	--
Mercer	---	--	3.0	--	--	--
Eden	2.0	13.0	3.0	--	--	--
Ian	<0.5	11.8-29.2	2.5	--	--	--
Awun	3.4	12.6	3.5	--	--	--

Appendix Table B-2. Continued.

System and lake	Mean total phosphorus (µg/L)	Mean total nitrogen (µg/L)	Summer secchi depth (m)	Total dissolved solids (mg/L)	Chlorophyll (µg/L)	Morpho-edaphic index
Mainland B.C. (coastal)						
Sakinaw	0.5-1.4	3.4-4.6	6.5-7.5	--	--	--
Heydon	<0.5	68.7	7.0	--	--	--
Phillips	5.5	83.0	3.0	--	--	--
Owikeno	5.1-8.5	--	1.5-2.9	24-34	0.9-1.9	--
Kitlope	0.5-5.8	18.9	1-6	11	0.0-1.8	--
Lowe	4.6	--	5.9	9	1.2	--
Fraser River						
Pitt	3.0	--	2.2-3.0	26	0.2	0.56
Harrison	3.3	--	3.0-5.5	40	0.8	0.26
Cultus	--	--	3.0-17.0	104	--	3.25
Lillooet	21.1	--	0.3	29	0.8	0.47
Seton	8.0	--	1.5-2.5	45	1.4	0.53
Anderson	3.5	--	11.0	61	0.9	0.44
Little Shuswap	3.5	--	8.0	52	2.5	3.71
Mara	5.0	--	7.0	69	1.8	3.83
Shuswap	3.7	--	8.5-11.0	53	1.6	0.86
Adams	2.3	--	8.0-8.5	31	1.7	0.18
Momich	3.5	--	7.0	32	2.1	0.00
Stuart	3.5	--	7.0-7.5	78	2.0	3.90
Fraser	10.7	--	4.0	34	4.5	2.62
Trembleur	3.5	--	5.5-7.0	58	1.7	1.45
Takla	3.5	80.4-97.6	5.5-7.0	48	1.7	0.45
François	4.5	--	--	76	1.9	0.87
Quesnel	2.0	--	9.0-13.0	62	1.2	0.39
Bowron	3.8	--	5.0-5.5	49	1.5	3.06
Chilko	2.9	--	3.0-7.0	39	0.9	0.36
Taseko	17.8	--	0.3	29	0.4	0.67

[a] Sources: Wolcott (1961), Stockner and Northcote (1974), Bortleson et al. (1976), Dion et al. (1976a, b), Edmondson (1977a), Welch et al. (1977), Bortleson and Dion (1979), Mesner and Davis (1984), Mullan (1986), Edmondson and Abella (1988), Brenner et al. (1990), Stockner et al. (1993), Gross et al. (1993), Teuscher et al. (1994).

Appendix Table B-3. Crustacean zooplankton of sockeye salmon nursery lakes in Washington, Oregon, and Idaho. Dashes indicate species were absent or data were unavailable [a].

Scientific name	Wenatchee	Osoyoos	Redfish	Washington	Sammamish	Baker	Ozette	Pleasant	Quinault
Subclass Copepoda									
Cyclops bicuspidatus	--	--	--	X	X	--	--	--	--
Cyclops vernalis	--	--	--	X	--	--	--	--	--
Cyclops sp.	X	X	--	--	--	--	--	--	--
Diaptomus ashlandi	--	--	--	X	X	--	--	--	--
Diaptomus sp.	X	X	--	--	--	--	X	--	--
Epischura nevadensis	--	--	--	X	X	--	--	--	--
Epischura sp.	--	--	--	--	--	--	X	--	--
Subclass Branchiopoda									
Daphnia galeata	--	--	--	X	--	--	--	--	--
Daphnia pulicaria	--	--	--	X	--	--	X	--	--
Daphnia pulex	--	--	X	--	--	--	--	--	--
Daphnia rosea	--	--	X	--	--	--	--	--	--
Daphnia schødleri	--	--	--	--	X	--	--	--	--
Daphnia thorata	--	--	--	X	X	--	--	--	--
Daphnia sp.	--	X	--	--	--	--	--	--	--
Diaphanosoma leuchtenbergianum	--	--	--	X	X	--	--	--	--
Bosmina longirostris	--	--	X	X	X	--	--	--	--
Bosmina sp.	X	--	--	--	--	--	X	--	--
Holopedium gibberum	--	--	X	--	--	--	--	--	--
Holopedium sp.	--	--	--	--	--	--	X	--	--
Leptodora kindtii	--	--	--	--	X	--	X	--	--
Polyphemus pediculus	--	--	X	--	--	--	--	--	--

[a] Sources: Berggren (1974), Allen and Meekin (1980), Dlugokenski et al. (1981), Edmondson and Litt (1982), Beauchamp et al. (1995), Teuscher and Taki (1996).

Appendix Table B-4. Fishes of sockeye salmon nursery lakes in Washington, Oregon, and Idaho. Dashes indicate species were absent or data unavailable.

Common name	Scientific name	Wenatchee	Osoyoos	Redfish	Washington	Sammamish	Baker	Ozette	Pleasant	Quinault
River lamprey	*Lampetra ayresii*	--	--	--	X	--	--	--	--	--
Western brook lamprey	*Lampetra richardsoni*	--	--	--	X	--	--	--	--	--
Pacific lamprey	*Lampetra tridentata*	--	--	--	X	--	--	--	X[b]	--
Lamprey	*Lampetra* sp.	--	--	--	--	--	--	X	--	--
Chiselmouth	*Acrocheilus alutaceus*	--	X	--	--	--	--	--	--	--
Goldfish	*Carassius auratus*	--	--	--	X[c]	--	--	--	--	--
Common carp	*Cyprinus carpio*	--	X[c]	--	--	--	--	--	--	--
Peamouth	*Mylocheilus caurinus*	--	X	--	X	X	--	X	X[b]	X
Northern squawfish	*Ptychocheilus oregonensis*	X	X	X	X	X	--	X	X[b]	--
Longnose dace	*Rhinichthys cataractae*	X	--	--	--	--	--	--	--	X
Speckled dace	*Rhinichthys osculus*	--	--	--	--	--	--	--	--	X
Dace	*Rhinichthys sp.*	--	--	X	--	--	--	--	--	--
Redside shiner	*Richardsonius balteatus*	X	X	X	X	X	--	X	--	X
Tench	*Tinca tinca*	--	X[c]	--	X[c]	--	--	--	--	--
Longnose sucker	*Catastomus catastomus*	--	X	--	--	--	--	--	--	--
Bridgelip sucker	*Catastomus columbianus*	--	X	--	--	--	--	--	--	--
Largescale sucker	*Catastomus macrocheilus*	X	X	--	X	--	--	--	X[b]	X
Sucker	*Catastomus* sp.	--	--	X	--	--	--	--	--	--
Black bullhead	*Ameiurus melas*	--	X	--	--	--	--	--	--	--
Brown bullhead	*Ameiurus nebulosus*	--	--	--	X[c]	X[c]	--	--	--	--
Channel catfish	*Ictalurus punctatus*	--	--	--	--	--	--	X[c]	--	--
Olympic mudminnow	*Novumbra hubbsi*	--	--	--	--	--	--	X	--	--
Longfin smelt	*Spirinchus thaleichthys*	--	--	--	X	--	--	--	--	--
Lake whitefish	*Coregonus clupeaformis*	--	X	--	--	--	--	--	--	--
Cutthroat trout	*Oncorhynchus clarki*	X	--	X	X	--	X	X	--	X
Coho salmon	*Oncorhynchus kisutch*	--	--	--	X	--	X	X	X	X
Steelhead/rainbow trout	*Oncorhynchus mykiss*	X	X	--	X	--	X	X	X	X
Sockeye salmon/kokanee	*Oncorhynchus nerka*	X	X	X	X	X	X	X	X	X
Chinook salmon	*Oncorhynchus tshawytscha*	X	--	X	X	X	--	--	--	X
Mountain whitefish	*Prosopium williamsoni*	--	X	X	--	X	X	--	--	X
Pygmy whitefish	*Prosopium coulteri*	--	X	--	--	--	--	--	--	--
Brown trout	*Salmo trutta*	--	--	--	--	--	X[c]	--	--	--
Bull trout	*Salvelinus confluentus*	--	--	X	--	--	--	--	--	--
Brook trout	*Salvelinus fontinalis*	--	--	X[c]	--	--	X[c]	--	--	--
Dolly Varden	*Salvelinus malma*	X	--	--	--	--	X	--	X[b]	X

Appendix Table B-4. Continued.

Common name	Scientific name	Wenatchee	Osoyoos	Redfish	Washington	Sammamish	Baker	Ozette	Pleasant	Quinault
Lake trout	*Salvelinus namaycush*	--	--	X[c]	--	--	--	--	--	--
Threespine stickleback	*Gasterosteus aculeatus*	--	--	--	X	--	--	X	X[b]	X
Coastrange sculpin	*Cottus aleuticus*	--	--	--	X	--	--	--	--	--
Prickly sculpin	*Cottus asper*	X	X	--	X	X	--	X	X[b]	X
Riffle sculpin	*Cottus gulosus*	--	--	--	X	X	--	--	--	--
Torrent sculpin	*Cottus rhotheus*	--	--	--	X	--	--	--	--	--
Sculpin	*Cottus* sp.	--	--	X	--	--	--	--	--	--
Pumpkinseed	*Lepomis gibbosus*	--	X[c]	--	X[c]	X[c]	--	--	--	--
Smallmouth bass	*Micropterus dolomieui*	--	X[c]	--	--	--	--	--	--	--
Largemouth bass	*Micropterus salmoides*	--	X[c]	--	X[c]	X[c]	--	X[c]	--	--
White crappie	*Pomoxis annularis*	--	--	--	X[c]	--	--	--	--	--
Black crappie	*Pomoxix nigromaculatus*	--	X[c]	--	X[c]	--	--	--	--	--
Yellow perch	*Perca flavescens*	--	X[c]	--	X[c]	X[c]	--	X[c]	--	--

[a] Sources: Evermann and Latimer (1910), Schultz and DeLacy (1935-1936), Mullan (1986), Ajwani (1956), Johnson (1977), Dlugokenski et al. (1981), Edmondson and Abella (1988), Teuscher and Taki (1996), Jacobs et al. (1996).

[b] Species present in Lake Pleasant in 1897 (this lake was rotenoned in 1956 and present status of non-anadromous fish fauna is unknown).

[c] Introduced species.

APPENDIX C - LIFE HISTORY TRAIT INFORMATION

Appendix Table C-1. Age (as designated in "Age Compostion" section) distribution of selected adult sockeye salmon populations. N = number aged; proportions in bold indicate the mode for that year.

Location			Proportion of fish in each age class												
	Year	N	0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2
Quinault Lake[a, b, c]	1913	560					0.42	**0.55**			0.03				
	1914	503					**0.92**	0.05		<0.01	0.03				
	1915	524					**0.50**	0.44	0.02		0.03	0.02			
	1916	919					0.29	**0.63**			0.07	0.01			
	1917	276					0.41	**0.52**	0.01		0.01	0.05			
	1918	123					**0.92**	0.07			0.01				
	1919	511		<0.01			**0.50**	0.48			0.02				
	1921	1127					**0.80**	0.12			0.08	<0.01			
	1923	1205				0.03	**0.61**	0.30		0.01	0.05	<0.01			
	1924	350					0.29	**0.63**			0.07	0.01			
	1971	156				0.05	**0.77**			0.03	0.13	0.01			0.01
	1975	336				0.18	**0.67**			0.08	0.06	0.01			
	1976	491				0.02	**0.67**			0.26	0.05				
	1977	506				0.03	**0.84**			0.07	0.05	0.01			
	1978	919				0.02	**0.53**	0.27		0.16	0.02	<0.01			
	1979	861					**0.89**	0.05	<0.01		0.05	0.01		<0.01	
	1980	1039					0.15	**0.70**	0.01		0.11	0.03	<0.01		
	1981	1093					**0.80**	0.12	<0.01		0.04	0.03			0.01
	1982	1043					0.11	**0.79**	<0.01		0.07	0.03			
	1983	148					0.24	**0.62**			0.03	0.11			
	1984	164					**0.61**	0.19			0.18	0.02			
	1985	1309					0.09	**0.83**			0.06	0.02	<0.01		
	1986	346					0.14	**0.52**	0.01		0.13	0.20			
	1987	812				<0.01	**0.78**	0.08		<0.01	0.12	0.01			
	1988	2915				<0.01	0.20	**0.74**	<0.01		0.03	0.03			<0.01
	1989	577					0.15	**0.62**	0.01		0.15	0.07			
	1990	936				<0.01	**0.66**	0.20	<0.01		0.12	0.02			<0.01
	1991	892					0.22	**0.63**			0.02	0.12		<0.01	
	1992	1177					0.40	**0.52**	0.01		0.05	0.01		<0.01	
	1993	2327					0.04	**0.86**	<0.01	0.02	0.06	0.02			
	mean			0.00		0.01	**0.54**	0.38	<0.01	0.02	0.06	0.03	0.00	0.00	0.00

Appendix Table C-1. Continued.

Location			Proportion of fish in each age class											
	Year	N	0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1
Baker Lake	1991 ^{d}	240					0.29	**0.71**						
	1992 $^{e, f}$	100					**0.97**	0.03						
	1992 ^{d}	199					**0.99**	0.01						
	1993 $^{e, f}$	100					**0.69**	0.31						
	1993 ^{d}	193				<0.01	**0.83**	0.14						
Lake Washington ^{g}	1970	?				0.05	**0.77**	0.19						
(entire drainage basin)	1971	?				0.04	**0.94**	0.02						
	1972	?				0.05	**0.88**	0.07						
	1973	?				0.05	**0.91**	0.04						
	1974	?				0.05	**0.93**	0.02						
	1975	?				0.05	**0.85**	0.10						
	1976	?				0.10	**0.82**	0.08						
	1977	?				0.03	**0.97**	<0.01						
	1978	?				0.01	**0.98**	0.01						
	1979	?				0.11	**0.87**	0.02						
	1980	?				<0.01	**0.95**	0.04						
	1981	?				0.04	**0.58**	0.37						
	1982	?				0.03	**0.96**	0.01						
	1983	?				0.01	**0.65**	0.34						
	1984	?				<0.01	**0.83**	0.16						
	1985	?				0.03	**0.75**	0.22						
	1986	?				0.01	**0.81**	0.18						
	1987	?				0.02	**0.64**	0.34						
	1988	?				<0.01	**0.91**	0.09						
	1989	?				<0.01	0.36	**0.64**						
	1990	?				0.01	**0.68**	0.31						
	1991	?				0.02	**0.80**	0.18						
	1992	?				<0.01	**0.84**	0.15						
	1993	?				<0.01	**0.84**	0.16						
	1994	?				<0.01	**0.91**	0.08						
	mean					0.03	**0.82**	0.15						

Appendix Table C-1. Continued.

			Proportion of fish in each age class											
Location	Year	N	0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1
Lake Washington Basin														
Cedar River[f]	1992[e]	100					**0.84**	0.16						
	1993[e]	100				0.01	**0.61**	0.38						
	1994[h]	99					**0.93**	0.07						
Pleasure Point Beach[e, f]	1992	100				0.05	**0.64**	0.31						
	1993	100				0.10	**0.67**	0.23						
Big Bear Creek[f]	1992[e]	100				0.02	**0.90**	0.08						
	1993[e]	99				**0.41**	0.29	0.29						
	1994[h]	99					**1.00**							
Cottage Lake Creek[e, f]	1992	100				0.04	**0.96**							
	1993	100				**0.41**	0.26	0.33						
Issaquah Creek	1992[e, f]	100					**1.00**							
	1993[e, f]	100					0.10	**0.90**						
	1996[i]	99					**1.00**							
Lake Wenatchee	1958[j]	54				0.02	**0.74**				0.24			
	1959[k]	44					**0.70**				0.30			
	1962[l]	143					**0.64**			0.02	0.34			
	1985[m]	195					**0.93**	0.01			0.06			
	1987[m]	144					**0.74**	0.11			0.14	0.01		
	1988[m]	196					0.31	0.32			**0.36**	0.01		
	1989[m]	722					**0.71**	0.11			0.17	0.01		
	1990[m]	500					**0.72**	0.09			0.18	0.01		
	1991[m]	414					**0.77**	0.21			0.02	<0.01		
	1992[m]	383				<0.01	**0.48**	0.12			0.40	<0.01		
	1993[m]	521					**0.76**	0.14			0.09	0.01		
	mean					0.00	**0.68**	0.10		0.00	0.21	0.01		

Appendix Table C-1. Continued.

Location	Year	N	Proportion of fish in each age class											
			0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1
Ozette Lake[n]	1994	76					**0.99**	0.01						
Lake Pleasant[o]	1994	42				**0.62**	0.31			0.05	0.02			
	1995	19				0.22	0.16			0.10	**0.42**			
	1996	150				0.12	**0.88**							
Okanogan River	1962[l]	73				**0.59**	0.41							
	1985[p]	?				0.07	**0.88**	0.01		0.01	0.03			
	1987[p]	?				**0.49**	0.46	0.03		0.01	0.01			
	1988[p]	?					**0.96**	0.02		0.01	0.01			
	1989[p]	?				0.03	**0.93**	0.03		0.01	<0.01			
	1990[p]	?				**0.45**	0.26	0.23		0.02	0.04	<0.01		
	1991[p]	?				0.15	**0.77**	0.02		0.06	<0.01			
	1992[p]	688				0.17	**0.73**	0.02		0.07	0.01			
	1993[m]	475					**0.90**	0.05		<0.01	0.05	<0.01		
	mean					0.22	**0.70**	0.05		0.02	0.02	0.00		
Nooksack River	1996[i]	25					**0.56**	0.32	0.08			0.04		
Skagit River														
Upper Skagit River	1996[i]	21					**0.50**	0.45					0.05	
Sauk River	1996[i]	15					0.13	**0.60**				0.20	0.07	
Mainland, B.C. Coast[q]														
Long Lake	1984	131	0.04				**0.54**	0.38			0.03	0.02		
	1989	100					**0.79**	0.21						
Owikeno Lake	1984	92					**0.72**	0.27			0.01			
	1989	96		0.01			**0.56**	0.42				0.01		
Koeye Lake	1985	100				0.04	**0.58**	0.35			0.01	0.02		
Tenas Lake	1985	98		0.01		0.02	**0.55**	0.38			0.01	0.03		
Kimsquit Lake	1986	78				0.13	**0.56**			0.13	0.18			
Tankeeah Lake	1986	99				0.18	**0.75**			0.05	0.02			

Appendix Table C-1. Continued.

Location			Proportion of fish in each age class											
	Year	N	0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1
Mainland, B.C. Coast[q]														
Canoona Lake	1986	96					**0.80**	0.01			0.19			
Kitlope Lake	1986	38	0.03	0.03		0.03	**0.55**	0.32			0.05			
Banks Lake	1986	98					**0.68**	0.07		0.03	0.21			
Mikado Lake	1986	91				0.08	0.29	0.03		0.09	**0.48**	0.03		
Devon Lake	1985	99					0.17	**0.65**			0.01	0.17		
Bonilla Lake	1983	50					**0.66**	0.24			0.10			
Lowe Lake	1986	92					0.33	**0.63**			0.01	0.03		
Queen Charlotte Islands[q]														
Mathers Lake	1982	42				0.02	**0.40**	0.07		0.05	0.36	0.10		
Skidegate Lake	1982	26				0.23	**0.42**	0.04			0.31			
	1989	49				0.04	**0.51**			0.04	0.41			
Yakoun Lake	1982	49				0.08	**0.68**	0.22						
	1989	78				0.01	0.36	**0.60**			0.03			
Mercer Lake	1982	49				0.02	0.29	0.22		0.06	0.10	**0.31**		
	1983	78				0.03	0.02	0.38		0.01	0.10	**0.45**		
Awun Lake	1982	50					**0.72**	0.26			0.02			
Eden Lake	1982	46					**0.65**	0.11		0.02	0.20	0.02		
Vancouver Island[q, r, s]														
Cheewhat Lake	1984	99				0.38	**0.53**			0.01	0.08			
Hobiton Lake	1982	973				<0.01	**0.71**	0.26			0.02	<0.01		
	1987	97				0.05	**0.91**	0.01			0.03			
Henderson Lake	1983	296				0.01	0.32	**0.66**			<0.01	<0.01		
	1988	163					0.30	**0.69**	0.01					
Kennedy Lake	1986	88				0.01	0.43	**0.56**						
Sproat Lake	1983	1094				0.06	**0.63**	0.27		0.01	0.02	0.01		
	1990	50				0.16	**0.58**	0.24			0.02			
Great Central Lake	1983	938				0.02	**0.64**	0.29		<0.01	0.02	0.03		
	1990	96				0.24	0.19	**0.27**		0.06	0.22	0.01		
Woss Lake	1985	98					**0.63**	0.37						

Appendix Table C-1. Continued.

Location	Year	N	0.2	0.3	0.4	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.3
			Proportion of fish in each age class											
Stikine River[t]														
Mainstem	1985	75	0.03	0.41			0.04	**0.49**	0.01			0.01		
	1985[f]	273	<0.01				0.03	**0.91**			0.03	0.03		
Iskut R. at Verrett R.	1984	140		0.02		0.01	0.14	**0.79**	0.01		0.01	0.01		
	1985	156	0.01	0.17			0.08	**0.69**	0.01		0.01	0.04		
Iskut River (km 10)	1985	170	0.01	0.15			0.15	**0.65**	0.01		0.01	0.02		
Scud River	1984	44		0.23			0.09	**0.64**				0.05		
	1985	66	0.02	0.17	0.02		0.04	**0.76**						
Chutine River	1984	61		0.02			0.13	**0.82**				0.03		
	1985	47		0.04		0.02		**0.94**						
Chutine Lake	1984	80					0.23	**0.34**		0.01	0.25	0.16		0.01
	1985	45					0.20	0.24			**0.31**	0.24		
Christina Lake	1984	72					0.01	**0.42**			0.04	0.51	0.01	
Tahltan Lake	1984[c]	85					0.38	**0.55**				0.07		
	1985[f]	126					0.08	**0.90**			0.02			
Fraser River	1915-1960[u]	88,000				0.02	**0.89**	0.07				0.02		

[a] QIN (1995a)
[b] Davidson and Barnaby (1936)
[c] Age determined from scales only
[d] Sprague (1996b)
[e] Hendry (1995)
[f] Age determined from otoliths only
[g] Shaklee et al. (1996)
[h] Hendry and Quinn (1997)
[i] Young (1997)
[j] Craddock and Major (1958)
[k] Craddock and Major (1959)
[l] Tufts and Craddock (1963)
[m] Chapman et al. (1995)
[n] MFMD (1995)
[o] Sneva (1997)
[p] Fryer (1995)
[q] Rutherford et al. (1992)
[r] Tschaplinski and Hyatt (1990)
[s] Manzer et al. (1984)
[t] Wood et al. (1987b)
[u] Killick and Clemens (1963)

Appendix Table C-2. Age composition of the Okanogan River sockeye salmon stock by total age. Freshwater and saltwater age breakdown unknown. Dashes indicate data were unavailable. N = number aged; proportions in bold indicate the mode for that year.

Location Population	Year	N	Age 3	Age 4
Okanogan[a]	1953	?	**0.86**	0.14
	1954	?	0.21	**0.79**
	1955	1,221	0.13	**0.87**
	1956	929	0.25	**0.75**
	1957	695	0.30	**0.70**
	1958	208	**0.84**	0.16
	1959	326	0.15	**0.85**
	1960	140	0.33	**0.67**
	1961	38	**0.79**	0.21
	1966	259	0.48	**0.52**
	1967	421	0.49	**0.51**
	1968	480	0.14	**0.86**
	1969	137	0.18	**0.82**
	1970	867	**0.93**	0.07
	1971	626	0.06	**0.94**
	1972	453	**0.51**	0.49
	1973	479	0.25	**0.75**
	1974	78	0.40	**0.60**

[a] Allen and Meekin (1980).

Appendix Table C-3. Fecundity measurements of selcted sockeye salmon populations. SE = standard error, SD = standard deviation. Dashes indicate data were unavailable.

Location		Age			Fecundity			
Population	Year(s)	class	Mean	SE	SD	Max.	Min.	N
Washington								
Okanogan River[a]	1957	1.1	1928	--	289	2216	1478	7
		1.2	2887	--	437	3593	1958	16
Lake Wenatchee[a]	1957	1.2	2871	--	317	3481	2314	17
		2.2	2890	--	513	3799	2328	6
Cedar River	1968-69[b]	--	3588	--	536	4671	2427	92
	1973[c]	--	3575	--	583	4606	2344	21
	1993[d]	1.2	3374	--	473	4535	2187	41
		1.3	4058	--	557	5336	2748	33
	1994[d]	--	3639	--	696	5870	1809	80
Ozette Lake	1979[e]	1.2	3193	--	--	--	--	4
	?[f]	1.2	3300	--	--	--	--	--
Quinault Lake[g]	1914-47	--	2700	--	--	--	--	--
Vancouver Island								
Hobiton Lake[h]	1979-82	1.2	2636	48	--	--	--	89
		1.3	3107	86	--	--	--	31
		2.2	2722	--	--	--	--	1
Henderson Lake[h]	1976-80	1.2	3835	101	--	--	--	72
		1.3	5142	126	--	--	--	50
		2.2	4163	280	--	--	--	4
Great Central Lake[h]	1971-73, 1979-80	1.2	3240	33	--	--	--	244
		1.3	4278	84	--	--	--	66
		2.2	3613	106	--	--	--	35
Sproat Lake[h]	1979-80	1.2	2889	73	--	--	--	61
		1.3	3786	115	--	--	--	21
		2.2	3032	130	--	--	--	10
Mainland B. C.								
Kitlope Lake[h]	1979-80	1.2	4288	174	--	--	--	11
		1.3	4641	225	--	--	--	8
		2.2	4001	224	--	--	--	9
Lowe Lake[h]	1979-80	1.2	3435	384	--	--	--	3
		1.3	4018	118	--	--	--	20
		2.2	2887	--	--	--	--	2
Curtis Lake[h]	1980-81	1.2	3601	136	--	--	--	3
		1.3	3998	192	--	--	--	11
		2.2	4561	--	--	--	--	1
Bonilla Lake[h]	1980-81	1.2	3420	139	--	--	--	14
		1.2	3604	304	--	--	--	7
		2.2	3467	127	--	--	--	4

Appendix Table C-3. Continued.

Location		Age			Fecundity			
Population	Years	class	Mean	SE	SD	Max.	Min.	N
Queen Charlotte Islands								
Ian Lake[h]	1979-80	1.2	3047	180	--	--	--	14
		1.3	3293	221	--	--	--	11
		2.2	3069	--	--	--	--	1
Awun Lake[h]	1979-80	1.2	2990	128	--	--	--	12
		1.3	3481	166	--	--	--	15
Fraser River								
Early Stuart[i]	--	1.2	4259	92	--	--	--	71
	--	1.3	5539	173	--	--	--	5
Nadina[i]	--	1.2	3205	28	--	--	--	342
	--	1.3	4108	82	--	--	--	46
Stellako	1950-51[j]	1.2	3776	--	--	--	--	148
	--[i]	1.2	3435	48	--	--	--	88
	--[i]	1.3	4155	100	--	--	--	10
Adams River	1950-51[j]	1.2	4252	--	--	--	--	118
	--[i]	1.2	4222	24	--	--	--	463
	--[i]	1.3	4391	295	--	--	--	9
Horsefly[i]	--	1.2	3439	46	--	--	--	172
	--	1.3	4122	108	--	--	--	18
Late Shuswap[i]	--	1.2	4034	37	--	--	--	167
	--	1.3	3626	238	--	--	--	3
Seymour[i]	--	1.2	4217	71	--	--	--	50
	--	1.3	4569	344	--	--	--	4
Birkenhead[i]	--	1.2	4365	44	--	--	--	126
	--	1.3	5104	61	--	--	--	77
Chilko	1945-46, 1948[j]	1.2	2592	--	--	--	--	144
	--[i]	1.2	2991	22	--	--	--	276
	--[i]	1.3	3656	156	--	--	--	8
	--[i]	2.2	2939	81	--	--	--	19
Gates[i]	--	1.2	3381	36	--	--	--	186
	--	1.3	3993	780	--	--	--	7
Weaver[i]	--	1.2	4263	62	--	--	--	78
	--	1.3	4592	128	--	--	--	21
Pitt[i]	--	1.2	4123	75	--	--	--	51
	--	1.3	4918	92	--	--	--	51
Cultus Lake[k, j]	1932-35, 1937-38	1.2	4055	--	--	--	--	305
	1943-44	1.2	3913	--	--	--	--	96

Appendix Table C-3. Continued.

Location Population	Years	Age class	Fecundity Mean	SE	SD	Max.	Min.	N
Kamchatka[l]								
Ozernaya River	--	5-6 yr	2100-4100	--	--	--	--	--
Kamchatka River	--	--	3760	--	--	6448	1570	--
Paratunka River								
Lake Blizhnee	--	--	2000-2400	--	--	--	--	--
Lake Dalnee	--	--	2500-2600	--	--	--	--	--
Paratunka Springs	--	--	5000	--	--	--	--	--
Bolshaya River								
Karymaysk Springs	--	--	4500-5165	--	--	--	--	--

[a] Major and Craddock (1962)
[b] Heiser (1969)
[c] Bryant (1976)
[d] A. Hendry (Univ. Washington, unpublished data)
[e] Dlugokenski et al. (1981)
[f] Jacobs et al. (1996)
[g] QIN (1981, p. 50)
[h] Manzer and Miki (1985)
[i] Linley (1993)
[j] Ward (1952)
[k] Foerster and Pritchard (1941)
[l] Smirnov (1975)

Appendix Table C-4. Smolt sizes of selected sockeye salmon populations in Washington (WA), Idaho (ID), and British Columbia (BC). Length measurements are fork lengths. Dashes indicate data were unavailable.

Location Lake system	State/ Province	Year(s)	Age	N	Mean Length (mm)	Range (mm)	Mean Weight (g)	Range (g)	Source
Columbia River Basin									
Lake Osoyoos	WA	1957	--	366	94	75-154	--	--	Allen and Meekin (1980)
		1958	--	412	103	75-189	--	--	Allen and Meekin (1980)
		1972	1	120	106	85-120	--	--	Allen and Meekin (1973,1980)
		1972	2	2	180	179-180	--	--	Allen and Meekin (1980)
		1973	1	360	112	90-134	--	--	Allen and Meekin (1980)
		1974	1	22	111	100-124	--	--	Allen and Meekin (1980)
		1981	--	1,385	128	84-151	--	--	Weitkamp and Neuner (1981)
		1982	--	6,994	114	75-232	--	--	McGee and Truscott (1982)
		1983	--	3,884	105	84-123	--	--	McGee et al. (1983)
Lake Wenatchee	WA	1972	1	81	84	68-108	--	--	Allen and Meekin (1973)
		1973	1	132	81	65-114	--	--	Allen and Meekin (1980)
		1974	1	23	91	70-124	--	--	Allen and Meekin (1980)
Redfish Lake	ID	1956-66	1	--	91	70-113	--	--	Bjornn et al. (1968), Chapman et al. (1990)
			2	--	120	96-163	--	--	Bjornn et al. (1968), Chapman et al. (1990)
		1994	1+	722	96	--	--	--	Kline and Younk (1995)
Washington (Puget Sound)									
Lake Washington	WA	1965	1	245	120	--	16.7		Bryant (1976)
		1966	1	24	132	--	--		Bryant (1976)
		1967	1	306	129	--	20.5		Bryant (1976)
		1968	1	76	127	--	19.5		Bryant (1976)
		1969	1	227	124	--	17.1		Bryant (1976)
		1996	0	21	95	86-110	--	--	Warner (1996)
			1	541	133	100-185	--	--	Warner (1996)
Baker Lake	WA	1952	--	317	≅ 97	≅78-130	--	--	Hamilton and Andrew (1954)
		1990	1	33	148	112-180	--	--	Sprague (1996b)
			2	1	230	--	--	--	Sprague (1996b)
		1994	--	926	152	72-280	--	--	Sprague (1996b)
		1995	--	235	138	83-240	--	--	Sprague (1996b)
		1996	--	673	136	100-266	--	--	Sprague (1996b)

Appendix Table C-4. Continued.

Location Lake system	State/ Province	Year(s)	Age	N	Mean Length (mm)	Range (mm)	Mean Weight (g)	Range (g)	Source
Washington (coastal)									
Ozette Lake	WA	1977	1+	--	113	--	14.2	--	Dlugokenski et al. (1981)
		1979-84	1	--	117	41-164	15.3	--	Blum (1988)
		1989	1	255	122	--	17.4	--	LaRiviere (1990)
		1990	1+	457	120	--	17.2	--	Jacobs et al. (1996)
		1991	1+	74	127	--	18.7	--	Jacobs et al. (1996)
		1992	1+	214	130	--	21.4	--	Jacobs et al. (1996)
Lake Pleasant	WA	1958	--	--	--	--	29.5	--	Crutchfield et al. (1965)
		1995	--	14	145	133-159	33.1	25.0-46.0	NMFS, unpublished data
Quinault Lake	WA	4/14/71	--	66	80	58-105	--	--	USBSFW (1971)
		4/27/71	--	99	87	60-112	--	--	USBSFW (1971)
		1974	1	144	70	55-95	3.9	2.1-7.8	Tyler and Wright (1974)
			2	3	109	101-115	11.2	9.6-12.8	Tyler and Wright (1974)
Vancouver Island									
Great Central L.	BC	1969-1976	1	--	69	64-78	--	--	Eggers (1978)
		1989	1+	922	71	54-95	2.9	--	Wood et al. (1993)
			2+	6	--	85-96	--	--	Wood et al. (1993)
Mainland B. C. (coastal)									
Owikeno Lake	BC	1914-16	--	--	59	59-60	--	--	Gilbert (1918)
		1956	--	--	61	--	2.0	--	Foskett (1958)
		1961-63	--	--	--	--	--	1.8-2.4	Ruggles (1966)
Port John Lake	BC	5 total	1	--	84	83-94	6.2	4.4-6.8	Foerster (1968)
			2	--	104	98-109	11.2	8.5-13.0	Foerster (1968)
			3	--	126	120-127	21.7	--	Foerster (1968)

Appendix Table C-4. Continued.

Location Lake system or population	State/ Province	Year(s)	Age	N	Mean Length (mm)	Range (mm)	Mean Weight (g)	Range (g)	Source
Fraser River									
Cultus	BC	1925-71	1	--	82	68-94	6.2	3.0-8.6	Eggers (1978)
		11 total	2	--	120	106-127	16.8	12.6-22.6	Foerster (1944)
Harrison	BC	2 total	1	--	95	--	9.2	--	Clutter and Whitesel (1956)
Lillooet	BC	1 total	1	--	77	--	4.5	--	Clutter and Whitesel (1956)
Shuswap (Adams)	BC	7 total	1	--	74	--	4.0	--	Goodlad et al. (1974)
		2 total	1	--	63	--	2.3	--	Clutter and Whitesel (1956)
Chilko	BC	1950-70	1	--	82	73-101	4.6	3.1-8.4	Eggers (1978)
		1951-55	2	--	107	101-113	10.9	9.1-12.4	Clutter and Whitesel (1956)
Fraser (Stellako R.)	BC	1 total	1	--	90	--	7.8	--	Goodlad et al. (1974)
François	BC	1 total	1	--	105	--	12.0	--	Clutter and Whitesel (1956)
Stuart	BC	1 total	1	--	95	--	8.8	--	Clutter and Whitesel (1956)

Appendix Table C-5. Duration and peak smolt outmigration timing of selected sockeye salmon populations in Washington (WA), Oregon (OR), Idaho (ID), and British Columbia (BC). Dashes indicate data were unavailable.

Location Population	State/ Province	Duration of smolt outmigration	Peak smolt outmigration	Year(s) covered	Source
Columbia River Basin					
Okanogan River	WA	30 Apr-19 May	8 May-12 May	1981	Weitkamp and Neuner (1981)
		mid-Apr-20 May	late-Apr-20 May	1982	McGee and Truscott (1982)
		mid Apr-late May	several peaks	1983	McGee et al. (1983)
Lake Wenatchee	WA	26 Mar-25 May	27 Apr-15 May	1946-54	Mullan (1986)
		Apr-18 May	1-6 May	1955-56	French and Wahle (1959)
Redfish Lake	ID	late-Apr-late-May	3-18 May	1955-66	Bjornn et al. (1968)
Washington (Puget Sound)					
Baker River	WA	24 Apr-7 June	mid-May	1951-52	Hamilton and Andrew (1954)
Lake Washington	WA	Mar-early June	late Apr-early May	1967-70	Bryant (1976)
Ozette Lake	WA	3 Apr-29 May	6 May	1979	Dlugokenski et al. (1981)
Quinault Lake	WA	mid-Apr-25 June	late Apr-mid May	1974	Tyler and Wright (1974)
Vancouver Island					
Hobiton Lake	BC	2 Apr-18 June	late Apr-mid-May	1983	Hyatt et al. (1984)
Muriel Lake	BC	late Mar-18 June	early Apr-mid May	1983	Hyatt et al. (1984)
Mainland B. C. (coastal)					
Port John Lake	BC	2 Apr-18 June	7 May-21 May	1948-61	Hyatt et al. (1984)
Queen Charlotte Islands					
Mathers Lake	BC	9 Apr-21 May	30 Apr-7 May	1978	Hyatt et al. (1984)
Fraser River					
Late Stuart	BC	--	11 May	3 total	Linley (1993)
Nadina	BC	--	8 May	1 total	Linley (1993)
Horsefly	BC	--	2 May	4 total	Linley (1993)
Chilko	BC	--	30 Apr	34 total	Linley (1993)
Cultus	BC	16 Feb-20 July	5 Apr-early May	1926-36	Foerster (1937)
		--	27 Apr	12 total	Linley (1993)

Appendix Table C-6. Spawning habitat, duration (shaded) and peak (heavy shading) of freshwater entry, and spawn (s) and peak spawn (P) timing of selected sockeye salmon populations. I - inlet spawning population, B - beach spawning population, O - outlet spawning population, A - artificial spawning beach or channel, R - river spawning population.

Location Population	Spawn habitat	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
Columbia River Basin																									
Okanogan River[a]	I												▨	■	▨	▨			s	s	s				
Lake Wenatchee[a]	I												▨	■	▨	▨			s	s					
Deschutes River	?													▨	▨	▨	▨	▨	▨ s	s	s	s			
Redfish Lake	B														▨	▨	▨	▨		s	s				
Washington (Puget Sound)																									
Baker River[a]	A												▨	▨	▨	▨			s	s	s	s	s	s	s
Cedar River[a]	I	s											▨	▨	▨	▨	▨		s	s	P	s	s	s	s
Lake Washington tribs.[a]	I												▨	▨	▨	▨	▨		s	s	P	s	s		
Lake Washington beach[a]	B	s											▨	▨	▨	▨	▨				s	s	s	s	s
Washington (coastal)																									
Ozette Lake[a]	B	s	s	s	s	s	s	▨	▨	▨	▨	▨	▨	▨	▨	▨							s	s	s
Lake Pleasant[a]	B	s								▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				s	s	s
Quinault Lake[a]	I	▨ s	▨ s	▨ s	▨ s	▨	▨	▨	▨	▨	■	■	■	■	▨							s	s	s	s
Vancouver Island																									
Cheewhat Lake[b]	I				▨	▨	▨	▨	▨	▨	▨	▨	■	■	▨	▨	▨								
Hobiton Lake[c, d]	?							▨	▨	▨	▨	■	■	▨	▨					P	P	s	s		
Henderson Lake[c, e, f]	I														▨	▨	▨	■	■ s	P	P	s	s		
Sproat Lake[c, g]	B										▨	▨	▨	■	■	▨	▨	▨	▨						
Great Central Lake[h, e, g]	B										▨	▨	▨	■	■	▨	▨	▨	▨ s	P	P	s	s		
Mahatta River[c]	I																	s	s	P	P				
Nimpkish River[c]	?															s	s	P	P	s	s				
Kennedy River System																									
Kennedy Lake[c]	B																			s	s	P	P		
Clayoquot River[c]	I																			s	s	P	P		
Cold Creek[c]	I																			s	s	P	P		
Upper Kennedy River[c]	I																	s	s	P	P				
Muriel Lake	I, B																								

Appendix Table C-6. Continued.

Location Population	Spawn habitat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Fraser River													
Early Stuart^{i}	I^{j}							▓	P				
Early Nadina^{i}	I^{j}							▓	P				
Gates^{i}	I^{j}							▓	P				
Bowron River^{i}	I^{j}							▓	P				
Pitt River^{i}	I^{j}							▓		P			
Seymour River^{i}	I^{j}								▓ P				
Raft River^{i}	I^{j}								▓	P			
Late Stuart^{i}	I/O^{j}								▓	P			
Horsefly River (Quesnel)^{i}	I^{j}								▓	P			
Late Nadina^{i}	O/A^{j}								▓	P			
Chilko Lake^{i}	I/O^{j}								▓	P			
Stellako^{i}	I/O^{j}								▓	P			
Birkenhead^{i}	I^{j}								▓	P			
Weaver Creek^{i}	I/A^{j}									▓	P		
Adams (Late Shuswap)^{i}	I^{j}									▓	P		
Harrison^{i}	O^{j}										▓	P	
Cultus Lake^{i}	B^{j}										▓	P	
Queen Charlotte Islands													
Mathers Creek/Lake^{k}	?				░	▓	░						
Copper Cr./ Skidegate L.$^{c, k}$	?					░	░		s s	P P			
Yakoun Lake$^{c, l}$	?				░	░	░	s s	P P	s s			
Mercer Creek/Mercer L.$^{c, l}$	?						░	░	s s	P P			
Naden R./Eden Lake$^{c, l}$	?						░	░ s s	P P	s s			

Appendix Table C-6. Continued.

Location Population	Spawn habitat	Jan		Feb		Mar		Apr		May		June		July		Aug		Sept		Oct		Nov		Dec	
Mainland B.C. (coastal)																									
Sakinaw Lake[c]	?																	s	s	P	P				
Heydon Creek[c]	?															s	s	P	P	s	s				
Phillips River[c]	?															s	s	P	P	s	s				
Mackenzie Lake[c]	?															s	s	P	P	s	s				
Klinaklini River[c]	?															s	s	P	P	s	s				
Kakweiken River[c]	?															P	P	s	s						
Long Lake[c, l, m]	I												▨	▨	▨	▨		s	s	P	P	s			
Owikeno Lake[n]	I, B, O													▨	▨	▨	▨ s	s	P	P	s	s	s		
Kimsquit Lake[c]	?															s	s	P	P	s	s				
Atnarko R. (Tenas L.)[c, l]	I, B, O															s	s	P	P	s	s				
Kitlope Lake[c]	I, B															s	s	P	P						
Kamchatka Peninsula[o]																									
Ozernaya R./Lake Kuril	B											▨	▨	▨	▨	▓	▓ s	▓ s	▨ s	▨ s	s				
Kamchatka River (early)[p]	R, sea-type											▨	▨			P	P								
Kamchatka River (late)[p]	R, river-type																▨ P	▨ s							
Paratunka River (early)	B, deep										▨	▨	▨		s	s	s								
Paratunka River (late)	B, shallow														▨	▨	▨ s	s	s	s	s				
Bolshaya River (early)	I										▨	▓	▨		s	s	s								
Bolshaya River (late)	I, B														▓	▓ s	▨ P	P	P	s	s				

---

[a] WDF et al. (1993)

[b] K. Hyatt, Pers. commun., Department of Fisheries and Oceans, Pacific Biological Station, Hammond Bay Road, Nanaimo, BC, Canada V9R 5K6

[c] Aro and Shepard (1967)

[d] Manzer et al. (1984)

[e] Tschaplinski and Hyatt (1991)

[f] Tschaplinski and Hyatt (1990)

[g] Steer and Hyatt (1987)

[h] Barraclough and Robinson (1972)

[i] Gilhousen (1990)

[j] Brannon (1996)

[k] Marshall et al. (1978)

[l] C. C. Wood, Pers. commun., Department of Fisheries and Oceans, Pacific Biological Station, Hammond Bay Road, Nanaimo, BC, Canada V9R 5K6

[m] Thomson and Goruk (1988)

[n] Thomson et al. (1988)

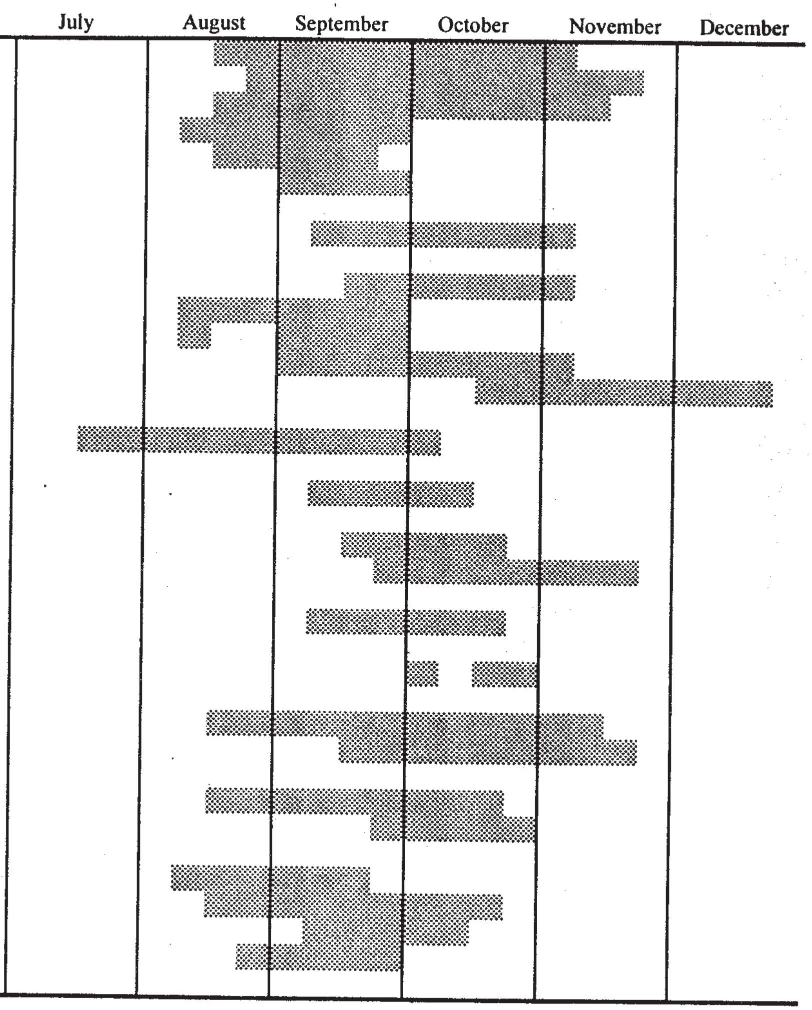
[o] Hanamura (1967)

[p] Bugaev (1987)

Appendix Table C-7. Location, timing, and abundance of sockeye salmon in river basins without lake rearing habitat in western Washington (Columbia River tributaries are not included). Includes streams or river reaches with 3 or more years of survey data. Based on Egan (1977, 1995, 1997).

River Basin	Tributary	Area surveyed (river km)	Time span	Total survey years	Peak count (range)
Nooksack	N. F. Nooksack	74-92	1990-96	6	1-6
	N. F. Nooksack	98-101	1961-96	5	3-52
	Kendall Creek	entire reach	1961-95	12	1-3
	Maple Creek	entire reach	1961-96	10	0-11
	Cornell Creek	entire reach	1961-95	4	1-5
	S. F. Nooksack	8-55	1979-96	10	1-75
Samish	Mainstem	7-17	1950-95	15	1-18
Skagit	Mainstem	140-149	1977-96	8	1-29
	Sauk River	51-64	1958-96	26	1-29
	Buck Creek	entire reach	1981-95	9	1-3
	Illabot Creek	entire reach	1962-96	10	1-16
	County Line Slough	entire reach	1980-96	10	1-30
Stillaguamish	N.F. Stillaguamish	33-55	1961-96	15	1-34
Snohomish	Wallace River	0-10	1975-96	11	1-6
Duwamish/Green	Green River	54-71	1953-96	11	1-16
	Green River	90-98	1976-90	3	1-2
Puyallup	S. Prairie Creek	entire reach	1945-96	13	1-4
Deschutes	Percival Creek	entire reach	1964-96	4	1-4
Kitsap Peninsula	Union River	0-5	1985-96	9	1-4
	Coulter Creek	entire reach	1991-96	4	1-2
Hood Canal	Skokomish & N.F.	8-21	1980-96	8	1-5
	Hamma Hamma	0.1-4	1971-96	4	1-7
Dungeness	Dungeness/Grey Wolf	0-30	1971-96	11	1-5
Elhwa	Elhwa	0-7	1969-96	6	1-2
Quillayute	S. F. Calawah	21-25	1981-83	2	0-4
Hoh	Hoh	entire reach	1979-83	2	1-8

Range of dates when fish have been observed



Appendix Table C-8. Mean snout to fork length and weight of adult returns for selected sockeye salmon populations for individual years, sex, and age. Length measurements have been converted to fork length where necessary (see text for conversion equations). SD = standard deviation. Dashes indicate data were unavailable.

Location			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
(Lake or river)	Year	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Quinault Lake [a]	1975	1.1	506	25	9	499	19	19	1687	267	8	1600	226	18
		1.2	514	21	11	519	22	15	1742	255	11	1830	262	14
		2.1	630	--	1	576	21	3	3629	--	1	2268	0	2
		2.2	512	17	2	528	6	2	1758	80	2	1758	240	2
	1976	1.1	488	26	2	406	--	1	1814	641	2	1360	--	1
		1.2	542	36	29	514	36	84	2327	321	28	2196	438	84
		2.1	563	91	7	581	39	17	2362	696	6	2726	588	17
		2.2	506	--	1	504	4	3	2494	--	1	2192	571	3
	1977	1.1	501	19	8	483	14	9	1790	238	8	1561	125	9
		1.2	599	26	186	500	23	212	1783	302	186	1691	259	212
		2.1	556	35	15	564	16	19	2335	448	15	2358	239	19
		2.2	527	32	11	514	28	15	1907	384	11	1911	424	15
		2.3	--	--	--	585	16	3	--	--	--	2607	145	3
	1978	1.1	499	22	10	503	17	11	1575	265	10	1623	103	11
		1.2	562	29	204	560	24	281	2354	372	204	2284	302	281
		1.3	598	21	117	585	20	131	2838	328	117	2660	325	131
		2.1	582	22	52	578	20	92	2559	304	52	2465	266	92
		2.2	553	18	9	556	21	12	2178	460	9	2238	362	12
	1979	1.2	495	37	399	485	24	357	1559	386	395	1446	224	356
		1.3	556	41	18	550	38	22	2203	533	18	2111	417	22
		1.4	626	--	1	--	--	--	3000	--	1	--	--	--
		2.2	505	51	20	493	29	26	1708	669	20	1506	256	26
		2.3	581	25	3	560	25	5	2467	276	3	2180	314	5
		3.1	--	--	--	429	--	1	--	--	--	900	--	1
	1980	1.2	493	24	72	488	22	85	1549	227	72	1461	187	84
		1.3	557	26	252	549	24	476	2224	387	251	2139	333	475
		1.4	599	62	5	573	25	3	2933	1058	5	2367	333	3
		2.2	504	21	62	489	20	51	1625	241	61	1456	223	52
		2.3	536	23	7	536	30	20	1971	287	7	2016	373	19
		2.4	536	--	1	--	--	--	2000	--	1	--	--	--

Appendix Table C-8. Continued.

Location (Lake or river)	Year	Age	Male Length (mm) Mean	SD	N	Female Length (mm) Mean	SD	N	Male Weight (g) Mean	SD	N	Female Weight (g) Mean	SD	N
Quinault Lake [a] (continued)														
	1981	1.2	482	22	474	477	26	396	1571	221	473	1521	232	395
		1.3	552	41	71	543	39	65	2313	429	71	2133	435	65
		1.4	--	--	--	574	--	1	--	--	--	2600	--	1
		2.2	492	38	20	488	27	22	1702	316	20	1598	211	21
		2.3	556	41	16	543	21	13	2379	657	17	2108	314	13
		3.2	502	37	3	520	41	8	1683	333	3	1981	525	8
	1982	1.2	492	21	68	498	26	45	1707	235	68	1739	246	45
		1.3	549	27	346	541	24	468	2300	383	346	2190	324	467
		1.4	591	--	1	--	--	--	2900	--	1	--	--	--
		2.2	503	30	43	494	16	31	1791	339	43	1655	180	31
		2.3	552	18	15	543	30	12	2311	263	14	2250	390	12
	1983	1.2	489	27	19	495	16	16	1550	319	19	1584	172	16
		1.3	571	30	38	555	25	54	2451	375	38	2267	297	53
		2.2	496	38	2	502	18	2	1675	460	2	1775	248	2
		2.3	548	25	5	545	27	12	2080	256	5	2021	384	12
	1984	1.2	490	24	73	480	21	26	1607	220	73	1512	224	26
		1.3	548	23	15	536	26	17	2227	266	15	2077	403	17
		2.2	519	31	20	486	15	9	1915	320	20	1511	234	9
		2.3	--	--	--	547	24	3	--	--	--	2217	293	3
	1985	1.2	498	31	61	496	22	49	1670	323	61	1620	216	49
		1.3	551	26	465	542	24	619	2208	325	465	2129	343	618
		2.2	501	25	35	495	25	42	1647	296	35	1573	249	42
		2.3	552	19	16	543	18	15	2191	263	16	2103	232	15
		2.4	--	--	--	525	--	1	--	--	--	1900	--	1
	1986	1.2	489	23	27	489	23	20	1615	263	26	1610	253	20
		1.3	566	45	65	556	22	111	2341	354	65	2259	259	111
		1.4	558	--	1	552	44	2	2250	--	1	2250	636	2
		2.2	508	22	21	495	20	24	1712	255	21	1625	184	24
		2.3	551	24	37	544	24	33	2139	302	37	2088	288	33

Appendix Table C-8. Continued.

Location			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
(Lake or river)	Year	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Quinault Lake [a] (continued)														
	1987	1.1	422	32	2	--	--	--	1125	177	2	--	--	--
		1.2	505	26	299	496	22	334	1752	297	299	1648	222	334
		1.3	567	32	24	562	25	41	2548	620	24	2407	356	41
		2.1	433	--	1	--	--	--	1050	--	1	--	--	--
		2.2	502	20	36	496	21	64	1655	246	36	1621	229	64
		2.3	562	18	3	563	14	7	2400	312	3	2357	181	7
	1988	1.2	502	30	298	495	22	272	1681	261	298	1578	234	271
		1.3	564	26	792	556	26	1349	2346	360	788	2239	312	1348
		1.4	536	--	1	--	--	--	1900	--	1	--	--	--
		2.2	515	19	33	500	21	44	1794	265	33	1626	223	44
		2.3	559	24	38	552	23	50	2232	288	38	2152	285	50
		3.2	--	--	--	498	14	2	--	--	--	1575	248	2
	1989	1.2	500	26	50	490	26	36	1641	280	50	1551	269	35
		1.3	570	28	131	559	23	224	2418	375	131	2287	317	224
		1.4	605	3	2	553	44	6	2900	141	2	2358	591	6
		2.2	508	30	35	502	22	51	1710	337	35	1637	269	51
		2.3	558	23	16	564	26	24	2272	248	16	2375	342	24
	1990	1.1	446	--	1	--	--	--	1100	--	1	--	--	--
		1.2	497	28	303	487	25	312	1592	286	303	1484	246	311
		1.3	556	30	73	542	25	111	2163	378	71	2035	295	111
		1.4	637	--	1	623	--	1	3250	--	1	2850	--	1
		2.2	496	21	38	492	23	73	1547	217	37	1530	266	73
		2.3	567	64	7	539	31	9	2300	812	7	2072	367	9
		3.2	542	4	2	519	17	2	2075	106	2	1725	106	2
	1991	1.2	487	25	111	488	24	89	1532	243	111	1499	229	90
		1.3	555	33	239	549	31	326	2251	438	236	2165	348	324
		2.2	501	24	7	502	24	9	1593	270	7	1667	386	9
		2.3	549	24	48	539	24	61	2103	298	48	1997	413	60
		3.1	--	--	--	462	--	1	--	--	--	1250	--	1

Appendix Table C-8. Continued.

Location (Lake or river)	Year	Age	Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
			Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Quinault Lake [a] (continued)														
	1992	1.2	485	26	317	477	23	159	1505	283	317	1426	191	159
		1.3	539	27	232	533	25	383	2058	335	231	1992	319	380
		1.4	532	6	5	546	29	6	1910	114	5	2092	287	6
		2.2	484	27	37	470	26	26	1457	186	37	1371	254	26
		2.3	556	28	6	539	35	5	2150	327	6	2090	256	5
		3.1	480	--	1	--	--	--	1350	--	1	--	--	--
	1993	1.2	501	29	46	493	22	41	1667	275	45	1610	233	41
		1.3	548	24	895	537	23	1110	2169	289	895	2060	274	1109
		1.4	--	--	--	520	44	2	--	--	--	1850	636	2
		2.1	566	27	23	544	29	22	2334	366	22	2086	337	22
		2.2	504	23	64	497	26	69	1688	228	64	1594	259	69
		2.3	533	21	21	531	23	31	1995	231	21	1961	276	31
Big Creek	1996 [b]	--	465	56	62	478	38	37	--	--	--	--	--	--
Ozette Lake	1977-9[c]	1.1	407[d]	--	--	--	--	--	910[d]	--	--	--	--	--
		1.2	564[d]	--	--	--	--	--	2200[d]	--	--	--	--	--
	1994 [e]	1.2	522	--	46	510	--	33	--	--	--	--	--	--
		1.3	--	--	--	572	--	1	--	--	--	--	--	--
Allen's Bay	1994 [b]	--	526	30	18	517	20	14	--	--	--	--	--	--
	1996 [b]	--	535	38	54	528	20	47	--	--	--	--	--	--
Olsen's Beach	1994 [b]	--	517	35	24	512	23	20	--	--	--	--	--	--
	1996 [b]	--	519	51	46	524	24	54	--	--	--	--	--	--
Lake Pleasant	1995 [f]	--	451	25	10	459	15	5	--	--	--	--	--	--
	1996 [b, g]	1.1	423	47	6	--	--	--	--	--	--	--	--	--
		1.2	464	19	64	456	21	26	--	--	--	--	--	--
Riverine spawners														
N.F. Nooksack River	1996[b]	--	558	9	2	532	25	9	--	--	--	--	--	--
S. F. Nooksack River	1996[b]	--	514	48	5	588	18	10	--	--	--	--	--	--
Skagit River	1996[b]	--	543	65	11	542	40	14	--	--	--	--	--	--
Sauk River	1996[b]	--	647	29	3	573	39	12	--	--	--	--	--	--

Appendix Table C-8. Continued.

Location			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
(Lake or river)	Year	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Baker Lake	1986[h]	1.2	622	2	8	584	2	32	--	--	--	--	--	--
	1989[h, i]	1.2	596	3	13	564	2	27	--	--	--	--	--	--
	1991[h, j]	1.2	594	4	20	544	3	50	--	--	--	--	--	--
		1.3	653	4	77	595	3	93	--	--	--	--	--	--
	1992[h, j]	1.2	606	3	66	552	3	131	--	--	--	--	--	--
		1.3	600	--	1	520	--	1	--	--	--	--	--	--
	1992[k]	1.2	544	--	--	521	--	--	--	--	--	--	--	--
	1993[h, j]	1.1	--	--	--	500	--	1	--	--	--	--	--	--
		1.2	601	3	72	551	3	89	--	--	--	--	--	--
		1.3	666	3	16	606	3	11	--	--	--	--	--	--
		2.2	635	5	2	555	1	2	--	--	--	--	--	--
	1993[k]	1.2	566	--	--	545	--	--	--	--	--	--	--	--
Lake Washington														
Cedar River	1964[l]	2.2	571	--	88	549	--	100	--	--	--	--	--	--
	1965[l]	2.2	564	--	71	543	--	122	--	--	--	--	--	--
	1992[k]	1.2	537	--	33	533	--	80	--	--	--	--	--	--
		1.3	592	--	8	589	--	13	--	--	--	--	--	--
	1993[k]	1.1	465	--	1	--	--	--	--	--	--	--	--	--
		1.2	514	--	32	522	--	41	--	--	--	--	--	--
		1.3	570	--	7	573	--	36	--	--	--	--	--	--
Pleasure Point Beach	1965[l]	2.2	530	--	75	506	--	205	--	--	--	--	--	--
	1992[k]	1.1	419	--	1	456	--	1	--	--	--	--	--	--
		1.2	510	--	15	497	--	11	--	--	--	--	--	--
		1.3	550	--	11	516	--	1	--	--	--	--	--	--
	1993[k]	1.1	426	--	4	--	--	--	--	--	--	--	--	--
		1.2	517	--	17	494	--	4	--	--	--	--	--	--
		1.3	578	--	3	563	--	6	--	--	--	--	--	--
Big Bear Creek[k]	1992	1.1	434	--	1	--	--	--	--	--	--	--	--	--
		1.2	518	--	30	490	--	27	--	--	--	--	--	--
		1.3	579	--	2	552	--	3	--	--	--	--	--	--
	1993	1.1	439	--	13	458	--	9	--	--	--	--	--	--
		1.2	542	--	9	520	--	7	--	--	--	--	--	--
		1.3	586	--	5	529	--	10	--	--	--	--	--	--

Appendix Table C-8. Continued.

Location (Lake or river)	Year	Age	Male Length (mm) Mean	 SD	 N	Female Length (mm) Mean	 SD	 N	Male Weight (g) Mean	 SD	 N	Female Weight (g) Mean	 SD	 N
Lake Washington (continued)														
Cottage Lake Creek[k]	1992	1.1	376	--	2	--	--	--	--	--	--	--	--	--
		1.2	523	--	26	500	--	20	--	--	--	--	--	--
	1993	1.1	448	--	11	430	--	5	--	--	--	--	--	--
		1.2	518	--	17	502	--	6	--	--	--	--	--	--
		1.3	575	--	8	590	--	5	--	--	--	--	--	--
Issaquah Creek	1992[k]	1.2	513	--	54	495	--	29	--	--	--	--	--	--
	1993[k]	1.2	534	--	4	558	--	2	--	--	--	--	--	--
		1.3	565	--	36	553	--	22	--	--	--	--	--	--
	1996[b]	1.2	530	30	42	519	27	58	--	--	--	--	--	--
Columbia River														
Okanogan River[m]	--	1.1	387	18	30	379	17	269	--	--	--	--	--	--
	--	1.2	509	27	500	499	27	515	--	--	--	--	--	--
	--	1.3	576	24	56	564	17	7	--	--	--	--	--	--
	--	2.1	427	21	9	411	20	31	--	--	--	--	--	--
	--	2.2	532	24	11	501	18	8	--	--	--	--	--	--
	--	2.3	563	11	2	565	--	1	--	--	--	--	--	--
Lake Wenatchee[m]	--	1.1	405	--	1	--	--	--	--	--	--	--	--	--
	--	1.2	507	23	580	494	20	469	--	--	--	--	--	--
	--	1.3	572	29	192	563	30	42	--	--	--	--	--	--
	--	2.2	519	27	157	500	24	171	--	--	--	--	--	--
	--	2.3	574	21	23	518	53	2	--	--	--	--	--	--
Vancouver Island														
Cheewhat Lake[n]	1984	1.2	434	--	40	450	--	12	--	--	--	--	--	--
Hobiton Lake	1982[o]	1.2	486	--	356	490	--	337	--	--	--	--	--	--
		1.3	553	--	112	540	--	137	--	--	--	--	--	--
	1987[n]	1.2	454	--	61	471	--	27	--	--	--	--	--	--
Henderson Lake	1983[n]	1.2	521	--	57	516	--	39	--	--	--	--	--	--
		1.3	585	--	103	571	--	93	--	--	--	--	--	--
	1988[p]	1.2	529	--	17	530	--	32	--	--	--	--	--	--
		1.3	607	--	66	595	--	47	--	--	--	--	--	--
		1.4				544	--	1	--	--	--	--	--	--

Appendix Table C-8. Continued.

Location			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
(Lake or river)	Year	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Vancouver Island (continued)														
Kennedy Lake[n]	1986	1.2	549	--	17	535	--	21	--	--	--	--	--	--
		1.3	592	--	29	561	--	20	--	--	--	--	--	--
Sproat Lake[n]	1983	1.2	527	--	224	505	--	462	--	--	--	--	--	--
		1.3	603	--	141	577	--	156	--	--	--	--	--	--
	1990	1.2	498	--	19	486	--	10	--	--	--	--	--	--
		1.3	600	--	7	589	--	5	--	--	--	--	--	--
Great Central L.[n]	1983	1.2	527	--	287	511	--	311	--	--	--	--	--	--
		1.3	604	--	120	579	--	151	--	--	--	--	--	--
	1990	1.2	505	--	13	478	--	5	--	--	--	--	--	--
		1.3	582	--	5	565	--	21	--	--	--	--	--	--
Woss Lake[n]	1985	1.2	519	--	44	511	--	18	--	--	--	--	--	--
		1.3	558	--	23	535	--	13	--	--	--	--	--	--
Mainland British Columbia														
Long Lake[n]	1982	1.2	544	--	11	548	--	2	--	--	--	--	--	--
		1.3	622	--	20	608	--	42	--	--	--	--	--	--
	1984	1.2	520	--	56	508	--	15	--	--	--	--	--	--
		1.3	596	--	35	570	--	15	--	--	--	--	--	--
	1989	1.2	502	--	40	506	--	39	--	--	--	--	--	--
		1.3	568	--	9	587	--	12	--	--	--	--	--	--
Owikeno Lake[n]	1984	1.2	511	--	47	539	--	19	--	--	--	--	--	--
		1.3	570	--	10	581	--	15	--	--	--	--	--	--
	1989	1.2	515	--	44	504	--	10	--	--	--	--	--	--
		1.3	538	--	27	578	--	14	--	--	--	--	--	--
Koeye Lake[n]	1985	1.2	501	--	37	494	--	21	--	--	--	--	--	--
		1.3	551	--	22	529	--	13	--	--	--	--	--	--
Tenas Lake[n]	1985	1.2	464	--	37	468	--	17	--	--	--	--	--	--
		1.3	558	--	19	537	--	18	--	--	--	--	--	--
Kimsquit Lake[n]	1986	1.2	607	--	17	570	--	27	--	--	--	--	--	--
Tankeeah Lake[n]	1986	1.2	524	--	31	526	--	7	--	--	--	--	--	--
Canoona Lake[n]	1986	1.2	520	--	20	517	--	57	--	--	--	--	--	--
Kitlope Lake[n]	1986	1.2	507	--	18	552	--	3	--	--	--	--	--	--
		1.3	640	--	10	623	--	2	--	--	--	--	--	--

Appendix Table C-8. Continued.

Location (Lake, tributary, or stock)			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
	Years	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Mainland British Columbia (continued)														
Banks Lake[n]	1986	1.2	531	--	48	520	--	19	--	--	--	--	--	--
		1.3	621	--	4	560	--	3	--	--	--	--	--	--
Mikado Lake[n]	1986	1.2	529	--	17	524	--	9	--	--	--	--	--	--
Devon Lake[n]	1985	1.2	507	--	15	512	--	2	--	--	--	--	--	--
		1.3	580	--	46	577	--	18	--	--	--	--	--	--
Lowe Lake[n]	1986	1.2	657	--	21	645	--	9	--	--	--	--	--	--
		1.3	678	--	35	654	--	23	--	--	--	--	--	--
Skidegate Lake[n]	1989	1.2	448	--	18	417	--	7	--	--	--	--	--	--
Yakoun Lake[n]	1989	1.2	463	--	12	534	--	16	--	--	--	--	--	--
		1.3	546	--	19	552	--	28	--	--	--	--	--	--
Mercer Lake[n]	1983	1.3	566	--	17	548	--	21	--	--	--	--	--	--
Fraser River														
Early Stuart	26[q]	1.2	--	--	--	563	--	--	--	--	--	--	--	--
	33[r]	1.2	599	--	--	563	--	--	--	--	--	--	--	--
	13[q]	1.3	--	--	--	617	--	--	--	--	--	--	--	--
Late Stuart	23[q]	1.2	--	--	--	546	--	--	--	--	--	--	--	--
	25[r]	1.2	525	--	--	541	--	--	--	--	--	--	--	--
	16[q]	1.3	--	--	--	593	--	--	--	--	--	--	--	--
Raft	30[r]	1.2	614	--	--	559	--	--	--	--	--	--	--	--
Nadina	26[q]	1.2	--	--	--	529	--	--	--	--	--	--	--	--
	17[q]	1.3	--	--	--	590	--	--	--	--	--	--	--	--
Late Nadina	34[r]	1.2	540	--	--	522	--	--	--	--	--	--	--	--
Stellako	29[q]	1.2	--	--	--	555	--	--	--	--	--	--	--	--
	40[r]	1.2	579	--	--	548	--	--	--	--	--	--	--	--
	25[q]	1.3	--	--	--	611	--	--	--	--	--	--	--	--
Adams	29[q]	1.2	--	--	--	578	--	--	--	--	--	--	--	--
	38[r]	1.2	630	--	--	577	--	--	--	--	--	--	--	--
	14[q]	1.3	--	--	--	618	--	--	--	--	--	--	--	--
Horsefly	24[q]	1.2	--	--	--	569	--	--	--	--	--	--	--	--
	29[r]	1.2	613	--	--	567	--	--	--	--	--	--	--	--
	12[q]	1.3	--	--	--	624	--	--	--	--	--	--	--	--

Appendix Table C-8. Continued.

Location (Lake, tributary, or stock)			Male Length (mm)			Female Length (mm)			Male Weight (g)			Female Weight (g)		
	Years	Age	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Fraser River (continued)														
Late Shuswap[q]	21	1.2	--	--	--	568	--	--	--	--	--	--	--	--
	8	1.3	--	--	--	613	--	--	--	--	--	--	--	--
Seymour[q]	26	1.2	--	--	--	581	--	--	--	--	--	--	--	--
	14	1.3	--	--	--	629	--	--	--	--	--	--	--	--
Birkenhead	29[q]	1.2	--	--	--	569	--	--	--	--	--	--	--	--
	38[r]	1.2	584	--	--	566	--	--	--	--	--	--	--	--
	29[q]	1.3	--	--	--	636	--	--	--	--	--	--	--	--
Chilko	29[q]	1.2	--	--	--	559	--	--	--	--	--	--	--	--
	41[r]	1.2	591	--	--	558	--	--	--	--	--	--	--	--
	25[q]	1.3	--	--	--	622	--	--	--	--	--	--	--	--
Gates	25[q]	1.2	--	--	--	582	--	--	--	--	--	--	--	--
	34[r]	1.2	619	--	--	572	--	--	--	--	--	--	--	--
	16[q]	1.3	--	--	--	629	--	--	--	--	--	--	--	--
Weaver[q]	29	1.2	--	--	--	580	--	--	--	--	--	--	--	--
	24	1.3	--	--	--	636	--	--	--	--	--	--	--	--
Pitt[q]	26	1.2	--	--	--	569	--	--	--	--	--	--	--	--
	26	1.3	--	--	--	634	--	--	--	--	--	--	--	--
Cultus[q]	24	1.2	--	--	--	552	--	--	--	--	--	--	--	--
	14	1.3	--	--	--	592	--	--	--	--	--	--	--	--

[a] QIN (1995a)
[b] Young (1997)
[c] Dlugokenski et al. (1981)
[d] Combined data for males and females.
[e] MFMD (1995)
[f] NMFS, unpublished data.
[g] Sneva (1997)
[h] Sprague (1996b)
[i] Adult length data derived from returns of pen-reared juveniles.
[j] Adult length data derived from returns of a combination of wild-reared and pen-reared juveniles.
[k] Hendry (1995)
[l] Woodey (1966)
[m] Chapman et al. (1995)
[n] Rutherford et al. (1992)
[o] Manzer et al. (1984)
[p] Tschaplinski and Hyatt (1990)
[q] Linley (1993)
[r] Cox and Hinch (1997)

Appendix Table C-9. Mean lengths of adult spawning kokanee populations for individual years, sex, and age. Dashes indicate data were unavailable.

Location (Lake or tributary)	Year	Age	Total length mean (mm)	Total length range (mm)	Total length N	Male length mean (mm)	Male length range (mm)	Male length N	Female length mean (mm)	Female length range (mm)	Female length N
Lake Washington Basin											
Swamp Creek	1920^{a}	--	--	183-260	7	--	--	--	--	--	--
Issaquah Creek - early entry	1981^{b}	2.0	--	--	--	--	--	--	218	--	2
		3.0	--	--	--	372	--	24	369	--	40
		4.0	--	--	--	--	--	--	417	--	2
	1981^{b}	--	--	--	--	376	265-460	123	363	250-449	132
	1982^{b}	--	--	--	--	386	287-457	332	370	282-428	375
	1993^{c}	--	--	--	--	278	240-323	15	285	240-375	5
Lake Stevens, WA											
	1975^{d}	1.0	--	--	--	215	171-245	37	222	169-307	45
		2.0	--	--	--	305	278-347	29	295	224-331	48
	1976^{d}	1.0	--	--	--	243	193-289	96	241	132-262	93
		2.0	--	--	--	273	251-312	6	273	247-294	6
Ozette Lake, WA											
Crooked Creek	1995^{e}	--	219	201-238	24	--	--	--	--	--	--
Siwash Creek	1995^{e}	--	220	208-246	27	--	--	--	--	--	--
Lake Sutherland, WA											
	1993^{f}	--	≅250	--	127	--	235-310	80	--	220-305	--
Sawtooth Valley Lakes, ID											
Fishhook Creek	1994^{g}	--	221	200-240	--	--	--	--	--	--	--
	1995^{h}	--	--	--	--	222	--	--	220	--	--
Stanley Lake Creek	1994^{g}	--	238	220-260	--	--	--	--	--	--	--
Alturas Lake Creek	1994^{g}	--	179	130-290	--	--	--	--	--	--	--
Pettit Lake	1994^{g}	--	245	--	--	--	--	--	--	--	--

Appendix Table C-9. Continued.

Location (Lake or tributary)	Year	Age	Total length mean (mm)	Total length range (mm)	Total length N	Male length mean (mm)	Male length range (mm)	Male length N	Female length mean (mm)	Female length range (mm)	Female length N
Dworshak Reservoir, ID											
	1994[i]	--	--	117-292	--	243	--	--	239	--	--
Lake Pend Oreille, ID											
Sullivan Springs	1991[j]	--	--	--	--	250	--	132	253	--	110
Trestle Creek		--	--	--	--	242	--	12	242	--	12
East Hope		--	--	--	--	251	--	29	237	--	14
North Gold Creek		--	--	--	--	245	--	16	233	--	12
Spring Creek		--	--	--	--	241	--	18	234	--	16
Flathead Lake, MT											
	1938[k]	--	--	--	--	380	350-407	23	--	--	--
	1947[k]	--	--	--	--	340	317-365	50	--	--	--
	1951[k]	--	--	--	--	335	299-372	101	318	287-343	50
Odell Lake, OR											
Early spawning	1971[l]	--	322	--	310	--	--	--	--	--	--
Late spawning	1971[l]	--	347	--	1897	--	--	--	--	--	--
Donner Lake, CA											
	1949[m]	--	470	--	7	--	--	--	--	--	--
Vancouver Island, B. C.											
Cowichan Lake[n]	1987	2.0	--	163-172	7	--	--	--	--	--	--
Kootenay Lake, B. C.											
South End streams	1951[o]	2.0	185	165-205	143	--	--	--	--	--	--
North End streams	1951[o]	3.0	215	195-235	104	--	--	--	--	--	--
West Arm streams	1951[o]	2.0	245	215-275	104	--	--	--	--	--	--

Appendix Table C-9. Continued.

Location (Lake or tributary)	Year	Age	Total length mean (mm)	Total length range (mm)	N	Male length mean (mm)	Male length range (mm)	N	Female length mean (mm)	Female length range (mm)	N
Babine Lake, B. C.											
	1953-65[p]	--	--	--	--	--	--	--	185	140-210	117

[a] Univ. Washington Fish Collection (fork length).
[b] Pfeifer (1992, fork length).
[c] A. Hendry in Ostergaard et al. (1995, mideye-hypural length).
[d] Pfeifer (1978, mideye-hypural length).
[e] NMFS, Northwest Fisheries Science Center, unpublished data (fork length).
[f] Hiss and Wunderlich (1994, fork length).
[g] Teuscher et al. (1995, fork length).
[h] Teuscher and Taki (1996, fork length).
[I] Fredericks et al. (1995, total length).
[j] Paragamian et al. (1993, total length).
[k] Brunson et al. (1952, total length).
[l] Lewis (1972, fork length).
[m] Kimsey (1951, measurement type unknown).
[n] Rutherford et al. (1988, posteye-hypural length).
[o] Vernon (1957, fork length).
[p] McCart (1970, posteye-hypural length).

APPENDIX D - RECORDS OF HATCHERY OUTPLANTS

Appendix Table D-1. Transfer of sockeye salmon eggs, fry, and fingerlings among U. S. Bureau of Fisheries (USBF) hatcheries and between USBF hatcheries and state hatcheries[a]. Hatchery, station, and organization names are as designated in original sources. Dashes indicate transfers did not occur or were not recorded.

Transferred to	Transferred from	Year (may be fiscal year)	Number of eggs transferred	Number of juveniles transferred	Planting location
Baker Lake Hatchery	Yes Bay Hatchery, AK	1925	5,645,000	--	unknown
		1926	5,621,000	--	unknown
	Samish River Hatchery	1916	6,022,000	--	unknown
		1917	672,000	--	unknown
Birdsview Hatchery	Baker Lake Hatchery	1905	--	10,000	unknown
		1914	50,000	--	unknown
		1915	180,000	--	unknown
		1923	25,000	--	unknown
		1925	200,000	--	unknown
		1929	50,000	--	unknown
		1930	100,000	--	unknown
		1931	100,000	--	unknown
	Quinault, Washington Station	1917	225,000	--	unknown
		1926	150,000	--	unknown
		1928	753,000	--	unknown
		1930	1,000	--	unknown
	Yes Bay Hatchery, AK	1931	1,187,000	--	Baker Lake (955,000 fry)
	Afognak Hatchery, AK	1922	278,616	--	unknown

Appendix Table D-1. Continued.

Transferred to	Transferred from	Date (fiscal year)	Number of eggs transferred	Number of juveniles transferred	Planting location
Quinault, Washington Station	Yes Bay Hatchery, AK	1916	100,000	--	unknown
	Afognak Hatchery, AK	1918	5,000,000	--	unknown
		1919	5,000,000	--	unknown
		1920	7,000,000	--	unknown
		1921	3,000,000	--	Quinault Lake
Quilcene Hatchery	Quinault, Washington Station	1931	1,005,000	--	unknown
	Birdsview Hatchery	1933	500,000	--	Lakes Pleasant, Mason, Isabella, Purdy, Beaver, and Big Quilcene River
		1937	850,000	600,000	Lakes Ozette, Pleasant, Mason, Isabella, Purdy, Beaver, and Big Quilcene River
	Baker Lake Hatchery	1934	348,000	--	Lakes Pleasant, Mason, Isabella, Purdy, and Big Quilcene River
Lake Crescent Trout Hatchery, WA	Quinault, Washington Station	1928	828,000	--	Lake Crescent (826,000 fry)
		1930	1,028,400	--	Lake Crescent (953,500 fry)
Startup Hatchery, WA	Baker Lake Hatchery	1914	50,000	--	unknown
		1915	50,000	--	unknown
	Birdsview Hatchery	1936	250,000	--	unknown

Appendix Table D-1. Continued.

Transferred to	Transferred from	Date (fiscal year)	Number of eggs transferred	Number of juveniles transferred	Planting location
Samish Hatchery, WA	Birdsview Hatchery	1936	500,000	--	unknown
Green River Hatchery, WA	Birdsview Hatchery	1936	500,000	--	unknown
Issaquah Hatchery, WA	Birdsview Hatchery	1937	--	868,000	unknown
Puget Sound Stations	Afognak Hatchery, AK	1927	3,402,000	--	unknown
	Yes Bay Hatchery, AK	1931	1,868,000	--	unknown
		1932	3,145,000	--	unknown
Hood Canal Stations	Quinault, Washington Station	1929	723,000	--	unknown
Little White Salmon Hatchery, WA	Yes Bay Hatchery, AK	1919	1,059,900	--	unknown
	Birdsview Hatchery	1933	100,000	--	unknown
State of Washington	?	1939	75,000	--	unknown
		1940	100,730	10,000	unknown
		1942	--	50,095	unknown
		1943	--	11,500	unknown
	Birdsview Hatchery	1941	322,000	--	unknown
		1942	1,200,000	--	unknown
		1943	193,000	--	unknown
	Quilcene Hatchery	1941	--	12,475	unknown

Appendix Table D-1. Continued.

Transferred to	Transferred from	Date (fiscal year)	Number of eggs transferred	Number of juveniles transferred	Planting location
State of Washington (continued)	Afognak Hatchery, AK	1922	534,464	--	unknown
		1926	3,402,000	--	unknown
		1928	1,852,550	--	unknown
		1929	4,553,200	--	unknown
	Yes Bay Hatchery, AK	1928	2,493,000	--	unknown
Rogue River, OR	Quinault, Washington Station	1926	25,000	--	unknown
		1927	30,700	--	unknown
		1928	50,000	--	unknown
		1929	40,000	--	unknown
Clackamas, OR	Quinault, Washington Station	1924	25,000	--	unknown
		1930	100,000	--	Columbia River, OR
	Birdsview Hatchery	1921	30,000	--	unknown
Bonneville, OR State Fish Hatchery	USBF-Alaska	1928	2,608,830	--	Herman Creek, OR
		1929	4,953,200	--	Herman Creek, OR
		1930	1,682,000	--	Herman Creek, OR
	USBF-Washington	1930	1,507,200	--	Herman Creek, OR
	USBF	1927	3,634,755	--	Herman Creek, OR
	Afognak Hatchery, AK	1917	3,000,000	--	unknown
		1919	3,000,000	--	unknown
		1922	5,045,000	--	unknown
		1921	3,000,000	--	unknown
		1922	5,200,000	--	unknown

Appendix Table D-1. Continued.

Transferred to	Transferred from	Date (fiscal year)	Number of eggs transferred	Number of juveniles transferred	Planting location
Bonneville, OR State Fish Hatchery (continued)	Yes Bay Hatchery, AK	1910	1,500,000	--	unknown
		1911	2,000,000	--	unknown
		1912	2,000,000	--	unknown
		1913	2,000,000	--	unknown
		1914	3,000,000	--	unknown
		1916	2,000,000	--	unknown
		1918	3,440,100	--	unknown
		1931	3,144,960	--	Herman Creek, OR
		1932	3,010,650	--	Herman Creek, OR
Enterprise, OR (Oregon Fish Commission)	Quinault, Washington Station	1924	3,120,000	--	unknown
		1925	3,000,000	--	unknown
State of Oregon	Yes Bay Hatchery, AK	1915	3,000,000	--	unknown
		1925	300,760	--	unknown
Afognak Hatchery, AK	Yes Bay Hatchery, AK	1916	15,000,000	--	unknown
Yes Bay Hatchery, AK	Afognak Hatchery, AK	1921	5,000,000	--	McDonald Lake, AK
Craig Brook, ME	Birdsview Hatchery	1906	575,500	--	unknown
		1921	20,000	--	Pleasant River, ME

[a] Sources: USBF (1906, 1907,1909, 1910, 1911, 1913), Johnson (1914, 1915, 1916), O'Malley (1917, 1918, 1919), Leach (1920, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934), WDFG (1920), Leach and James (1934, 1936, 1937, 1938), Leach et al. (1939, 1940, 1941, 1942, 1943), James and Meehan (1944, 1945), Kemmerich (1945), Roppell (1982), Kostow (1996a).

Appendix Table D-2. Known hatchery releases of sockeye salmon in Washington. Individual releases and percentages of releases of stocks originating out of basin are designated in bold [a].

Release location	Years fish released	Number of fish released	Stock of origin
Skagit River			
Baker Lake	1900-35	183,695,256	Baker Lake
	1931	**955,000**	**Yes Bay, Alaska**
	1941-44	511,364	Grandy Creek (Birdsview)
	1957-93	41,650,554	Fry from Baker Lake beaches
Lower Baker River	1904-10	4,359,255	Baker Lake
	1959	38,560	Issaquah Creek
	1987-93	512,350 (net pens)	Baker Lake
Skagit River	1914	120,000	Baker Lake
	1929-30	48,000	Baker Lake-Grandy mix
Bacon Creek	1934	10,000	Grandy Creek (Birdsview)
Big Lake	1933-37	440,500	Grandy Creek (Birdsview)
Clear Lake	1933-37	140,000	Grandy Creek (Birdsview)
Day Creek	1929-30	5,000	Baker Lake-Grandy mix
	1931-32	20,000	Baker Lake
	1934	10,000	Grandy Creek (Birdsview)
Diobsud Creek	1934-35	25,000	Grandy Creek (Birdsview)
Illabot Creek	1929-30	8,000	Baker Lake-Grandy mix
	1931-32	20,000	Baker Lake
Illabot Lake	1925-26	425,000 (eggs planted)	Baker, **Quinault, Yes Bay-Alaska**
Lake McMurray	1933	47,000	Grandy Creek (Birdsview)
Grandy Creek/Grandy Lake	1909	**46,000**	**Fraser River mix**
	1913-45	1,137,079	Grandy Creek (Birdsview)
	1917	211,275	**Quinault Lake**-Grandy mix
	1915-32	209,630	Baker Lake
	1922-29	119,000	Baker Lake-Grandy mix
		234,338,823	**<1% out of basin**
Samish River			
Lake Samish/Cain Lake	1915-18	**8,957,101**	**Fraser River mix**
Lake Samish	1934-37	**528, 170**	**Grandy Creek (Birdsview)**
		9,485,271	**100% out of basin**

Appendix Table D-2. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Stillaguamish River			
Lake Cavanaugh	1933-37	**379,000**	**Grandy Creek (Birdsview)**
Pilchuck Creek	1929-30	**5,175**	**Baker-Grandy mix**
	1931-32	**20,000**	**Baker Lake**
		404,175	**100% out of basin**
Snohomish River			
Skykomish River (Startup=Skykomish Hatchery)	1913-15	**99,481**	**Baker Lake?**
	1916-22	25,100	Skykomish (Startup)
Lake Stevens	1933-38	**653,500**	**Grandy Creek (Birdsview)**
		778,081	**97% out of basin**
Lake Washington/Lake Sammamish			
Lake Sammamish	1957, 1961	112,200	Issaquah Creek
Issaquah Creek	1935-44	**1,629,059**	**Grandy Creek (Birdsview)**
	1947-63	1,256,079	Issaquah Creek
	1950, 1954	**59,613**	**Cultus Lake, B.C.**
Sammamish River			
Big Bear Creek	1937	**576,000**	**Grandy Creek (Birdsview)**
North Creek	1944	**23,655**	**Cultus Lake, B.C.**
Lake Washington	1942	**41,065**	**Grandy Creek (Birdsview)**
Juanita Creek	1979	46,500	Unknown
	1980-82	343,985	Cedar River
N. Fork Kelsey Creek	1979-81	204,030	Cedar River
S. Fork Kelsey Creek	1979	10,805	Unknown
Thornton Creek	1979	50,000	Unknown
	1980-82	274,236	Cedar River
Cedar River	1935-45	**1,065,681**	**Grandy Creek (Birdsview)**
	1961	118,720	Issaquah Creek
	1977-79	3,765,000	Unknown
(egg box program)	1978-82	25,035,000	Cedar River
	1992-93	6,226,504	Cedar River
Lake Union	1951	19,344	Issaquah Creek
	1955	54,814	University of Washington
	1977	550	Unknown
Lake Washington drainage	1917	19,700	Unknown
		40,932,540	**8% out of basin**

Appendix Table D-2. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Green River			
Green River	1925	5,700	Green River
	1928	**49,100**	**Quinault Lake**
	1929	**238,000**	**Alaska**
		287,100	**100% out of basin**
South Puget Sound			
Mason Lake	1933, 1937	**175,000**	**Grandy Creek (Birdsview)**
	1934	**75,000**	**Baker Lake**
	1942	**9,954**	**Quilcene**
Isabella Lake	1933, 1937	**85,000**	**Grandy Creek (Birdsview)**
	1934	**25,000**	**Baker Lake**
		369,954	**100% out of basin**
Skokomish River			
Skokomish River	1922	**275,000**	**Afognak, Alaska**
			100% out of basin
Hood Canal			
Finch Creek (Hoodsport)	1961	**12,700**	**Issaquah Creek**
	1961	8,000	Finch Creek
		16,700	**76% out of basin**
Big Quilcene River			
Big Quilcene River	1933, 1937	**160,336**	**Grandy Creek (Birdsview)**
	1934	**29,100**	**Baker Lake**
	1939	41,520	Quilcene
		230,956	**82% out of basin**
Dungeness River			
Dungeness River	1957	**24,300**	**Lake Creek (Lake Pleasant)**
			100% out of basin
Lyre River			
Lake Crescent	1927	**995,700**	**Yes Bay, Alaska**
	1928-31	**3,489,600**	**Quinault Lake**
		4,485,300	**100% out of basin**

Appendix Table D-2. Continued.

Release location	Year(s) fish released	Number of fish released	Stock of origin
Ozette River			
Ozette Lake	1937	**449,000**	**Grandy Creek (Birdsview)**
	1983	**120,000**	**Quinault Lake**
	1984-95	490,445	Ozette Lake
	1991-92	14,398 (kokanee x sockeye)	Ozette Lake
Umbrella Creek	1992	8,490	Ozette Lake
		1,082,333	**53% out of basin**
Sol Duc River			
Lake Pleasant	1933, 1937	**285,000**	**Grandy Creek (Birdsview)**
	1934	**175,000**	**Baker Lake**
Beaver Lake	1933, 1937	**45,000**	**Grandy Creek (Birdsview)**
		505,000	**100% out of basin**
Quinault River			
Quinault Lake	1916-20	**20,100,000 (eggs)**	**Yes Bay and Afognak, Alaska**
	1916-36	117,389,000	fry, Quinault lake
	1916-47	73,215,000	fingerlings, Quinault Lake
	1937-47	1,092,000	yearlings, Quinault Lake
	1974-94	4,390,228	Quinault Lake
Falls Creek	1975	147,334	Quinault Lake
Ten O'Clock Creek	1976	300,000	Quinault Lake
Boulder Creek	1977	170,000	Quinault Lake
		196,590,343	**≤ 9% out of basin**
Willapa River			
Fork Creek	1972, 1977	8,463	Willapa River (Fork Creek)
			100% out of basin
Cowlitz River			
Spirit Lake	1956-59	**412,504**	**Leavenworth/Lake Wenatchee**
			100% out of basin
Lewis River			
Lewis River	1961	**515,200**	**Issaquah Creek**
	1961	**411,904**	**Voight Creek (Puyallup River)**
Speelyai Creek	1965	38,250	Lewis River
		965,354	**96% out of basin**

Appendix Table D-2. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Klickitat River			
Klickitat River	1952-53	**111,191**	**Leavenworth/ Lake Wenatchee**
			100% out of basin
Little White Salmon River			
Little White Salmon River	1951-56	356,748	Unknown
			100% out of basin
Wind River			
Wind River	1955	**144,452**	**Lake Wenatchee**
	1956	33,758	Unknown
		178,210	**100% out of basin**
Yakima River			
Cle Elum Lake	1988-91	**370,387**	**Lake Wenatchee**
Bumping Lake	1942	**25,777**	**Quinault Lake**
		396,164	**100% out of basin**
Wenatchee River			
Wenatchee River	1952	28,781	Lake Wenatchee
White River	1952-55	98,196	Lake Wenatchee
Icicle Creek	1942-60	1,190,494	Columbia River mix
	1954-69	101,706	Lake Wenatchee
	1954	**44,325**	**Methow River**
	1954-55	**274,545**	**Entiat River (Quinault progeny ?)**
	1966	**3,100**	**British Columbia**
	1966-69	18,416	Icicle Creek
Lake Wenatchee	1939-43	32,794 (adults)	Mixed Upper Columbia
	1941-69	51,127,121	Rock Island Dam progeny
	1949-62	**2,440,582**	**Entiat River (Quinault progeny ?)**
	1953-62	1,721,657	Methow River (RID +Bonneville progeny)
		56,983,547	**37% out of basin**
Chelan River			
Lake Chelan	1954	**31,036**	**Entiat River**
	1954	**8,912**	**Lake Wenatchee**
	1954	**10,952**	**Methow River**
		50,900	**100% out of basin**

Appendix Table D-2. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Entiat River			
Entiat River	1941	**603,669**	**Columbia River**
	1943-44	**719,702**	**Rock Island Dam**
	1942-43	**161,787**	**Quinault Lake**
	1952-53	**89,217**	**Lake Wenatchee**
		1,574,375	**100% out of basin**
Methow River			
Methow River	1945	**86,788**	**Icicle Creek**
	1946	**64,939**	**Bonneville**
	1946	**80,360**	**Wind River**
	1947	**79,812**	**Icicle Creek,** Methow River
	1948-58	973,333	Methow River
	1956	**190,575**	**Little Wenatchee River**
	1956	**305,526**	**RID**
		1,781,133	**45% out of basin**
Okanogan River			
Lake Osoyoos	1939-43	19,795 (adults)	Mixed Upper Columbia
	1941-44	**208,413**	**Rock Island Dam**
	1942	**395,420**	**Quinault Lake, Rock Island mix**
	1943	**587,175**	**RID, L. Wenatchee River, Methow River**
	1944	**1,147,831**	**Icicle creek**
	1947, 1949	**879,990**	**Methow River**
	1958	**1,086,233**	**Little Wenatchee River**
	1993-94	183,500	Wells Dam
	1996	150,000	Wells Dam
		4,638,562	**93% out of basin**
Similkameen River			
Palmer Lake	1966	**87,000**	**Lake Wenatchee**
			100% out of basin
Snake River			
Snake River	1969	**10,000**	**Lake Wenatchee**
			100% out of basin

Appendix Table D-2. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Unknown			
Unknown	1925-36	189,000	Grandy Creek (Birdsview)
	1926	150,000	Quinault Lake
	1951	49,903	Unknown
	1965	134,854	Russian River
	1965	85,480	Lake Wenatchee
		609,237	

---

[a] Sources: Ravenel (1901, 1902), Titcomb (1904, 1905), USBF (1905-1921), WDFG (1916a, 1917, 1919, 1920, 1924, 1928, 1930, 1932), O'Malley (1918, 1919), Leach (1920, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934), Leach and James (1934, 1936), Kemmerich (1945), Fulton (1966), Kolb (1971), Mullan (1986), MFMD (undated, 1995), Chapman et al. (1995), NRC (1995).

Appendix Table D-3. Known hatchery releases of sockeye salmon in Oregon. Individual releases and percentages of releases of stocks originating out of basin are designated in bold [a].

Release location	Years fish released	Number of fish released	Stock of origin
Columbia River			
Lower Columbia River	1914	**1,500,000**	**Alaska**
	1924, 1930	**125,000**	**Quinault Lake**
	1930-37	1,110,320	Unknown
Herman Creek	1919-42	**17,229,845**	**Bonneville (Afognak, Yes Bay, AK + WA)**
	1921-34	3,935,985	Unknown
Tanner Creek	1911-34	**9,776,744**	**Alaska**
	1915, 1932	4,707,020	Unknown
	1928	800,000	Herman Creek
	1936-46	**947,540**	**Bonneville (Afognak, Yes Bay, AK + WA)**
Corbett Station	1987	24,282	Columbia River mix
		40,156,736	**73% out of basin**
Willamette River			
Lake Oswego	1918	4,000	Unknown
Clackamas River	1967	**212,222**	**Adams River, B.C.**
Middle Fork Willamette River	1957-59	**195,361**	**Leavenworth**
	1958	**282,219**	**Leavenworth + Willamette mix**
Dexter Reservoir	1955	**52,089**	**Leavenworth**
Lookout Point Reservoir	1957	**94,827**	**Leavenworth**
North Santiam River			
Big Cliff Reservoir	1958	**86,507**	**Leavenworth**
South Santiam River			
Green Peter Reservoir	1968	242,976	Unknown
		1,452,420	**100% out of basin**
Deschutes River			
Deschutes River	1952-59	**125,000**	**Bonneville**
Metolius River	1951	75,960	Unknown
	1952-57	**191,994**	**Leavenworth + Metolius**
	1960	**26,438**	**Santiam + mix**
	1961	**42,619**	**Cascade**
Lake Creek	1948	**41,178**	**Bonneville**
Spring Creek	1950	99,922	Unknown
Suttle Lake	1937	**15,000**	**Bonneville**
	1952-58	**741,051**	**Leavenworth**
		1,359,162	**100% out of basin**

Appendix Table D-3. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Grande Ronde River			
Wallowa River	1902-03	14,382,000 (eggs planted)	Wallowa Lake
	1922-28	**19,017,821**	**Bonneville + Unknown**
	1933-37	2,766,700 ("blueback")	Unknown
Wallowa Lake	1914	**380,500**	**Alaska**
	1916-19	5,144,300	Unknown
		27,309,321	**71% out of basin**
Silticoos River			
Woahink Lake (Mid Coast)	1952-53	**101,594**	**Unknown**
			100% out of basin

[a] Sources: Cramer (1990), NRC (1995), Kostow (1996a).

Appendix Table D-4. Known hatchery releases of sockeye salmon in Idaho. Individual releases and percentages of releases of stocks originating out of basin are designated in bold [a].

Release location	Years fish released	Number of fish released	Stock of origin
Snake River			
Snake River	1940-48	469,940	Unknown
	1965	**474,689**	**British Columbia**
Henry's Fork	1946	76,140	Unknown
Clearwater River			
Selway River	1946	86,180	Unknown
Salmon River			
Alturas Lake	1983-84	**543,800**	**Babine Lake (Fulton River), B.C.**
Stanley Lake	1981-84	**731,288**	**Babine Lake (Fulton River), B.C.**
	1946	379,000	Unknown
Redfish Lake	1940-47	325,320	Unknown
	1986-96	136,834	Redfish Lake
Pettit Lake	1995	8,500	Redfish Lake
Payette River	1946	102,000	Unknown
Payette Lake	1940-47	1,480,066	Unknown
Warm Lake	1940-49	267,090	Unknown
		5,288,483	**33% out of basin**

[a] Sources: Howell et al. (1985), NRC (1995).

Appendix Table D-5. Known hatchery releases of kokanee in Washington, Oregon, and Idaho in areas of concern for the status review of west coast sockeye salmon. Individual releases and percentages of releases of stocks originating out of basin are designated in bold [a].

Release location	Years fish released	Number of fish released	Stock of origin
Skagit River, Washington			
Lake Shannon	1991-94	**1,158,200**	**Lake Whatcom**
			100% out of basin
Samish River, Washington			
Samish River	1922	50,000	Unknown
Lake Samish	1914-22	420,000	Unknown
		470,000	**?% out of basin**
Lake Washington/Lake Sammamish			
Lake Sammamish	1938-51	5,812,153	Lake Washington/Sammamish
	1976-79	**3,448,184**	**Lake Whatcom**
Issaquah Creek	1923-38	6,077,000	Lake Washington/Sammamish
	1926-78	**2,963,110**	**Lake Whatcom**
Unknown tributaries	1924-25	860,000	Lake Washington/Sammamish
Sammamish River			
Big Bear Creek and tribs.	1917-69	**35,077,293**	**Lake Whatcom**
	1923-39	9,118,368	Lake Washington/Sammamish
Little Bear Creek	1962-69	1,225,716 (eggs)	Unknown
	1968-69	483,720	Unknown
North Creek	1931-37	912,200	Lake Washington/Sammamish
	1932-69	**371,240**	**Lake Whatcom**
Swamp Creek	1933-39	486,166	Lake Washington/Sammamish
	1968	**526,000**	**Lake Whatcom**
Lake Washington	1938-45	9,236,748	Lake Washington/Sammamish
Lyon Creek	1979	**33,600**	**Lake Whatcom**
Mapleleaf Creek	1922	152,000	Lake Washington/Sammamish
May Creek	1928-39	826,129	Lake Washington/Sammamish
	1929-32	**150,000**	**Lake Whatcom**
McAleer Creek	1938-39	488,141	Lake Washington/Sammamish
Vasa Creek ?	1948-68	507,000	**Lake Whatcom**
Cedar River	1928-38	1,725,000	Lake Washington/Sammamish
	1929-68	**848,369**	**Lake Whatcom**
		80,102,421	**54% out of basin**

Appendix Table D-5. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
South Puget Sound			
Mason Lake	1916-20	88,900	Unknown
			100% out of basin
Deschutes River, , Washington			
Deschutes River	1918	50,000	Unknown
			100% out of basin
Ozette River, Washington			
Ozette Lake	1940	**108,054**	**Lake Crescent Hatchery**
			100% out of basin
Sol Duc River, Washington			
Beaver Lake	1916	50,000	Unknown
			?% out of basin
Quinault River, Washington			
Quinault Lake	1917-22	**317,600**	**Unknown**
	1925	**260,000** **(eggs tranferred)**	**Lake Whatcom**
			100% out of basin
Yakima River, Washington			
Yakima River	1915	75,000	Unknown
CleElum Lake	1916-19	312,000	Unknown
Kachess Lake	1916-19	300,000	Unknown
Keechelus Lake	1916-19	243,000	Unknown
Bumping Lake	1922	436,300	Unknown
		1,366,300	**?% out of basin**
Wenatchee River, Washington			
Wenatchee River	1916-17	613,200	Unknown
Nason Creek	1916	12,000	Unknown
Icicle Creek	1915-17	48,000	Unknown
	1944	29,189	Lake Wenatchee
Lake Wenatchee	1916-18	317,050	Unknown
	1934-83	**23,002,500**	**Lake Whatcom**
		24,021,939	**>95 % out of basin**

Appendix Table D-5. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Chelan River, Washington			
Lake Chelan	1916-17	318,035	Unknown
			?% out of basin
Entiat River, Washington			
Entiat River	1919	**40,000**	**Unknown**
	1944	**22,341**	**Lake Chelan**
		62,341	**100% out of basin**
Methow River, Washington			
Methow River	1920	**10,000**	**Unknown**
	1951	**25,006**	**Lake Whatcom**
		35,006	**100%**
Okanogan River, Washington			
Lake Osoyoos	1919-20	195,550	Unknown
			?% out of basin
Similkameen River, Washington			
Similkameen Dam	1920	25,000	Unknown
Palmer Lake	1919-20	132,500	Unknown
	1966	45,000	Unknown
Spectacle Lake	1916-22	562,485	Unknown
		764,985	**?% out of basin**

Appendix Table D-5. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Deschutes River, Oregon			
Deschutes River			
Lake Simtustus (Pelton Reservoir)	1965	100,431	Unknown (Fall River Hatchery)
	1966-73	542,591	Unknown (Oak Springs Hatchery)
	1972-74	374,415	Unknown (Wizard Falls Hatchery)
	1969-70	361,610	Unknown (Klamath Hatchery)
	1978-80	143,601	Suttle Lake
	1981-95	618,297	Paulina Lake
Lake Billy Chinook	1970-71	325,665	Unknown (Oak Springs Hatchery)
Paulina Lake	1978-80	56,895	Suttle Lake
	1981-95	335,757	Paulina Lake
Wickiup Reservoir	1965-69	65,480	Unknown (Fall River Hatchery)
	1965-72	136,688	Unknown (Klamath Hatchery)
	1966-68	150,450	Unknown (Oak Springs Hatchery)
	1967-74	481,657	Unknown (Wizard Falls Hatchery)
	1978-80	249,433	Suttle Lake
	1984-85	298,818	Paulina Lake
North Twin Lake	1966	**4,643**	**Lake Whatcom**
	1966	**4,600**	**Kootenay Lake, B.C.**
	1966	**4,590**	**Flathead Lake, Montana**
	1966-67	32,932	Unknown (Fall River Hatchery)
	1971-76	25,395	Unknown (Wizard Falls Hatchery)
	1981-83	15,020	Paulina Lake
Odell Lake (Lava dam)	1963-70	**824,679**	**Kootenay Lake, B.C.** (Wizard Falls, Rock Creek, Klamath Hatcheries)
	1966-71	**627,771**	**Flathead Lake, Montana** (Wizard Falls, Oak Springs Hatcheries)
	1967	**48,008**	**Lake Whatcom** (Fall River Hatchery)
Metolius River			
Suttle Lake	1961-63	142,900	Unknown (Fall River Hatchery)
	1962-73	202,233	Unknown (Wizard Falls Hatchery)
	1968	37,200	Unknown (Oak Springs Hatchery)
		6,211,759	**24% out of basin**

Appendix Table D-5. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Grande Ronde River, Oregon			
Wallowa River	1925-28	3,475,700 ("yanks")	Unknown
	1929-32	5,845,600 ("landlocked blueback")	Unknown
Wallowa County	1925-42	1,213,000 ("yanks")	Wallowa Lake
		5,362,396 ("yanks")	Unknown
Wallowa Lake	1926-50	1,335,718 ("yanks")	Unknown
	1938-41	1,926,742 ("yanks")	Wallowa Lake
	1953-54	147,910	Unknown
	1955-70	**2,588,513**	**Montana**
	1962-63	**304,269**	**Washington**
	1964-66	**615,550**	**British Columbia**
	1981-94	**136,730**	**Paulina Lake**
		22,952,128	**16% out of basin**
Salmon River, Idaho			
Alturas, Pettit, Redfish, Stanley Lakes	1930	17,500	Unknown (hatchery unknown)
Alturas Lake	1921	40,300	Unknown (hatchery unknown)
	1931-52	967,948	Unknown (Hayspur Hatchery)
	1940	262,000	Unknown (Hagerman Hatchery, USBF)
	1968	196,000	Northern Idaho
Pettit Lake	1932-33	18,400	Unknown (Hayspur Hatchery)
	1965	4,560	Unknown (Mackay Hatchery)
	1968	79,100	Northern Idaho
Redfish Lake	1930-71	271,800	Unknown (Hayspur Hatchery)
	1962	43,251	Lake Pend Oreille
	1972	51,435	Unknown (Mackay Hatchery)
Fishhook Creek	1971	50,344	Unknown (Mackay Hatchery)
Stanley Lake	1947-48	81,600	Unknown (Hayspur Hatchery)
	1988	49,926	Unknown (Eagle Hatchery, early spawning)
	1989	60,000	Unknown (Mackay Hatchery, early spawn)
Warm Lake (South Fork Salmon R.)	1951-52	119,400	Unknown (McCall Hatchery)
		2,313,564	**?% out of basin**

Appendix Table D-5. Continued.

Release location	Years fish released	Number of fish released	Stock of origin
Payette River, Idaho			
Payette Lake	1951-52	142,300	Unknown (McCall Hatchery)
Upper Payette Lake	1940	54,000	Unknown (Evergreen Hatchery)
	1946	20,700	Unknown (McCall Hatchery)
Little Payette Lake	1940	10,370	Unknown (McCall Hatchery)
		227,370	**?% out of basin**

[a] Sources: WDFG (1916b, 1917, 1918, 1919, 1920, 1921a, 1923), Lewis (1972), Goldstein (1982), Mullan (1986), Bowler (1990), Cramer (1990), Pfeiffer (1992), Knutzen (1995), ODFW (1995b), NRC (1995), Kostow (1996a).

Appendix Table D-6. Artificial propagation facilities in Washington that have reared or are continuing to rear sockeye salmon for release into specific evolutionarily significant units (ESUs). CCT, Colville Confederated Tribes; CHPUD, Chelan County Public Utility District; MFMD, Makah Fisheries Management Department; NFH, National Fish Hatchery; PUGP, Puget Sound Power and Light Co.; QIN, Quinault Indian Nation; USBF, United States Bureau of Fisheries; USCFF, United States Commission of Fish and Fisheries; USFWS, United States Fish and Wildlife Service; WDFW, Washington Department of Fish and Wildlife; WFC, Washington State Fish Commission.

ESU	Hatchery Facility	Operating Agency	Years of operation
ESU 1 - Okanogan River	Entiat NFH	USFWS	1941-44
	Leavenworth NFH	USFWS	1942-44
	Winthrop NFH	USFWS	1944-58
	Cassimer Bar	CCT	1993-present
ESU 2 - Lake Wenatchee	Leavenworth NFH	USFWS	1941-69
	Winthrop NFH	USFWS	1942-57
	Entiat NFH	USFWS	1944-60
	Rock Island FHC	CHPUD	1990-present
ESU 3 - Quinault Lake	Falls Creek-Quinault	USBF	1914-47
	Quinault Net Pens	QIN	1974-present
	Cook Creek	WDFW	1985
ESU 4 - Ozette Lake	Quilcene NFH	USFWS	1937
	Umbrella Creek	MFMD	1983-present
ESU 5 - Baker River	Baker Lake Hatchery	WFC, USCFF, USBF	1896-35
	Birdsview Hatchery	USBF	1909-45
	Artificial Spawning Beaches	PUGP, WDFW	1957-present
	Lake Shannon Net Pens	PUGP	1987-present

APPENDIX E - SUMMARY OF WEST COAST SOCKEYE SALMON STATUS

Appendix Table E-1. Summary of recent status information for U. S. west coast sockeye salmon stocks. Blanks indicate insufficient data. Asterisk (*) indicates that slope is significantly ($P<0.05$) different from zero.

		Status summaries[1]		Historical abundance				Recent abundance					
River/Stock	**Nursery Lake**	**A**	**B**	**Years**	**Value**	**Data Type**	**Source[2]**	**Data Years**	**Data Type[3]**	**Run Size[4]**	**Escape-ment[4]**	**1986-95 Trend[5]**	**Full Data Trend[5]**
Puget Sound Area													
Baker	Baker	A	NAC	1898-1901	20,000	Average Escapement	a	1926-95	LC		2,700	+31.6*	-1.5*
				1916	5,000	Escapement	a						
				1924	15,000	Escapement	a						
Cedar River	Washington		XWD					1967-95	LC	119,000	67,500	-18.2*	-3.6*
L. Washington beaches	Washington		UWD					1982-95	ET		1,400	-9.6	-12.5*
L. Washington Sammamish Tribs.	Washington/ Sammamish		UWD					1982-95	ST		15,800	-4.6	-7.2
Big Bear Creek	Washington/ Sammamish		---					1982-95	ST		11,400	-4.1	-7.0
Sherwood Cr.	Mason	X											
Washington Coast													
Elwha	Sutherland	X											
Ozette	Ozette	B	NWD	1926	few 1,000	Run	a	1977-96	LC		700	-9.9	-1.5
				1948-52	3,000 to 18,000	Catch	b						
Quillayute (Sol Duc)	Pleasant		NWU					1987-96				-12.0	-4.9

Appendix Table E-1. Continued.

		Status summaries[a]		Historical abundance				Recent abundance					
River/Stock	Nursery Lake	A	B	Years	Value	Data Type	Source[b]	Data Years	Data Type[c]	Run Size[d]	Escapement[d]	1986-95 Trend[e]	Full Data Trend[e]
Quinault	Quinault		NWH	1921-25	20,000 to 250,000	Escapement	a	1967-95	HA	39,000	32,000	-3.4	+1.0
				early 1900s	50,000 to 500,000	Run	a						
Columbia River Basin													
Deschutes		A						1957-95	LC		9	-11.9	-3.2
Metolius	Suttle	X											
Yakima	Bumping	X											
	Cle Elum	X											
	Kachess	X											
	Keechelus	X											
Wenatchee	Wenatchee	C	MWH					1961-96	ET		19,000	-9.8	-0.1
Okanogan	Osoyoos	C	NWH					1977-93	ST		23,000	-1.5	+1.5
								1960-96	LC		11,100	-19.9*	-2.7*
	Skaha	X											
	Okanagan	X											
Upper Columbia													
	Upper Arrow	X											
	Lower Arrow	X											
	Whatshan	X											
	Slocan	X											

Appendix Table E-1. Continued.

		Status summaries[1]		Historical abundance				Recent abundance					
River/Stock	Nursery Lake	A	B	Years	Value	Data Type	Source[2]	Data Years	Data Type[3]	Run Size[4]	Escape-ment[4]	1986-95 Trend[5]	Full Data Trend[5]
Snake River Basin													
Snake R. (at uppermost passable dam)								1970-95	LC		6	-13.2	-21.0*
Salmon	Redfish	A+						1954-95	LC		<1		
	Alturas	X											
	Pettit	X											
	Stanley	X											
	Yellowbelly	X											
Wallowa	Wallowa	X											
Payette	various	X											

[1] Status summaries from the following sources:

A--Nehlsen et al. (1991): X, extinct; A+, possibly extinct; A, high extinction risk; B, moderate extinction risk; C, special concern.

B--WDFW et al. (1993): Three characters represent stock origin, production type, and status, in that order. Origin: N, native; M, mixed; X, non-native; U, unknown; -, unresolved by state and tribes. Production: W, wild; C, composite; A, cultured; U, unknown; -, unresolved. Status: H, healthy; D, depressed; C, critical; U, unknown.

[2] References for historical estimates: a) Rounsefell and Kelez (1938), b) WDF (1974).

[3] Data types: ET--estimate of total spawners, method unknown; LC--ladder or weir count; ST--stream survey count (total spawners), HA--hydroaccoustic assessment.

[4] Recent run-size and escapement are geometric means (zeros recoded to 0.1) for the most recent 5 years of data.

[5] Trends are average percent annual change estimated from log-linear regression.

Recent NOAA Technical Memorandums NMFS
published by the
Northwest Fisheries Science Center

NOAA Tech. Memo.
NMFS-NWFSC-

30 **Grant, W.S. (editor). 1997.** Genetic effects of straying of non-native hatchery fish into natural populations. Proceedings of the workshop, June 1-2, 1995, Seattle Washington. 130 p. NTIS number pending.

29 **Emmett, R.L., and M.H. Schiewe (editors). 1997.** Estuarine and ocean survival of northeastern Pacific salmon: Proceedings of the workshop, March 20-22, 1996, Newport, Oregon. 313 p. NTIS number pending.

28 **Northwest Fisheries Science Center and National Marine Fisheries Service. 1997.** Investigation of scientific information on the impacts of California sea lions and Pacific harbor seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. 172 p. NTIS PB97-155154.

27 **Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996.** Status review of west coast steelhead from Washington, Idaho, Oregon, and California. 261 p. NTIS PB96-210166.

26 **McCabe, G.T., Jr., and S.A. Hinton. 1996.** Benthic invertebrates and sediment characteristics in freshwater beach habitats of the lower Columbia River, 1994-95. 111 p. NTIS PB96-186879.

25 **Hard, J.J., R.G. Kope, W.S. Grant, F.W. Waknitz, L.T. Parker, and R.S. Waples. 1996.** Status review of pink salmon from Washington, Oregon, and California. 131 p. PB96-162607.

24 **Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995.** Status review of coho salmon from Washington, Oregon, and California. 258 p. NTIS PB96-106554.

23 **Hinton, S.A. G.T. McCabe, Jr., and R.L. Emmett. 1995.** In-water restoration between Miller Sands and Pillar Rock Island, Columbia River: Environmental surveys, 1992-93. 47 p. NTIS PB95-274445.

22 **Waknitz, F.W., G.M. Matthews, T. Wainwright, and G.A. Winans. 1995.** Status review for mid-Columbia River summer chinook salmon. 80 p. NTIS PB95-260923.

21 **Reppond, K.D., and J.K. Babbitt. 1995.** Frozen storage stability of fillets, mince, and mixed blocks prepared from unfrozen and previously frozen pink salmon *(Oncorhynchus gorbuscha).* 57p. NTIS PB-95-239828.

20 **Hinton, S.A., and R.L. Emmett. 1994.** Juvenile salmonid stranding in the lower Columbia River, 1992 and 1993. 48 p. NTIS PB-95-199352.

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