

The Sockeye Salmon
Oncorhynchus nerka
Population in Lake Ozette,
Washington, USA

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Technical Report NPS/CCSOSU/NRTR-96/04

August 1996



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ABSTRACT

The number of adult sockeye salmon (*Oncorhynchus nerka*) returning to Lake Ozette, Washington has declined substantially from numbers indicated by 1949-51 harvest data. Currently about 2,200 sockeye salmon return to the lake as mature four-year-old adults in years of high returns, and fewer than 350 return in years of low returns. The majority of adults spawn at two principal lakeshore sites, although a few now spawn in a large tributary of the lake (Umbrella Creek). A hatchery has been operated by the Makah Tribe in the Umbrella Creek drainage to supplement natural sockeye salmon production since 1982. Sockeye salmon smolts produced in the lake are large in size and feed sympatrically with adult and juvenile kokanee on *Daphnia* and other zooplankton species. The large size of sockeye salmon smolts and the apparent abundance of large zooplankton species in the lake may be evidence that food supplies do not limit the size of the Lake Ozette population of sockeye salmon. Several predatory fish species, including some introduced species, reside in the lake and prey on juvenile salmon, although the impact of these predators on the survival of juvenile salmon largely is unknown. Few estimates of number of smolts are available. For the 1988 brood year when an estimated 2,191 adults returned and spawned, an estimated 7,942 smolts left the lake. The estimated number of adults returning in 1992 was 2,166. The Ozette Lake Basin has been extensively clear-cut logged, and there is considerable speculation that this practice has affected natural production of sockeye salmon in the lake and tributaries, although actual cause-effect relationships remain poorly studied.

Several agencies maintain an interest in increasing the size of the Lake Ozette population of sockeye salmon, and four scientists met on May 8, 1996 to discuss options to restore the population. Population limiting factors could not be specifically defined with existing information, although the decline was judged to be most likely the consequence of a series of cumulative impacts. Continuation of weir counts of adults, with improvement in the quality of the counts, was recommended as the highest priority. Monitoring of the fate of hatchery fish was the second priority presented by three of the four panel members. All agreed a planning process for a program of adaptive management must be initiated. A holistic perspective, population sustainability, appropriately conducted science, adaptability, defined and periodically reviewed project objectives, diagnosis of population condition, risk assessment of possible actions, and monitoring and evaluation should all be built into the restoration process.

SECTION I

Information Summary: The Sockeye Salmon *Oncorhynchus nerka* Population in Lake Ozette, Washington, USA

Lake Ozette, on the western edge of the Olympic Peninsula in the State of Washington, is one of only a few lake systems in the state supporting a population of sockeye salmon *Oncorhynchus nerka* (Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes 1993, 1994). Only this lake system and the Quinault system support populations of sockeye salmon in Olympic National Park. The Lake Ozette population is of special interest not only because of the rare occurrence of these fish in the state and in the park, but also because the population has experienced a decline in abundance over the last several decades. For all practical purposes, the population and the fishery targeting it have collapsed. The number of adult sockeye salmon returning to Lake Ozette exceeded 17,000 as recently as 1949 (Dlugokenski et al. 1981). Some have speculated that the historical adult population size was 30,000 (Makah Fish. Manage. 1987a), although count or harvest records to support the higher figures do not exist. Since the late 1950s, only rarely have more than 2,000 adults returned to the lake, and in some recent years, returning adults have numbered less than 300. Harvest data indicate that other salmonid populations using the Lake Ozette Basin also have declined in abundance (Table 1). A commercial river gillnet fishery operated by members of the Makah Tribe (hereafter Makah) captured returning adult sockeye salmon and other species at the mouth of the Ozette River through 1977. Between 1978 and 1983, a tribal ceremonial and subsistence fishery with a quota of 30 adult sockeye salmon occurred, although no harvest occurred in the last year of that allowance.

Table 1. Numbers of salmon taken by the Makah Tribe from the Ozette River near the mouth of the river using set nets or drag seines as reported to the State of Washington, Department of Fisheries by Makah Tribe (Ward et al. 1976 for years 1948-1975 as reported in Dlugokenski et al. 1981 and Meyer and Brenkman 1995 for years 1976-1994).

Year	Chinook	Chum	Coho	Sockeye	Totals
1948	491	1063	1991	3850	7395
1949	1876	1339	1572	17638	22525
1950	1629	1226	2407	14556	19818
1951	1213	1021	1103	15074	18411
1952	396	682	3697	3047	7822
1953	431	431	906	2380	4148
1954	823	907	862	2110	4702
1955	404	806	1031	1107	3348
1956	241	0	1149	1396	2786
1957	428	0	1119	512	2059
1958	147	0	721	395	1263
1959	0	0	0	682	682
1960	0	0	0	1851	1851
1961	3	0	281	1054	1338
1962	0	0	385	1645	2030
1963	1	1	263	1551	1816
1964	1	0	350	448	799
1965	1	0	407	257	665
1966	0	0	504	405	909
1967	0	0	272	313	585
1968	0	0	385	468	853
1969	0	0	189	295	484
1970	1	0	296	432	729
1971	0	0	244	328	596
1972	0	0	325	346	671
1973	0	0	0	49	49
1974	0	0	0	0	0
1975	33	0	0	0	33
1976	0	0	0	0	81
1977	0	0	0	84 ¹	30
1978	0	0	0	30	30
1979	0	0	0	30	30
1980	0	0	0	30	30
1981	0	0	7	0	0
1982	0	0	15	29	15
1983	0	0	20	0	20
1984	0	0	0	0	0
1985	0	2	80	0	82
1986	0	0	55	0	55
1987	0	0	0	0	0
1988	0	0	0	0	0
1989	0	0	0	0	0
1990	0	0	0	0	0
1991	0	0	0	0	0
1992	0	0	0	0	0
1993	0	0	0	0	0
1994	0	0	0	0	0

¹Makah Tribal regulations limited the sockeye harvest to 30 fish for ceremonial purposes.

Reasons for the collapse of the population of Lake Ozette sockeye salmon remain poorly defined. Speculation has focused on degradation of spawning habitat from forestry practices in the Lake Ozette Basin, over exploitation, introduction of nonnative fish and plant species to Lake Ozette, disruption of the natural predator-prey equilibrium in the lake, disruption of competitive relationships within the lake's fish community, and limitations of lake productivity. Physical characteristics of the watershed, water quality, spawning habitat, plankton populations, diseases, sockeye salmon life history, and predatory and competitive relationships within the lake's fish community have been studied to varying degrees in attempts to identify key limiting factors. A small hatchery program has been operated on a tributary to the lake (Umbrella Creek) by the Makah since 1983 to supplement natural production.

The Makah, Olympic National Park, the State of Washington, the National Marine Fisheries Service, and several other management agencies maintain an interest in increasing the size of the sockeye salmon population and several other salmonid populations in Lake Ozette and its tributaries. Recently the American Fisheries Society reviewed the status of Lake Ozette sockeye salmon and concluded that the population is at moderate risk of extinction (Nehlsen et al. 1991). This same review concluded that the stock of coho salmon in Lake Ozette is of special concern and that chum and chinook salmon stocks in the system face a high risk of extinction. A comprehensive state-wide stock status assessment called the Salmon and Steelhead Stock Inventory recently was conducted by Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Treaty Tribes (1994). Via this effort, the population of Ozette sockeye salmon was classified as depressed based on chronically low returns of adults. Information was judged to be insufficient to assess the status of populations of Lake Ozette chum salmon, coho salmon, and winter steelhead, but Lake Ozette chinook salmon

were considered either extinct or no longer present in sufficient numbers to constitute a viable population.

Recent interest in increasing the size of the sockeye salmon population in Lake Ozette adds to a long series of attempts to address the issue. The first extensive multi-agency approach began in 1981 with the formation of the Lake Ozette Steering Committee. The committee's task was to develop a rational approach to rehabilitation of the Lake Ozette sockeye salmon (Blum 1984). The Makah, Olympic National Park, U.S. Fish and Wildlife Service, Washington Department of Fisheries, Washington Department of Game, University of Washington, and the Fisheries Research Institute at the University of Washington were represented on the committee. Active during 1981 and 1982, the recommendations of the steering committee provided some direction to the efforts conducted in the Lake Ozette Basin by the Makah, although the committee's preferred approach, importation of a stock of sockeye salmon from Lake Quinault to restore a stream-spawning component of the run, only included one introduction of 120,000 juveniles from 1982-brood-year stock. The condition of the Lake Ozette sockeye salmon population was discussed again at a meeting of a multi-agency watershed planning team comprised of state, federal, and tribal representatives in July, 1987 (Watershed Planning Team, Cape Flattery Meeting Summary). The team recommended a compilation of all background information pertaining to Lake Ozette sockeye salmon, tributary spawning-ground surveys to determine status of stream spawners, and revival of the Lake Ozette Sockeye Committee. In 1987, the Makah unsuccessfully attempted to reform a steering committee to focus on restoration of Lake Ozette sockeye salmon (letter from M. LaRiviere, Makah Fisheries Biologist to agency representatives dated August 14, 1987). Since then, research and management directed at the population have continued to varying degrees by the Makah, National Park Service, and State of

Washington without much multi-agency coordination. Albeit some limits on coordination exist because of varying regulatory jurisdictions, additional coordination in research and management is desirable on the part of all groups interested in this population of sockeye salmon.

The long-term goal of the Makah is to restore the population of sockeye salmon to a size that is sufficient to allow a sustainable harvest of returning adults. National Park Service policies regarding fish management and restoration are described in NPS (1988) and state that “In natural, cultural, and park development zones, fisheries management will seek to preserve or restore natural aquatic habitats and the natural abundance and distribution of native aquatic species, including fish, together with the associated terrestrial habitats and species.” This policy statement goes on to elaborate on the importance of maintaining natural processes in park aquatic ecosystems and riparian zones. Coupled with these policies is the directive to the National Park Service in the 1988 Washington Parks Wilderness Act to conduct a study of the watershed of Lake Ozette and consider alternatives to protect the area. Meeting the interests of the various agencies, including the Makah, involved with Lake Ozette sockeye salmon and complying with the legal directives related to this fish stock requires ongoing coordination of research and management in the Lake Ozette Basin.

In 1994, the National Park Service provided funding to the National Biological Service’s Forest and Rangeland Ecosystem Science Center at Oregon State University to compile information about sockeye salmon in Lake Ozette, convene a panel of experts to review that information, and provide recommendations to Olympic National Park on future directions for research and management efforts directed at sockeye salmon in the system. This report contains the information that was compiled in advance of the panel meeting on May 8, 1996 and also contains the reports developed by the four panel members following that meeting. Ultimately it

is hoped that planning and actions that flow from this effort will result in well-designed, coordinated, and timely efforts to diagnose, treat, and restore the depleted sockeye salmon population in the Lake Ozette Basin.

Characteristics of the Lake Ozette Basin

Lake Ozette is a deep 2,954-ha lake located in the northwest corner of Washington State's Olympic Peninsula (Figure 1). The Ozette River flows north out of the north end of the lake and continues westward for a total length of about 8 km until it drains into the Pacific Ocean. The area west of the lake is underlain by Pleistocene-age glacial drift composed of gravel, sand, silt, and clay. Eastern portions of the lake's watershed are predominately underlain by Pliocene- and Pleistocene-age terrace deposits composed of fluvial and glacio-fluvial sand and gravel. The only major exceptions to this are the headwaters of Umbrella Creek and Big River, two tributaries whose watersheds lie northeast of the lake, which are underlain by marine and non-marine sandstone and siltstone of Tertiary age (Hunting et al. 1961, Tabor and Cady 1978). On the Olympic Peninsula in general, natural watershed characteristics are conducive to accelerated erosion (SCS 1984). Sedimentary rocks, primarily sandstones and siltstones are typically poorly consolidated. These type of rocks, which occur in the Ozette Basin, tend to rapidly decompose through chemical weathering associated with the region's heavy rainfall and break apart by abrasion during transport events (Benda 1993). Soils in upland areas of the Ozette Basin are dominated by Palix loams, and soils along valleys tend to be Ozette and Tealwhit silt loams (McHenry et al. 1994).

The watershed of Lake Ozette generally is low in relief, with well-rounded hills and ridges rising approximately 120-185 m above the adjacent valley floors. The lake itself lies

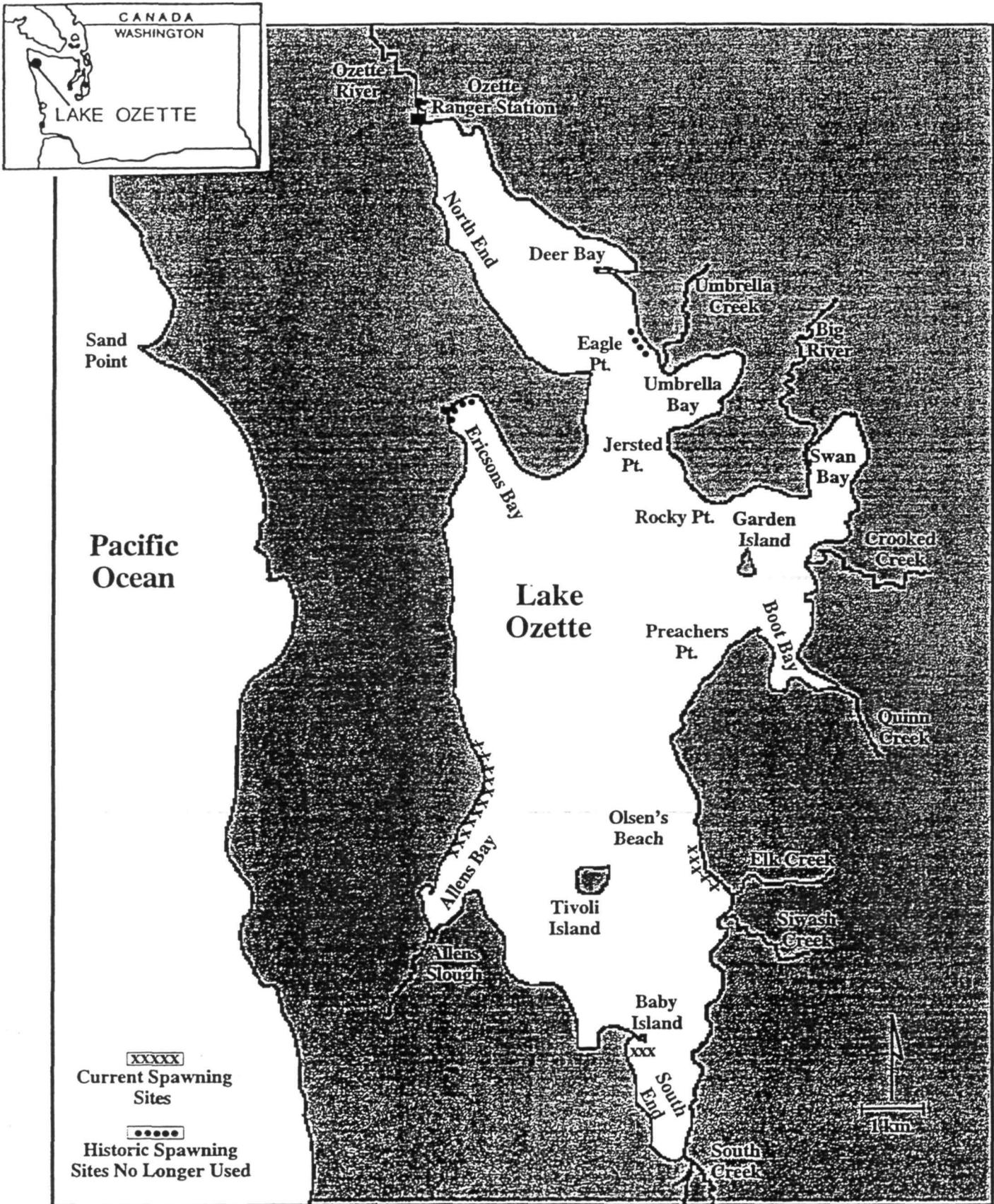


Figure 1. Area map of Lake Ozette, with current and historic spawning sites for sockeye salmon indicated.

approximately 9 m above sea level, and the maximum altitude in the watershed is approximately 580 m above mean sea level.

The climate of the northwestern Olympic Peninsula is marine, with cool summers and mild winters. Based on national climatological data collected at Forks, Washington about 24 km southeast of Lake Ozette, the mean annual temperature is 9.5°C (Figure 2). January tends to be the coldest month and July the warmest (4°C and 16°C mean monthly temperatures, respectively). The mean annual precipitation is 305 cm, of which about 80 percent falls as rain from October to March, sometimes in extremely heavy amounts exceeding 5 cm in a day.

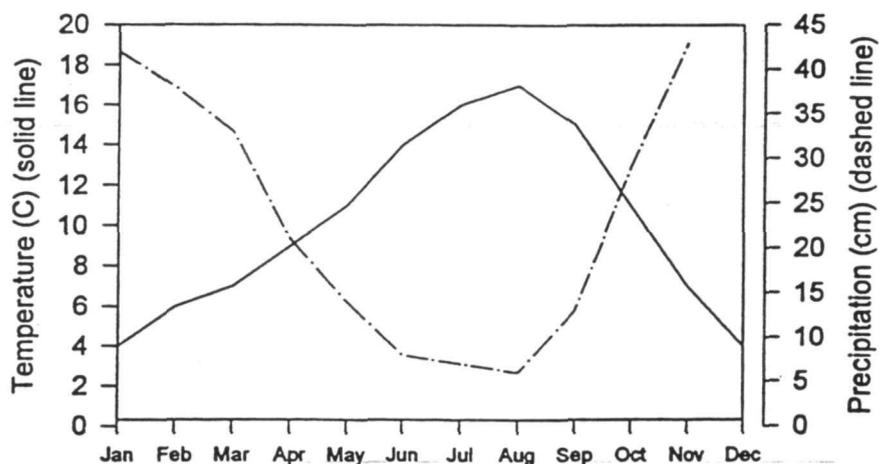


Figure 2. Mean monthly temperature and precipitation patterns at Forks, Washington on the northwest Olympic Peninsula.

The forest community surrounding Lake Ozette, the Ozette River, and the lower reaches of the tributaries of the lake are classified as Olympic rain forest (Franklin and Dyrness 1973). Sitka spruce *Picea sitchensis* and western hemlock *Tsuga heterophylla* are the dominant trees, but western redcedar *Thuja plicata* and several other conifer species also are present. Shore pine *Pinus contorta* is common near the ocean. The mature forests on the higher elevations are dominated by western hemlock, with Douglas-fir *Pseudotsuga menziesii* and western redcedar

also prevalent. Most of the forests in the Lake Ozette Basin are in early stages of succession rather than mature or climax condition, largely induced by intensive clear-cut logging (Table 2). Extensive stands of red alder *Alnus rubra* are present, as well as young mixed stands of alder, other hardwood species, and conifer species. The riparian vegetation immediately adjacent to

Table 2. Characteristics of five Lake Ozette watersheds based on data detectable from 1990 aerial photographs (unpubl. data of Makah Tribe and Olympic National Park).

	Umbrella Cr.	Big Cr.	Crooked Cr.	Siwash Cr.	South Cr.
Watershed areas (km ²)	30.4	59.4	29.9	7.6	8.1
Road length (km)	9.3	14.0	6.1	1.9	2.5
Stream length (km)	9.5	17.5	9.6	3.0	3.5
No. road crossings of streams	83	150	48	22	42
Percent of forest community in various age classes	1.24	1.21	1.64	0.16	0.02
Unknown Age	32.71	27.67	52.98	74.11	46.27
0-10 years	46.35	21.58	7.03	0.56	37.36
11-20 years	14.39	34.88	8.99	6.84	0
21-40 years	4.18	13.8	12.64	2.05	0.57
41-80 years	0.07	0.62	16.7	16.28	15.78
80+ years	1.05	0.24	0	0	0
lakes and marshes					

Lake Ozette is dominated in several locations by an ubiquitous native shrub -- sweetgale *Myrica gale*. Horsetail *Equisetum*, sedges *Carex*, pondweed *Potamogeton*, smart-weed *Polygonum*, bur-reed *Sparganium*, watershield *Brasenia*, and a variety of grasses are good examples of other vegetation around the lakeshore (Bortleson and Dion 1979, Meyer and Brenkman 1995).

Extensive stands of red alder now are common along riverine riparian corridors, whereas based

on the natural vegetation patterns of the Olympic Peninsula (Franklin and Dyrness 1973), historically old-growth conifers were abundant. In the nearby Hoh Basin, early aerial photographs indicate dominance of riparian habitat by old-growth conifers, whereas now alder have assumed a dominance of over 90 percent cover (Pentec Environmental Inc., unpubl. data). With the exception of the Ozette River, abundance of large woody debris in Ozette Basin streams is now low, although quantitative debris surveys have not occurred (N. Currence, Makah Fish. Manage., pers. comm., Apr. 1996).

Sockeye Salmon Population Characteristics

In general, sockeye salmon spend one to four years in the ocean, usually two, and two years in fresh water. With the onset of maturity, sockeye salmon travel from their feeding areas in the ocean to their natal streams. After ascending the natal stream, they spend one to eight months in lake habitat before moving to their natal spawning areas (Pauley et. al. 1989, Forester 1968). Spawning areas selected by adults may be in streams flowing into a lake; in the upper sections of a lake's outlet river; or along the shores of the lake where seepage outflows, springs, or wind-induced waves occur (Foerster 1968). Members of a population in a basin may utilize one or more of these areas for spawning, but spawning area selection appears to be inherent within sub-populations (Brannon 1972, Bugaev 1987). The timing of spawning for sockeye salmon in general occurs between August and January with variation within this time frame, depending on the population (Pauley et al. 1989). Juvenile sockeye salmon normally live in their nursery lake for one or two years (Forester 1968). During the period of lake residence, sockeye juveniles are pelagic schooling fish with a diet of zooplankton. Diel vertical movements occur covering tens of meters, with the juveniles rising toward the surface at dusk and descending during the daytime (Levy 1987).

Adult Returns to Lake Ozette

Lake Ozette sockeye salmon have a four-year life cycle, with slightly under two years of freshwater residence up to the smolt stage and two years of ocean residence. Adult sockeye salmon return to the mouth of the Ozette River during late spring and summer, with the returning run peaking in abundance in late June and early July (Figures 3 and 4). The general assumption is that marine interception of the population of Lake Ozette sockeye salmon is very low because the route of the returning adult migration is presumed to be along the west shore of Vancouver Island and, thus, away from the marine areas heavily fished for returning sockeye salmon (J. Meyer, Olympic Natl. Pk., pers. comm., Aug. 1995). Extensive commercial fisheries for sockeye salmon occur in marine waters, but with the exception of a limited troll fishery off the coast of Vancouver Island, the salmon fisheries in the vicinity of the Olympic Peninsula normally occur inside the Strait of Juan de Fuca or close to the mouth of the targeted salmon population's natal river. It is possible that some Lake Ozette sockeye salmon migrate along the east shore of Vancouver Island and the Strait of Juan de Fuca, which would make these individuals susceptible to commercial harvest. The sockeye fishery targeting the Fraser River sockeye never starts before late July, which is after the majority of the Lake Ozette sockeye salmon have entered the lake. No commercial harvest of sockeye salmon currently occurs near the Ozette River mouth. The level of interception of members of the Lake Ozette population in high-seas fisheries remains unstudied.

The return of sockeye salmon to Lake Ozette has been systematically monitored in most years since 1977 and only sporadically prior to then. The first known attempt to count adult sockeye salmon as they returned to Lake Ozette was in 1924, when a U.S. Fish and Wildlife

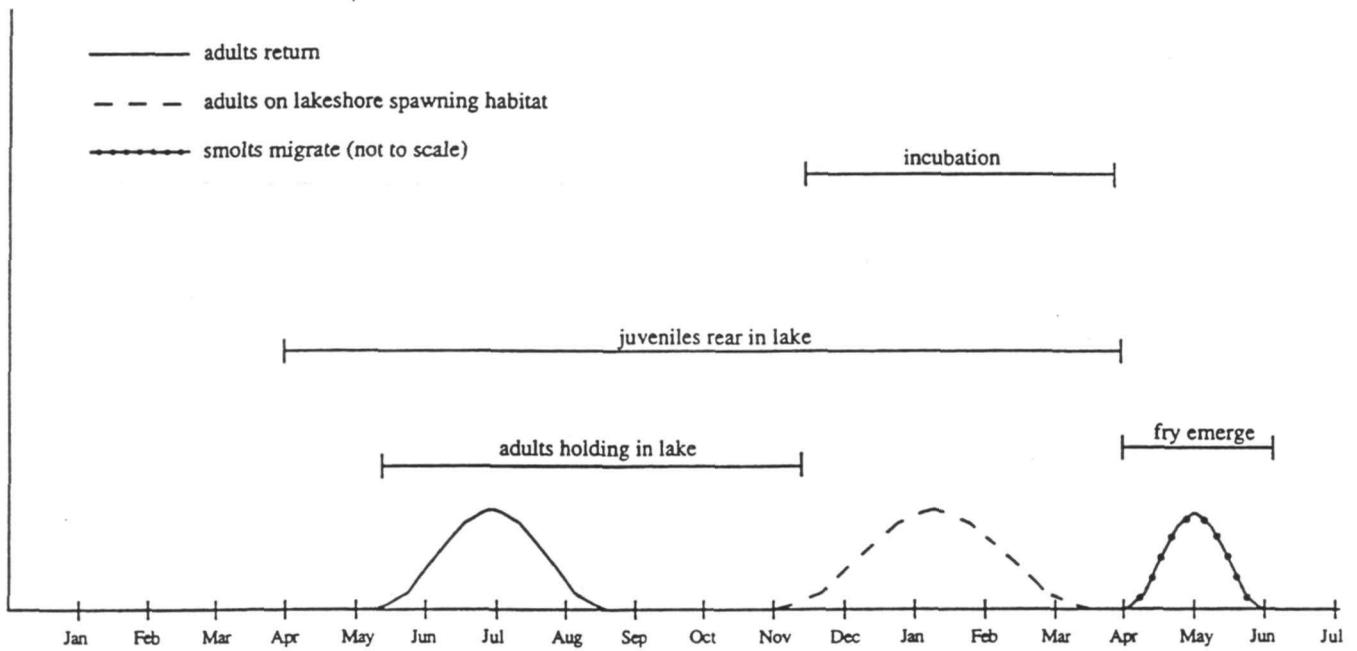


Figure 3. Timing of use of the Lake Ozette Basin by sockeye salmon.

Service District Supervisor (Kemmerich 1945) established a counting weir in the Ozette River. Kemmerich counted 3,241 adults between May 27 and August 8 in what was labeled a partial count during this period due to several days of inoperable weir conditions. Early in May, 1925 the counting weir was again installed, and 6,343 adults were counted between June 8 and September 15. Records of the number of adult sockeye harvested by the Makah between 1948 and 1975 provide a general index of run size for these three decades (Table 1). Three years of systematic counts, covering nearly the entire period of the run, first were done from 1977 to 1979 under a joint study between the Makah, U.S. Geological Survey, and the U.S. Fish and Wildlife Service using a net weir and counting board positioned in the Ozette River just downstream of Lake Ozette (Dlugokenski et al. 1981). Since then, the Makah have continued the monitoring to varying degrees, with some assistance from the National Park Service (Table 3). Over the last two decades, the run size has tended to number between 300 and 2,200 adults, with intermittently large runs but tentative indications of a decline in abundance in years between dominant runs (Makah Fish. Manage. 1992).

Age and Size Data

One-hundred and eleven returning adults collected from the tribal fishery and at a counting weir in the Ozette River between 1977-79 were aged. The vast majority of these fish were four years old, having spent their first two years in freshwater and their last two years in the ocean. These findings were biased by the fact that the gill nets used by the Makah were selective for four-year-old fish. The average length of the four-year-old fish was 56.4 cm and their average weight was 2.2 kg (Dlugokenski et al. 1981). More random sampling since then accompanied by aging of scales has confirmed that the majority of adult sockeye salmon entering Ozette Lake are

Table 3. Estimates of total escapement of adult sockeye salmon to Lake Ozette from 1977 through 1995.

Return Year	Number of Adults Observed ¹	Estimated Run Size ²	Method of Estimate	Citations
1977	920 + 84 adults harvested	1,004	No. fish observed passing weir + no. harvested	Dlugokenski et al. 1981
1978	890 + 30 adults harvested	920	No fish observed passing weir + no. harvested	Dlugokenski et al. 1981
1979	510 + 30 adults harvested	540	No fish observed passing weir + no. harvested	Dlugokenski et al. 1981
1980	255 + 30 adults harvested	432	N=nq plus number harvested	Dlugokenski et al. 1981
1981	No data collected			
1982	2061 + 29 adults harvested	2147	N=nq	Blum 1988; WA Dept. Fish & Wildl. & W. WA Treaty Indian Tribe
1983	Not available for this report	350	N=nq	WA Dept. Fish & Wildl. & WA Treaty Indian Tribe
1984	804	2170	N=nq	Blum 1988, LaRiviere 1991; WA Dept. Fish & Wildl. & WA Treaty Indian Tribe
1985	No data collected			
1986	Not available for this report	691	N=nq	LaRiviere 1991; WA Dept. Fish & Wildl. & WA Treaty Indian Tribe
1987	No data collected			
1988	218 (only 3 days of collection)	2,191	N=nq	LaRiviere 1991
1989	143	588 ³	N=nq	LaRiviere 1991
1990	175	263	N=nq	LaRiviere 1991
1991	Not available for this report	684	N=nq	Makah Fish. Manage. 1991
1992	1,175	2,166	N=nq	Makah Fish. Manage. 1992
1993	69 ⁴	≤267	N=nq	Makah Fish. Manage. unpubl. data
1994	Not available for this report	498	N=nq	
1995	Not available for this report	314	N=nq	Makah Fish. Manage. unpubl. data

¹This column of data provides a general indication of the intensity of monitoring via a comparison of the number of adults observed versus the estimated run size.

²Run Size estimated computed using the model developed by Dlugokenski et al. (1981): $N=nq$ where N =estimate of total run size, n =sample size, $q=1/p$, and p =average proportion of total run that passed the weir during a given period. Data collected throughout the adult run in 1977-1979 were used to calculate p for the time period of observation in 1980. Data collected throughout the adult run in 1982 and 1984 were used to calculate p for the time period of observation in 1988-1995.

³An additional 50 adult sockeye were known to migrate up the Ozette River on October 20, 1989. These fish were added to the calculated escapement estimate of 538 adults to reach the estimate of 588 adults.

⁴Field data sheets were lost. Makah Fish. Manage. know that 69 fish passed the weir, but the timing cannot be defined. Escapement estimate of 267 is calculated with the assumption that all fish passed the weir during the standardized counting interval. If some of the 69 fish passed outside this counting interval, the estimate is high.

four years old (Makah Fish. Manage., unpubl. data). A few three-year-old fish that returned during 1977, 1978 or 1979 were measured and weighed. They had an average length of 40.7 cm and an average weight of 0.91 kg (Dlugokenski et al. 1981, sample size not provided). The length-weight relationship for the Lake Ozette sockeye from newly emerged fry through mature adults, sexes combined is $\text{Log } W = 1.83 \text{ Log Fork Length} - 1.68$, with $r^2=0.96$ ($n=206$). The equation of the length-weight relationship for returning adult sockeye is $Y = -2,309.06 + 8.05x$ ($n = 111$) (Dlugokenski et al. 1981).

Timing of Return

The entry of adult sockeye into the Ozette River and the apparent rapid movement of the fish to Lake Ozette currently begins in middle or late May, ends about mid-August, and peaks in early-through-mid-July, with some interannular variation within these general patterns (Figure 4). A footnote to a tabular report of Ozette River salmon catches from 1948 through 1957 ("Ozette River Salmon Catches, Indian Personal Use and Commercial, April 28, 1958", Makah Files, Neah Bay) states that the Lake Ozette sockeye salmon run began in mid-April, was greatest during May and June, and peaked June 2-15 in the lower river. Occasionally groups of adults now enter the lake as late as October (LaRiviere 1991). The fish appear to cover the short distance from the ocean to the lake (7.2 km) in less than 48 hours. Actual movements of individual fish from the river mouth to the lake have not been monitored, but some fish have been observed to arrive at the lake with the marine parasite (*Argulus* sp.) attached (Dlugokenski et al. 1981). Most of the adults travel at night and very close to the channel bottom (Biosonics 1988).

Spawning-Ground Activity

Lake Ozette sockeye salmon spend about three months in the lake before moving to their spawning grounds on the lakeshore in about October (Dlugokenski et al. 1981). Actual spawning takes place from November through March. The abundance of sockeye salmon on spawning grounds in the Lake Ozette system is monitored intermittently using walking surveys in tributaries and lakeshore counts from a boat (Tables 4 and 5). Virtually all sockeye salmon spawning in the Lake Ozette Basin now occurs along the lake shoreline, with two principal spawning sites -- (1) Olsen's Beach (in some literature referred to as Elk Creek) located just north of Siwash Creek on the eastern shore of Lake Ozette and (2) the area north of Allen's Slough on the west shore (Figure 1). Some spawning also takes place on the south shore of Baby Island at the southern end of the lake (Meyer and Brenkman 1995). Other lakeshore areas where sockeye have been reported spawning in the last twenty years are Umbrella Point and Ericsons Bay (Figure 1, Dlugokenski et al. 1981, Makah Fish. Manage. unpubl. data).

There is indirect evidence of historic spawning activity in Boot Bay near Quinn Creek in the form of several ripe sockeye captured in a gill net during January 1979 (Dlugokenski et al. 1981). The most common presumption is that sockeye salmon once used tributaries of Lake Ozette for spawning. In general, most sockeye salmon that enter lake systems have a population component that uses tributary habitat for spawning (Forester 1968).

Dlugokenski et al. (1981) cited personal communications in 1978 from Pete Ward (a fish biologist with the Makah), Emil Person (an Ozette Basin resident), and J. Ayerst (a fish biologist with Washington Department of Wildlife) as evidence that sockeye historically utilized Lake Ozette tributaries. In discussions with N. Currence (Makah Fish Biologist), John Cowan, a settler in the region of Lake Ozette, recalled seeing eight adult sockeye salmon in a hole near a

bridge on Big River at about river kilometer 11.6. Big River is the largest tributary of Lake Ozette and flows into the northeastern portion of the lake. Cowan's observation was made in late May or June on one occasion only in the mid 1920's, the only occasion that he was there at that time of year. He recalled that some of the fish were green only, whereas others were beginning to turn red. By 1973, when U.S. Fish and Wildlife Service staff conducted stream surveys in tributaries of Lake Ozette specifically targeting sockeye salmon, this species was not detected

Table 4. Lake Ozette shoreline observations for adult sockeye salmon.

Year of Adult Return	Lakeshore Areas Surveyed	Period of Surveys	Observations	Citation
1973	Lake Ozette in general	January 10, 1974	Sockeye observed to have spawned on a beach north of Elk Creek. Five dead and one live sockeye observed on this beach	Written communication from J. Meyer to Bortleson and Dion cited in Bortleson and Dion (1979)
1975	Beach north of Elk Creek	February 8, 1977	Six to 10 live sockeye and approximately six redds in 1-2 ft of water. One dead sockeye on beach.	Bortleson and Dion (1979)
1976	Beach from Elk Creek north to Preachers Point and the north side of Ericsons Bay	November 9, 1976	No sockeye or redds observed	Bortleson and Dion (1979)
1978	East, West, and North shores	Nov. 22, 1978 - Mar. 1, 1979	Sockeye found on the east shore north of Elk Creek., on the west shore from a point west of Tivoli Island to Allen's Bay, and on the north shore at the mouth of Umbrella Creek. This is the last report of spawning activity at Umbrella Creek.	Dlugokenski et al. 1971
1987	Olsen's Landing, Allen Bay	October 16, 1987- January 31, 1988	Sockeye salmon first observed at both sites in early December; spawning activity observed at both sites by mid-December; surveys conducted in conjunction with brood stock capture.	Makah Fish. Manage. 1987a
1994	Olsen's Beach, South side of Baby Island, north of Allen's Slough	December, 1994 and January, 1995	Sockeye salmon redds found at all three sites	Meyer and Brenkman 1995

Table 5. Stream surveys in Ozette Drainage Basin targeted at detection of spawning sockeye salmon.

Year of Adult Return	Streams Surveyed	Period of Surveys	Observations	Citation
1977	Quinn, Elk, South, Coal, and Umbrella creeks; Ozette River.	Oct. 20-Dec 1, 1977	No sockeye found; coho found in northeast branch of Umbrella Cr and in Ozette R.	Dlugokenski et al. 1981
1978	Crooked, Quinn, Elk, Siwash, Lost Net, South, Coal, Umbrella, NE Br. Umbrella, E. Br. Umbrella, and W. Br. Umbrella creeks; Ozette River.	Oct. 17, 1978-Jan. 4, 1979	No sockeye found; coho found in Crooked, South, Coal and E. Br. Umbrella creeks and in Ozette R.; kokanee found in Crooked, Elk, Siwash, Lost Net, and South creeks.	Dlugokenski et al. 1981
1979	Solberg, Trout, Elk, Siwash, Lost Net creeks, Big and Ozette rivers	Oct. 10, 1979-Jan 6, 1980	No sockeye found; coho found in Big and Ozette rivers and in Solberg and Trout creeks; kokanee found in Elk, Siwash, and Lost Net creeks	Dlugokenski et al. 1981
1987	Umbrella, Siwash, Crooked, and South creeks	October-December	No sockeye found; kokanee found in Umbrella and Siwash creeks; late November survey found thousands of kokanee spawning or holding in Siwash Creek.	Makah Fish. Manage. 1987a
1990	Not described in report cited	September	no sockeye; other species not described in report cited; says that kokanee observed spawning in the southern tributaries during November and December; Siwash Creek had the largest number of kokanee spawners, and a total of 81 females collected for brood stock on November 16 and 21; little effort expended after September survey in search of sockeye due to past experiences and other duties	Makah Fish. Manage. 1991b

¹Lost Net Creek's location is not documented. This is not a common name used by any other than Dlugokenski et al. 1981.

(J. Meyer, National Park Service, pers. comm., Aug. 1995). Blum (1984, 1988) stated that a small river-spawning population was observed in 1982 while he was working for the fisheries staff of the Makah, but no details are provided in the written accounts. His recent recollection is that around 10 adults were observed in lower reaches of a tributary in December, 1982. These fish were sexually mature, although redds were not observed (J. Blum, pers. comm., Nov. 1995). Blum also recalls descriptions by a member of the Makah Tribe now deceased (William Parker, Sr.) of harvests of sockeye salmon in tributaries of Lake Ozette using nets. Mr. Parker also discussed operations of fish traps targeting sockeye salmon in the lake and lower reaches of tributaries of the lake.

Stream surveys conducted with varying degrees of thoroughness starting in 1977 and continuing to the present have yielded several observations of adult sockeye salmon in Umbrella Creek. This creek is the site of a small hatchery operated by the Makah (see later section). A single adult male was "recovered" from Umbrella Creek in early December, 1988 (Makah Fish. Manage. 1989), possibly as a carcass, although records are not specific. Although there is some question of the condition of this fish, even if it were alive and sexually mature, this fish would not have been captured and used for broodstock in the hatchery program because only broodstock collected from the lakeshore were used at that time (J. Hinton, Makah Fish. Manage., pers. comm., Apr. 1996). This was reportedly the "first tributary-spawning sockeye observed in Lake Ozette in over 15 years of surveys" and was viewed as a "good sign of the success of the enhancement program designed to reestablish tributary spawners in lake Ozette" (Makah Fish. Manage. 1989). More recently, some of the adults observed in Umbrella Creek have been known or suspected to be returns from accidental and intentional releases from the hatchery (unpubl. data, Makah Tribe). Some of the progeny of adults collected from lakeshore spawning areas in

fall and early winter of 1987 were accidentally released from the hatchery site into Umbrella Creek in 1988 when hatchery screens clogged. Within 24 hours of the release, an attempt was made to recover the juveniles with electrofishing in Umbrella Creek downstream of the hatchery. None were recovered, indicating rapid movement of the juveniles into the lake. Some of these fish returned as adults to Umbrella Creek in the fall of 1991, and eggs and sperm from two females and one male, as well as lakeshore spawners, were collected for the 1991-92 hatchery program. Several thousand fingerlings that were offspring of the adults that returned to Umbrella Creek were released below the hatchery into Umbrella Creek in late June, 1992. About half of these fingerlings were marked with a fin clip. In the fall of 1995, about 50 adults returned to Umbrella Creek, and 36 redds were recorded in the creek in late November and early December from the mouth of the river up to river km 2.9. Five carcasses were observed, of which two exhibited fin clips from the hatchery release and a third exhibited a clip, but origin could not be distinguished. Broodstock was not collected from the stream for hatchery production purposes in the fall of 1995.

Some sockeye salmon may have spawned in Coal Creek, a tributary of the Ozette River downstream of Lake Ozette, in the winter of 1984-85. On 31 July 1984, 31 sexually mature adults were observed downstream of the weir on the Ozette River that is used to monitor adult returns. These adults were never observed passing through the weir, and operation protocol for the weir was judged to be adequate to detect them if they had migrated by. In late September and early October, 1990 a few sockeye in spawning colors were observed below the adult weir and at least one redd was deposited in the Ozette River immediately downstream of the weir (Makah Fish. Manage. 1991b).

There is some evidence of differences in spawning time at locations used around the lakeshore. This may indicate discrete subpopulations, which may have naturally diverted from a common population or may be a result of past stocking of hatchery-reared juveniles from Baker Lake and Lake Quinault populations (see Genetics section). The only time that shoreline surveys have been frequent enough to tentatively identify differential use was during the 1978-79 spawning season (Figure 5). During this season, Dlugokenski et al. (1981) first observed beach spawners at a site he labeled Elk Creek (more recently Olsen's Beach) on November 20 and did not detect any additional spawning activity, including redd protection at this site after mid-March. The fish were concentrated in an area 25 m long from a depth of 0.3 m to an observed depth of 2.8 m. The largest number of spawners observed at any time at this site during that year of observation was 60 fish in mid-December. Dlugokenski et al. (1981) also observed spawning sockeye along the west shore of the lake in Allen's Bay from mid-December 1978 to April 1979. The spawners numbered 150 in late January and were fairly evenly spaced along this shore at a depth of 1 to 3 m. The third beach area used in 1978-79 was north of the mouth of Umbrella Creek. Sockeye salmon no longer appear to use this site. Thirty spawners were observed utilizing the beach area north of the mouth of Umbrella Creek on January 20, 1979 and a sexually mature gravid male sockeye was recorded in March 1979 at this location.

Eggs and Fecundity

In general, a sockeye salmon redd consists of 3 to 10 nesting pockets, each with an average of 750 eggs (Hart 1973). The number of eggs per female averages about 3,500 and varies with size of the fish (Manzer and Miki 1986). The egg incubation period varies with water temperature and usually lasts six to nine weeks (Wydoski and Whitney 1979). Eggs develop

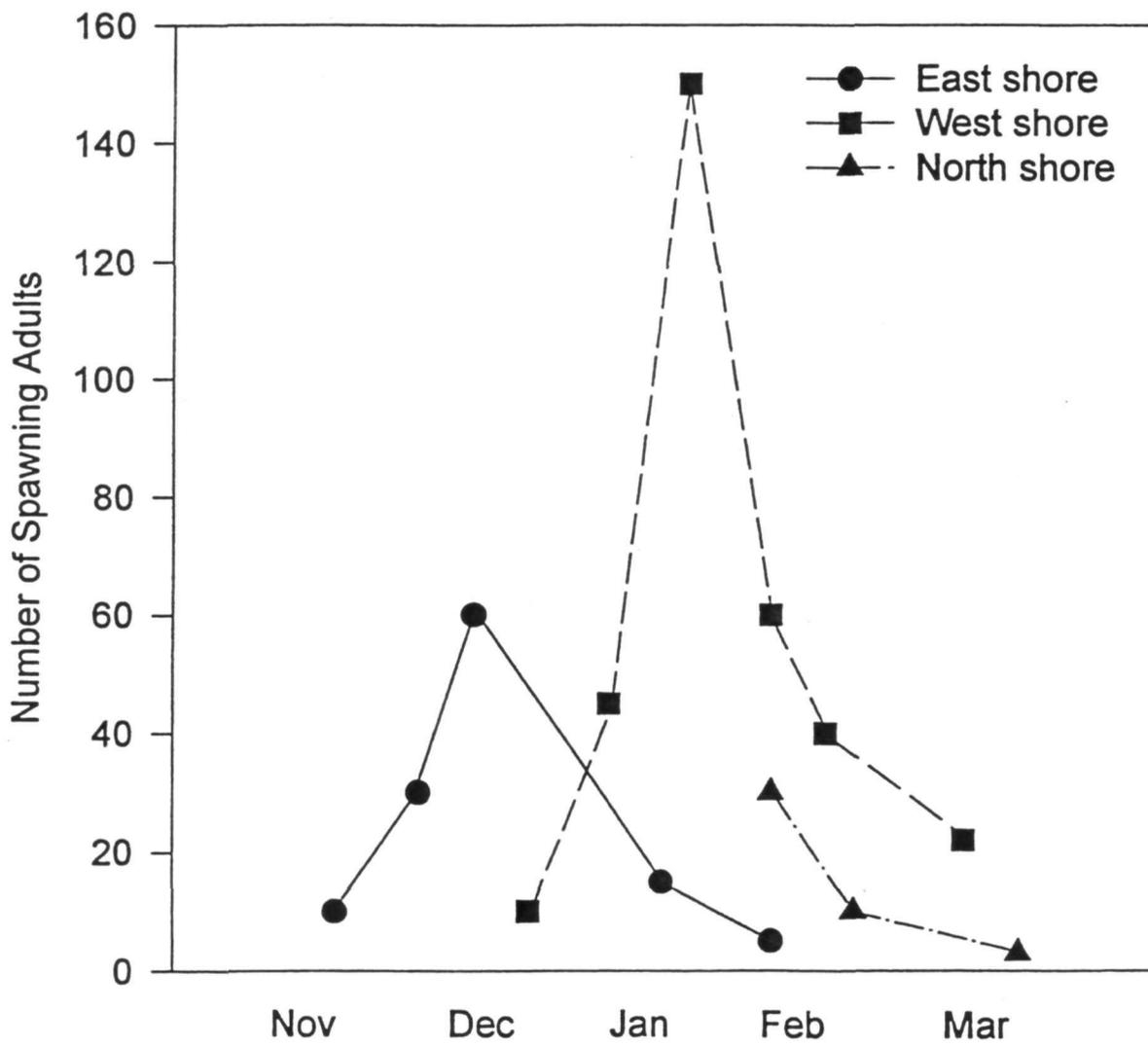


Figure 5. Timing and abundance of lakeshore spawning sockeye salmon in the 1978-1979 spawning season (from Dlugokenski et al. 1981).

normally between 4 and 14°C (Reiser and Bjornn 1979). The mean number of sockeye degree-day units based on rates of development in 10 hatchery facilities is 593°C (Foerster 1968).

The average number of eggs per redd has not been well described for sockeye salmon in Lake Ozette. Dlugokenski et al. (1981) obtained 404 eyed eggs and 458 dead eggs from a portion of a single redd on the east shore of Lake Ozette on February 20, 1989. Mean egg content of eight four-year-old sockeye salmon, with a mean length of 54.5 cm, captured in 1979 was 3,193 (Dlugokenski et al. 1981), which agrees well with current observations of an average of 3,300 eggs in females captured for broodstock at the Umbrella Creek Hatchery (J. Hinton, Makah Fish. Manage., pers. comm., Apr. 1996). Regression analysis by Dlugokenski et al. (1981) of length against egg content reveals that Ozette adults are intermediate when compared to adult sockeye salmon from an array of other lake systems from Alaska through Washington as reported by Forester (1968). In regard to the rate of egg development, based on observations at one redd on the east shore of the lake in 1979 (Dlugokenski et al. 1981), the period of incubation for Ozette sockeye is 68-82 days and the Celsius degree day units are 531-657. Based on current information from the Umbrella Creek Hatchery in the Ozette Basin, time from initial fertilization until a strongly visible eye is evident is 258 Celsius degree days, hatching occurs at 482 to 510 Celsius degree days, and fry usually start swimming at 650 to 760 Celsius degree days (J. Hinton, Makah Fish. Manage., pers. comm., Apr. 1996). Prickly sculpins *Cotus asper*, cutthroat trout *Oncorhynchus clarki*, and peamouth *Mylocheilus caurinus* have been observed eating sockeye salmon eggs on spawning beaches at Lake Ozette, but Dlugokenski et al. (1981) did not believe these eggs were redd-deposited. Information is not available on mortality of alevins in Lake Ozette after they have emerged from a redd and are freely swimming and actively feeding. Mortality of these young fish could occur prior to or in the course of migration to off-shore lake

habitats for rearing, although Beauchamp et al.'s (1995) data indicate that two major predators, northern squawfish and cutthroat trout, do not show a numerical response to the nearshore concentrations of migrating fry of sockeye salmon and kokanee in Lake Ozette.

Lake Residence of Juveniles

Juvenile sockeye salmon in Lake Ozette emerge from the spawning gravel from about April through June and migrate to the pelagic zone of the lake where they rear for a year before undergoing smoltification and emigration to the ocean in April and May. They mix with juvenile kokanee that have hatched in tributary streams, and the two groups become morphologically indistinguishable. They also mix with marked hatchery-produced juvenile sockeye salmon, once the latter are released into the lake in late June or early July. The exact timing and rate of movement from shoreline nursery areas to pelagic habitats has not been described, although most researchers who comment on the subject believe it happens quickly. General evidence for this is the fact that juvenile sockeye salmon and kokanee are found in the nearshore zone of Lake Ozette only briefly during the springtime fry migration into the lake and the springtime smolt migration out of the lake. Sockeye and kokanee fry abundance estimates range from 490-1,770,000 for the time period 1982-1991 based on the range of abundances of kokanee and sockeye salmon spawners observed during these years and factoring in commonly cited levels of egg production and survival from incubation to the fry stage (Beauchamp et al. 1995). These estimates should be viewed as extremely crude because the abundance of kokanee spawners is very poorly documented in the Lake Ozette Basin. The only estimate of annual survival of under-yearling kokanee and sockeye salmon in Lake Ozette is 6.7% (Beauchamp et al. 1995).

Based on analysis of stomach contents, *Daphnia pulicaria* dominates the diet of juvenile kokanee and sockeye throughout the year (Beauchamp et al. 1995). Bioenergetic simulations

and *Daphnia* egg-ratio analysis indicate that the combined consumption by juvenile sockeye salmon and all year classes of kokanee accounts for less than 1% of the mean monthly standing stock of *Daphnia* in the lake that are in a size class 1.0 mm and larger and less than 1% of the monthly production of this size class of *Daphnia* (Beauchamp et al. 1995). Such data support the belief that food supplies in Lake Ozette are adequate to support more juvenile sockeye salmon and kokanee than those presently in the lake. This same belief was presented by Dlugokenski et al. (1981) based on the size of the smolts he observed leaving the lake (see below) and by Bortleson and Dion (1979) based on a comparison of the quantity of zooplankton they observed in Lake Ozette with the quantity observed in several other sockeye-producing lakes in Washington and Alaska.

Sockeye salmon juveniles become adapted for saltwater residence and migrate from Lake Ozette after about one year of lake residence. Estimates of the size of the population of sockeye salmon smolts leaving the lake have been conducted intermittently since 1977 (Table 6). The same trapping system has been used each time (Makah Fish. Manage. 1990b, Dlugokenski et al. 1981), although timing of sampling and logistical problems have varied. The trap consists of a fyke net with an attached live trap. The net is supported from an alder tree hanging suspended over the river about 0.3 km downstream of the bridge at the Ozette Ranger Station. Lines and pulleys are attached for retrieval, cleaning, and checking of the net and live box.

The pattern of peak catches of smolts as they leave the lake consistently peaks in early May, and the smolt emigration from the lake is essentially complete by late May (Makah Fish. Manage. 1990b, Figure 6). The vast majority (over 99 percent) of the sockeye smolts are 1+ fish; their average fork length is about 12 cm, and their average weight is consistently over 14 g and commonly over 17 g (Makah Fish. Manage. 1990b, Table 7). Size of the smolts may taper

Table 6. Estimated abundance of sockeye salmon smolts migrating from Lake Ozette.

Year	No. Smolts	Comments	Citation
1977	9600	Based on trapping from 3 April through 29 May, with four 24-hour trapping session. Mark - recapture of coho smolts used to estimate 11% trap efficiency.	Dlugokenski et al. 1981
1982	insufficient data	Trap operated only from 11 May through 1 Jun.	
1984	insufficient data	Trap operated from early April through mid-May based on data presented in report cited.	Makah Fish. Manage. 1990b
1988	insufficient data	Trap operated one day in mid-May based on data presentation in report cited.	Makah Fish Manage. 1990b
1989	insufficient data	Trap operated from 10 April through 26 May and fished two nights per week. Some problems with high flows trap clogging, and smolt mortality. Captured 255 sockeye salmon smolts. Trap efficiency roughly estimated to be 30% based on captures of marked fish.	Makah Fish. Manage. 1990b
1990	7,942	Qualified as a minimum estimate. Migrants prior to the night of 22-23 April and after the night of 18-19 May were excluded from the analysis. Trap operated from April 1-Jun 11, 1990 on a schedule of five days per week, except for last two weeks when catches of smolts declined. Estimate does not include migrants on days of no sampling. Estimate developed by Bob Conrad, Northwest Indian Fisheries Commission.	Unpubl. report from B. Conrad, NW Indian Fish. Manage. 1991. Makah Fish. Manage. 1991c
1991	insufficient data	Trap operated between April 17 and May 30, with the trap set for fish capture two or three nights per week. Number of smolts captured was too small to effectively use the model developed to estimate the size of the 1990 sockeye salmon smolt population.	Makah Fish. Manage. 1991c
1992	2,752	Trap operated between March 31 and May 14 and checked a minimum of every other day until catches of sockeye salmon smolts dropped off. This estimate was considered the best of the two estimates for the 1992 data. SE 634.1, coefficient of variation 23.0%, 95% confidence interval 1,869-4,339; same sampling for estimate (below) but bootstrap method of estimated used per Efron 1982 and Buckland 1980.	Unpubl. report from B. Conrad, NW Indian Fish. Manage. 1993; Makah Fish. Manage. 1992
1992	2,467	Trap SE 496.6, coefficient of variation 20.1%, 95% confidence interval 1,494-3,441 same sampling for estimate (above) with estimation based on trap efficiency and the number of smolts caught by the trap during the days of standard operation.	Unpubl. report from B. Conrad, NW Indian Fish. Com. to D. Drange, Makah Fish. Manage. 1993; Makah Fish. Manage. 1992

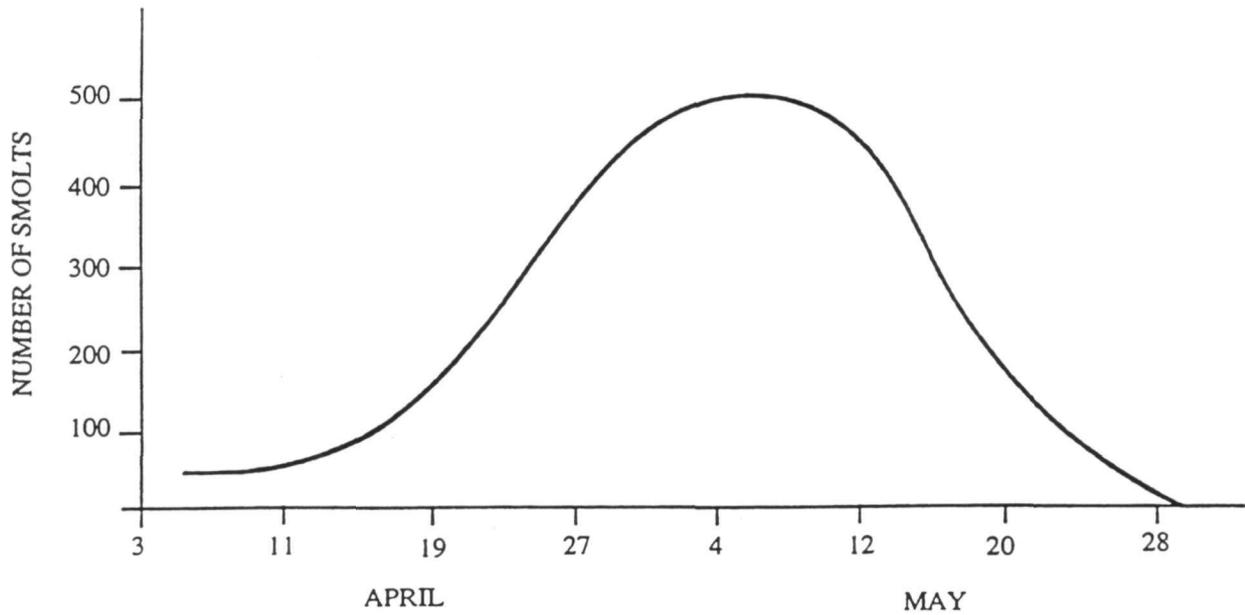


Figure 6. Timing and abundance of the emigration of sockeye salmon smolts from Lake Ozette in 1979 based on Dlugokenski et al. 1981).

Table 7. Size data for Lake Ozette sockeye salmon smolts.

Year of Smolt Migration	Average Fork Length (cm)	Average Weight (g)	Sample Size	Citation
1977 and 1988 (combined)	11.3	14.2	not specified	Dlugokenski et al. 1981
1989	12.2	17.4	255	Makah Fish. Manage. 1990b
1990	12.0	17.2	457	Makah Fish. Manage. 1990b
1991	12.7	18.7	74	Makah Fish Manage. 1992
1992	13.0	21.4	214	Makah Fish. Manage. 1992

off slightly toward the end of the run, but this suggestion has not been adequately tested (Figures 7 and 8).

The Lake Ozette smolts are exceedingly large based on comparative information in Burgner (1987), a fact that also supports the conclusion that food supplies do not limit survival of sockeye salmon juveniles. Burgner (1987) provided comparative size data for age-1 sockeye smolts from 34 lake systems, with the average weight and length of age-1 smolts 8.9 cm and 7.5 g, respectively. The Ozette smolts are about as large as Lake Washington smolts, which attain fork lengths of 12.7 cm and weights of 18.5 g on the average (Eggers 1978). The possibility that sockeye salmon smolts are being confused with adult kokanee has been considered by comparing the size of these age groups of the two species. Lake Ozette kokanee adults are larger than sockeye salmon smolts based on measurements of kokanee spawners collected from Siwash Creek for viral disease investigations in November, 1989. These adult kokanee averaged 23.4 cm fork-length (Makah Fish. Manage. 1990b, no weight provided).

Recruits per Spawner

Although the data are considered to be minimally adequate, some information is available for calculating estimates of recruits per spawning sockeye salmon. For the 1988 brood year when an estimated 2,191 adults returned, an estimated 7,942 smolts left the lake and an estimated 2,166 adults returned in the summer and fall of 1992. For the 1990 brood year when an estimated 263 adults returned, an estimated 2,752 smolts left the lake, and an estimated 498 adults returned in the summer and fall of 1994. The ratio of recruits per spawner for these two cycles are notably different, 0.99 for the 1988 brood year and 1.89 for the 1990 brood year. Ocean survival based on these data is high, 27% for the 1988 brood year and 18% for the 1990 brood year.

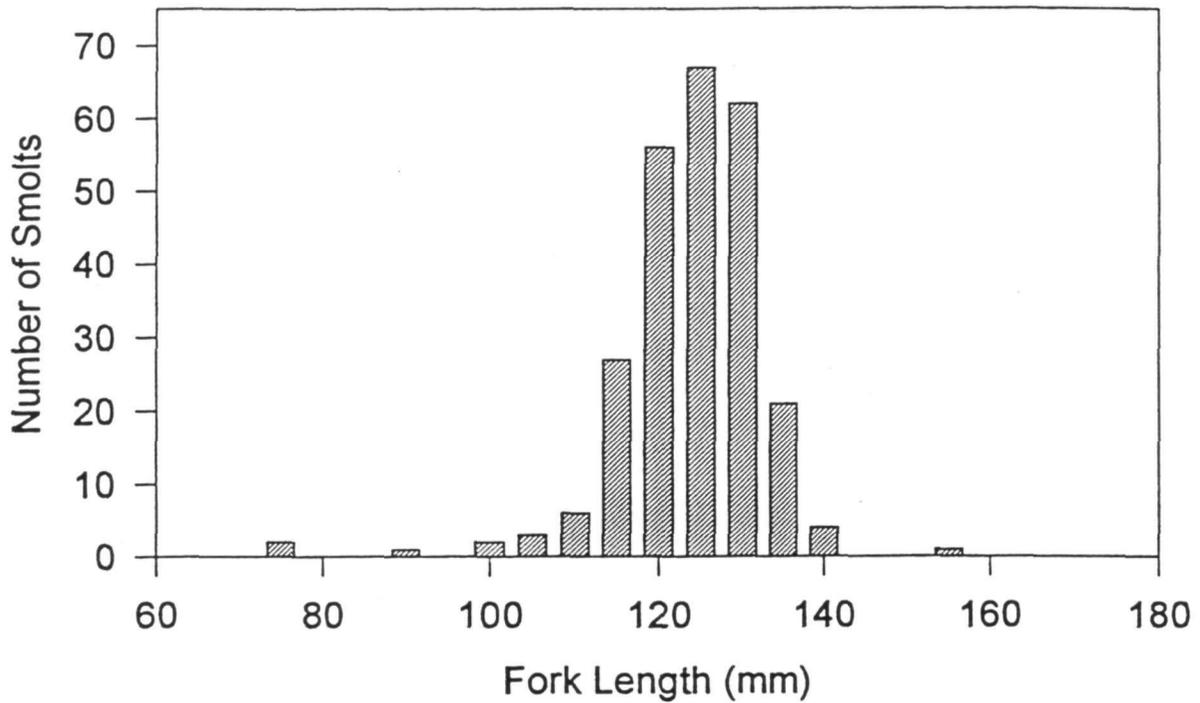


Figure 7. Lengths of Lake Ozette sockeye salmon smolts collected in 1989 using a fyke net and trap set from 4 April through 26 May (adapted from Makah Fish. Manage. 1990b).

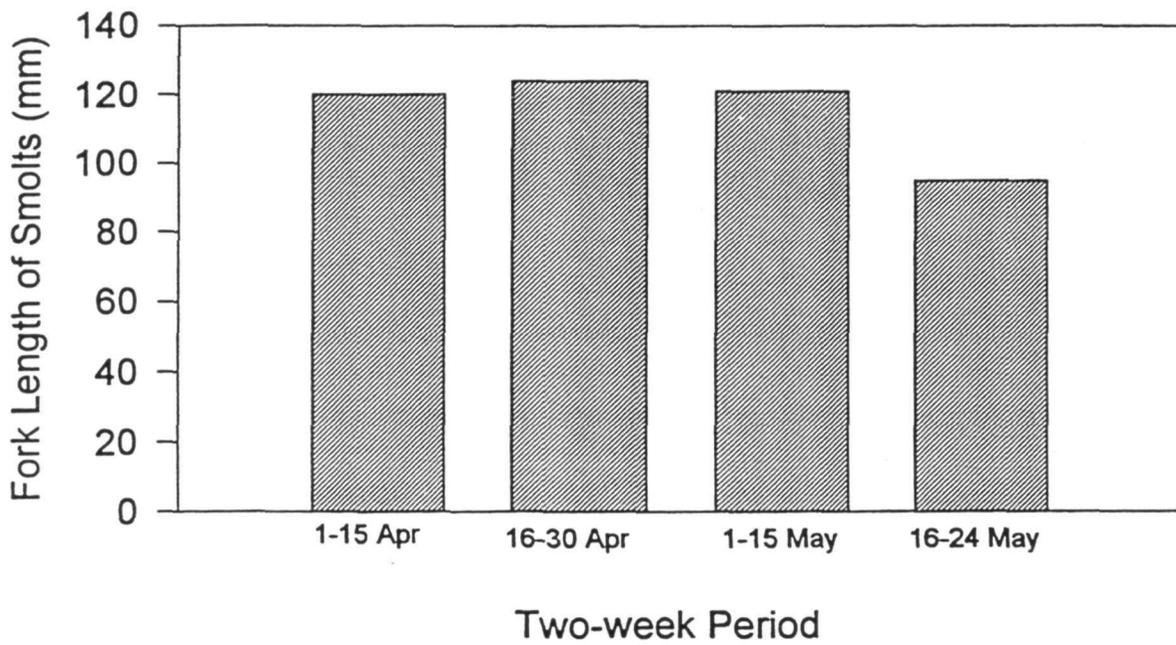


Figure 8. Mean length of Lake Ozette sockeye salmon smolts by two-week intervals. Sampling conducted in 1989 (adapted from Makah Fish. Manage. 1990b).

Genetics

The sockeye salmon returning to Lake Ozette have four possible origins: native Ozette Lake, Baker River, Quinault Lake, a hybridization of these, or a hybridization of Lake Ozette kokanee and sockeye salmon. A total of 449,000 sockeye salmon from Baker Lake (Birdsview Station) for the 1936 brood year were planted into Lake Ozette in three separate releases of fingerlings (250,000 in April, 1937; 175,000 in July, 1937; and 24,000 in November, 1937) (Kemmerich 1945, US Fish & Wildl. Serv., unpubl data provided to R. Gustafson, Natl. Marine Fish. Serv., Seattle). Quinault Lake sockeye salmon fry also may have been stocked prior to 1945, but records of number of fish are not available (Kemmerich 1945). Quinault Lake sockeye salmon fry (120,000) from the 1982 brood year also were stocked into the lake in 1983 after being reared at the Umbrella Creek Hatchery. Adult male sockeye salmon from the 1990 and 1991 brood years were crossed with adult female kokanee at Umbrella Creek and released into the lake.

In general, genetic characteristics of Lake Ozette sockeye salmon remain poorly studied, with the principal information currently available in the form of unpublished data from an analysis of a pooled sample of 34 sockeye salmon smolts captured in the Ozette River in 1990 and 1991 (G. Winans, Natl. Marine Fish. Serv., pers. comm., Oct. 1995). Genetic characteristics of a pooled sample of 21 kokanee collected in Lake Ozette in 1991 also have been analyzed. Genetic research on this and other populations of sockeye salmon is continuing, and any generalizations provided here should be viewed as very tentative. The hatchery-induced mixed pedigree of Lake Ozette sockeye salmon and kokanee populations has slight potential to complicate interpretation of the current genetic status of these populations, although survival of these hybrids was probably extremely low based on data collected elsewhere by Foote et al.

(1992). Compared to sockeye salmon and kokanee populations sampled from 20 other localities in the Pacific Northwest, tentative indications are that the population of Lake Ozette sockeye exhibits higher than average heterozygosity (0.036). Compared to sockeye salmon only sampled at six of these geographic locations, the Lake Ozette population shows only a weak genetic affinity to populations in the Puget Sound Basin (Lake Washington and Baker Lake). In general, no clear geographic pattern to the sockeye salmon differentiation is evident over the locations represented in the analysis. The sympatric population of sockeye salmon and kokanee in Lake Ozette shows statistically significant differences in allele frequencies at several protein loci, which indicates genetic differences between the two life-history forms. Additional collections of sockeye salmon and kokanee have taken place in the Ozette Basin, and analysis of these data should assist in describing genetic characteristics and affinities of these populations.

Disease

Mature adult sockeye salmon from Lake Ozette have periodically tested at or near 100% infection by the infectious hematopoietic necrosis virus (IHN) when sampled on the spawning grounds (Makah Fish. Manage 1990a, Table 8). Kokanee salmon in the Lake Ozette Basin seem to have a lower incidence of IHN infection than sockeye. For example, a total of 185 kokanee collected from Siwash Creek in November and December between 1988 and 1990 were surveyed and screened for a suite of pathogens—IHN, infectious pancreatic necrosis virus, and viral hemorrhagic septicemia virus all three years and *Renibacterium salmoninarum*, *Aeromonas salmonicida*, and *Yersinia ruckeri* I, II in 1990 only. Screening was conducted by the Tribal Fish Health Center of the Northwest Indian Fisheries Commission. The only positive test result was for *R. salmoninarum* in the 1989 brood stock (Northwest Indian Fisheries Commission 1988, 1989, 1990).

Table 8. Infectious hematopoietic necrosis virus (IHN) in Ozette Lake sockeye salmon (Makah Fish. Manage., unpubl. data).

Brood year	Test results	Sample pools	No fish tested	Lab ¹	Comments
1995	None detected	12	47	NWIFC	
1994	None detected	6	40	NWIFC	
1993	None detected	5	23	NWIFC	
1992	Positive	11	41	NWIFC	All pools positive; entire lot destroyed
1991	None detected	4	16	NWIFC	Lake Ozette; no males
	None detected	1	6	NWIFC	Umbrella Creek
1990	None detected	6	6	NWIFC	1 sample frozen
	Positive	Ovarian & milt	6	NWIFC	Spawning-ground milt sample positive
1989					No broodstock acquired
1988	Positive	12	57	NWIFC	No males tested
	None detected	12	60	NWIFC	Fry retested in June
1987	Positive	16	66	USFWS	15 of 6 pools positive
1980	None detected	99	unknown	USFWS	
1979	None detected	19	unknown	USFWS	

¹Northwest Indian Fisheries Commission or US Fish and Wildlife Service.

Fish Communities of the Lake Ozette Basin

Ozette River and Lake Tributaries

Species composition of fish communities in streams flowing in the Ozette Basin vary locally depending on habitat characteristics, although the community composition of most streams has not been thoroughly inventoried (Table 9). Tributaries are used for spawning by coho salmon, steelhead, rainbow and cutthroat trout, kokanee, and possibly chum salmon and chinook salmon. Squawfish are notably abundant in the Ozette River. Many of the salmonid species have experienced declines sufficient to warrant concern about the possibility of extinction (Nehlsen et al. 1991). Current estimates of abundance of many of the fish populations in the Ozette River and tributaries of Ozette Lake are unavailable, but some historical data are available (Table 1). For coho salmon, harvest records from the late 1950s indicated that adults returned to the Ozette River in September and continued to move through the system through the

Table 9. Fish captured by electrofishing in four reaches of Big River, July 26, 1994 and Siwash Creek, July 25, 1994.

	Reach	Species ¹	Number Captured	Mean Fork Length (mm)	Effort ²	
Big River	1	sculpin	25	--	30 m	
		2	sculpin	94		--
	coho salmon	4	69			
	rainbow trout/ steelhead	18	75			
	trout fry	9	--			
	3	sculpin	62	--	20 m	
	coho salmon	1	80			
	rainbow trout/ steelhead	12	67			
	trout fry	4	--			
	4	sculpin	54	--	40 m	
		coho salmon	2	66		
		rainbow trout/ steelhead	6	67		
	Siwash Creek	1	sculpin	62	--	90 m
			cutthroat trout	4	111	
			coho salmon	1	72	
lamprey			2	--		
2		sculpin	68	--	150 m	
		cutthroat trout	6	83		
		coho salmon	1	--		
		lamprey	1	--		
		trout fry	1	--		
3		sculpin	124	--	50 m	
		cutthroat trout	22	67		
		coho salmon	1	67		
		trout fry	8	--		
4		cutthroat trout	2	90	20 m	
		trout fry	1	--		

¹Sculpin (*Cottus*), coho salmon (*Oncorhynchus kisutch*), rainbow trout/steelhead (*Oncorhynchus mykiss*), lamprey (*Lampetra*), cutthroat trout (*Oncorhynchus clarki*).

²One-pass electrofishing without block-nets was conducted, and effort for each site was measured in terms of approximate distance shocked.

first week in December, with a peak of the run in mid-October (Ozette River Salmon Catches, Indian Personal Use and Commercial, April 28, 1958, Makah Files, Neah Bay). Peak historical catches in the Ozette River were on the order of 2,000 to 3,000 adults. Washington Department of Fisheries and Wildlife et al. (1994) reported that coho salmon historically entered the Ozette River from mid-October through January. Spawning-ground surveys by Washington Department of Fisheries and Wildlife documented peak spawning from late November through early February. The agency conducted extensive fish surveys of the lake's tributaries in 1980 and observed coho redds in the majority of the tributaries. For winter steelhead, spawning-ground surveys have not been conducted consistently in the Ozette drainage, but spawning adults are known to be present from January through June (Makah Fish. Manage., unpubl. data). Substantial numbers of winter steelhead appear to use the main-stem Ozette River for spawning, based on observations of redds by Meyer and Brenkman (1995) in June and by Makah fisheries staff (N. Currence, pers. comm., Aug. 1995). The period of spawning of cutthroat trout is not documented but probably occurs in late winter.

Kokanee appear to be abundant in several tributaries to the lake, but systematic surveys to document abundance are lacking. Dlugokenski et al. (1981) conducted kokanee surveys in 1977, 1978, and 1979. Although not systematically repeated, the surveys revealed substantial numbers of spawning kokanee in Crooked, Elk, Siwash, and South creeks. Peak counts occurred in late November and early December, when up to 240 adults were observed in a 1-km section of Elk Creek and another 220 adults were observed in a 1.6-km section of Siwash Creek. No adult sockeye were found in tributaries during extensive walking stream surveys from October through December 1989, but kokanee were observed spawning in several tributaries during November and December (Makah Fish. Manage. 1990a). Beauchamp et al. (1995) cited

a figure of 5,000-10,000 tributary-spawning kokanee in the Lake Ozette Basin, but surveys by the Makah are not sufficient to refine or confirm this estimate. Meyer and Brenkman (1995) conducted a survey of spawning kokanee in Siwash Creek on December 7, 1994 and observed about 400 spawning adults over a distance of 0.8 km. They observed kokanee redds throughout the lower portions of Siwash Creek in 1993 and 1994 in small pea gravel, and while conducting water-quality monitoring, observed kokanee in Umbrella Creek.

Chum salmon rarely are observed in the lake's tributaries, and an occasional chum salmon is captured in the lake (Meyer and Brenkman 1995). These lake-inhabiting chum salmon could be strays, or possibly adults continue to use the main-stem Ozette River for spawning, as they did historically. Chinook salmon are thought to be completely extirpated from the Ozette Basin. The lower mainstem of the Ozette River is inaccessible from late fall through winter for fish surveys because of high stream flows and is difficult to survey from the bank due to size and depth of the river, dense riparian vegetation, and absence of a trail along the river. Consequently, little effort has been made to determine if chinook and chum salmon continue to use the Ozette River.

Ozette Lake

The fish community of Lake Ozette is comprised of 13 species (Table 10). Several of these fish species overlap in distribution with sockeye salmon (Figure 9), and interspecific interactions with some of these species could suppress the abundance of sockeye salmon. Kokanee are the most studied of these species because of their high potential for dietary overlap with juvenile sockeye salmon in offshore lake habitats. Interspecific interactions could occur in nearshore habitats, but are more likely in offshore habitats where juvenile sockeye salmon and kokanee tend to reside. Although the nearshore zone of the lake is used by

Table 10. Species of fish inhabiting Lake Ozette, Washington.

coho salmon	<i>Oncorhynchus kitsutch</i>	native
kokanee salmon	<i>Oncorhynchus nerka kennerlyi</i>	native
sockeye salmon	<i>Oncorhynchus nerka</i>	native
cutthroat trout	<i>Oncorhynchus clarki</i>	native
rainbow trout and steelhead	<i>Oncorhynchus mykiss</i>	native
Olympic mudminnow	<i>Novumbra hubbsi</i>	native?
reduceside shiner	<i>Richardsonius balteatus</i>	native
northern squawfish	<i>Ptychocheilus oregonensis</i>	native?
peamouth	<i>Mylocheilus caurinus</i>	native
threespine stickleback	<i>Gasterosteus aculeatus</i>	native
largemouth bass	<i>Micropterus salmoides</i>	introduced
yellow perch	<i>Perca flavescens</i>	introduced
prickly sculpin	<i>Cottus asper</i>	native

sockeye salmon during several critical life stages -- fall and winter spawning and incubation, springtime fry migration from nearshore to offshore habitats, and the springtime migration of smolts from the lake to the ocean (Dlugokenski et al. 1981, Beauchamp et al. 1995), there is no evidence that the two major known predators on sockeye salmon juveniles (northern squawfish and cutthroat trout) consume large numbers of juvenile sockeye salmon or kokanee during the periods of nearshore residence (Beauchamp et al. 1995). There is some evidence of consumption of sockeye salmon eggs in nearshore habitats by some species (Dlugokenski et al. 1981).

The offshore zone of Lake Ozette is heavily used by juvenile sockeye salmon (juveniles up to age-1), where they mix extensively with kokanee up to the age of 3 or 4 years and several other fish species. Based on hydroacoustic assessments conducted between spring 1979 and autumn 1982, total fish abundance in offshore habitats of Lake Ozette appears to be about 439,000 fish (Table 11). Based on gill-net surveys conducted in April 1991, over 90 percent of these fish larger than 100 mm are kokanee and sockeye salmon juveniles. Representatives of the fish

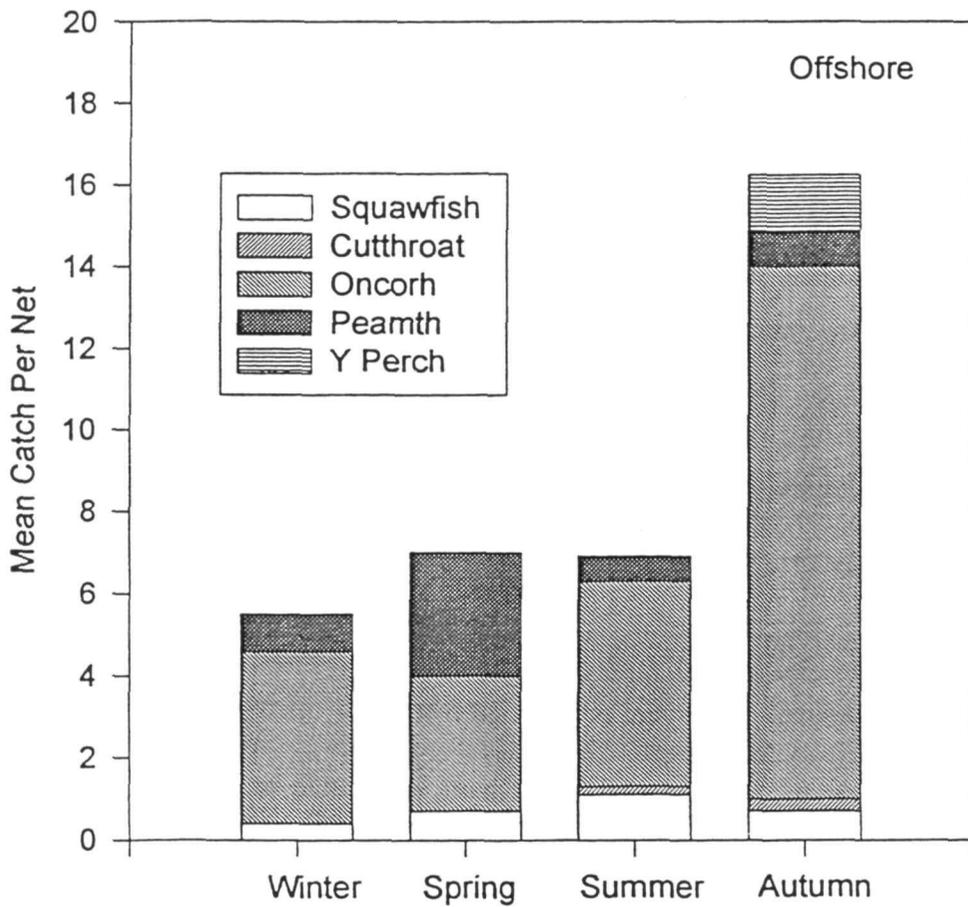
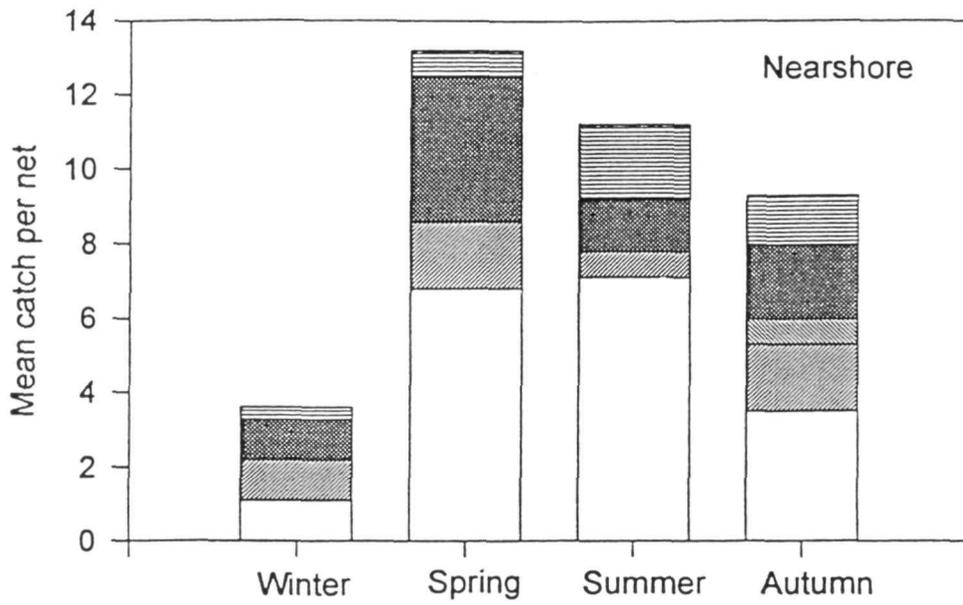


Figure 9. Seasonal distribution of mean catches of the major fishes captured with gill net in nearshore areas and fish captured in vertical gill nets fished in offshore areas of Lake Ozette, from 1990-1991 (from Beauchamp et al. 1995). Abbreviations are Oncorh (*Oncorhynchus spp*), Peamth (peamouth) and perch (yellow perch).

Table 11. Abundance estimates of offshore fishes and 95% confidence intervals (CI) from eight hydroacoustic surveys in Lake Ozette, 1979-1982 (from Beauchamp et al. 1995). Maximum and minimum temperatures were recorded with Ryan TempMentors. Other temperature data were collected with a Hydrolab Datasonde 3 multiparameter water-quality probe.

Month and year	Abundance (95% of CI)
Mar 1979	542,000 (532,000-552,000)
Jul 1979	550,000 (512,000-582,000)
Apr 1980	431,000 (398,000-464,000)
Jul 1980	451,000 (379,000-523,000)
Apr 1981	347,000 (280,000-414,000)
Sep 1981	413,000 (363,000-463,000)
Apr 1982	395,000 (342,000-448,000)
Aug 1982	381,000 (338,000-424,000)

community smaller than 100 mm remain unsurveyed. During summer after the age-1 sockeye salmon have departed, kokanee greater than 100 mm represent over 50 percent of the offshore community (Beauchamp et al. 1995). The major potential predators on juvenile sockeye salmon during their offshore residency in Lake Ozette are cutthroat trout and squawfish. Abundance estimates for these piscivores are lacking, but based on model simulations by Beauchamp et al. (1995), there is some evidence that these species could exert considerable control over the abundance of sockeye salmon in the lake.

Cutthroat Trout (Oncorhynchus clarki)

Both nonmigratory and anadromous forms of cutthroat trout occur in many coastal lakes of Washington (Wydoski and Whitney 1979), and both forms probably occur in the Lake Ozette Basin (N. Currence, Makah Fish. Manage., pers. comm. Apr. 1996). Cutthroat trout are opportunistic in their feeding habitats and are known to consume insects, fish, crayfish, terrestrial arthropods, salamanders, and salmonid and sculpin eggs (Wydoski and Whitney 1979). This species is potentially an important predator on sockeye salmon in Lake Ozette (Beauchamp et al. 1995). The only available estimate of abundance of cutthroat trout in the lake is speculation by

Beauchamp et al. (1995) that 5,000-10,000 large (≥ 300 -mm fork length) cutthroat trout might reside in Lake Ozette. Cutthroat trout captured in both nearshore and offshore habitats consume kokanee and juvenile sockeye salmon, with 40 percent of the spring and summer diet of large cutthroat trout in offshore habitats of Lake Ozette consisting of age-0 and age-1 sockeye salmon and kokanee (Beauchamp et al. 1995). For every 1,000 cutthroat trout 300 mm and longer, an estimated 138,900 age-0 kokanee and sockeye salmon combined and 27,700 age-1 kokanee are consumed by age 4-7 cutthroat trout from spring through autumn (Beauchamp et al. 1993). Cutthroat trout also are known to prey on eggs of sockeye salmon in Lake Ozette (Dlugokenski et al. 1981). Abundance of the population of cutthroat trout in Lake Ozette remains unstudied.

Rainbow Trout and Steelhead (Oncorhynchus mykiss)

A wild winter run of steelhead is seasonally present in Lake Ozette. Based on general patterns for this species on the Olympic Peninsula, adult steelhead move through the lake, probably from December through May on their return from ocean habitat to tributary habitat for spawning. Timing of spawning is not documented, but probably occurs between mid-February and early June (Washington Dept. Fish & Wildl. & W. Wash. Treaty Indian Tribes 1994). Juvenile steelhead migrate from natal streams to the ocean in late spring and early summer. Two years of stream rearing is common for steelhead in the region of Lake Ozette. Some resident rainbow trout may stray into the lake from tributary habitat, but the lake is not ideal habitat for this primarily stream-resident fish. Both rainbow trout and juvenile steelhead feed primarily on foods associated with the bottom of aquatic habitats, although occasionally they eat small fish (Wydoski and Whitney 1979). Neither life-history form of this species is currently regarded as a major competitor or predator of sockeye salmon in Lake Ozette. Preliminary genetic evidence in the form of microsatellite DNA indicates that the Lake Ozette Basin may be an area of natural

hybridization between the race of steelhead found on the Washington coast containing 58 chromosomes and the race in the Puget Sound area containing 60 chromosomes (unpubl. data, C. Ostberg, Washington State University). Thus the Lake Ozette Basin may be a natural transition area between the two chromosome races of this species.

Coho Salmon (Oncorhynchus kisutch)

This anadromous Pacific salmon spawns in the tributaries of Lake Ozette. Individuals pass through the lake as returning adults and as emigrating juveniles in the spring. Population abundance is unknown, although river-entry timing recently has been observed from mid-October through January (Washington Dept. Fish & Wildl. & W. Wash. Treaty Indian Tribes 1994). Kemmerich (1945) observed migration from the river into the lake between late September and mid October in 1924. Operation of a juvenile trap to capture sockeye and coho salmon smolts in 1992 in the Ozette River yielded a peak catch of emigrating coho salmon smolts in early May. The estimated number of smolts for that year was 2,562 (95% CI 1,317-3,807) using standard mark-recapture and trap-efficiency calculations or 2,913 (95% CI 1,736-5,372) using a bootstrap estimation method (unpubl report from B. Conrad, NW Indian Fish. Com. to D. Drange, Makah Fish. Manage. dated 1993). The extent to which juvenile coho salmon use the lake as rearing habitat remains unstudied; however juvenile coho salmon feed primarily on zooplankton and emerging insects in lake and reservoir habitats (Wydoski and Whitney 1979). Thus, there is some potential for competition for food with sockeye salmon.

Kokanee (Oncorhynchus nerka)

Kokanee are the nonanadromous form of sockeye salmon. Kokanee have a life history similar to sockeye salmon, except adult kokanee stay in fresh water and feed on zooplankton and aquatic insect larvae instead of migrating to the ocean for rearing. Historical abundance of

kokanee is unknown for Lake Ozette, but a plant of kokanee into the lake by the Washington Department of Game in 1958 resulted in these fish appearing in the sport fishery (Dlugokenski et al. 1981). The population size of kokanee in Lake Ozette is poorly documented, although Beauchamp et al. (1995) have very roughly estimated that about 7,500 kokanee spawn each year in the lake's tributaries. Kokanee spawn from November through January in the Lake Ozette Basin, and young-of-the-year enter the lake for rearing in spring, where they mix extensively with juvenile sockeye salmon. There are several lines of evidence to indicate that sockeye salmon abundance is not currently suppressed by competition for food with kokanee. Although sockeye salmon and kokanee are the predominant species in offshore habitats and both feed almost exclusively on *Daphnia pulicaria*, together they consume less than 1% of the instantaneous production and standing stock of the preferred large-bodied *Daphnia* during the growing season (Beauchamp et al. 1995). Furthermore, Lake Ozette produces exceedingly large age-1 smolts (Dlugokenski et al. 1981).

Olympic Mudminnow (Novumbra hubbsi)

The Olympic mudminnow is a small minnow, less than 7 cm long as an adult, usually found in quiet waters with a mud substrate and dense aquatic vegetation. It is commonly associated with the slow-moving brownish water of bogs and swamps. The question of nativeness of the mudminnow in Lake Ozette remains unresolved. Harris (1974) was the first to report the Olympic mudminnow in Lake Ozette, an occurrence that he thought difficult to explain from past geological and climatological data, suggesting instead that it might have been introduced. He further noted that the species has spread throughout the Ozette system, which would suggest that the assumed introduction was not in the immediate past. It would be difficult to explain the objective of any intentional introduction given the characteristics of the species. The Olympic

mudminnow does not appear to feed selectively, although oligochaete worms, crustacean zooplankton, insects, and mollusks commonly appear in its diet. This species is not regarded as a major competitor with sockeye salmon.

Redside Shiner (Richardsonius balteatus)

Little is known about redbase shiners in Lake Ozette except that they are found in the lake and are presumed to be native to the basin. As summarized in Wydoski and Whitney (1979), this species tends to move about in schools and to stay in vegetation when in shallow areas. Redside shiners have regular seasonal and daily patterns of movement in British Columbia lakes and probably elsewhere. During the day they stay in shallow water but after dark, move out over deep water. Spawning takes place in the spring and early summer over the gravel bottom of streams or in vegetation along the lake shoreline. Fry feed on zooplankton and algae, and adults feed on insects, snails, and when in pelagic areas, zooplankton. At certain times they eat fish eggs and fry, including their own young.

Although direct interactions between sockeye salmon and this species have not been documented in the Lake Ozette system, information collected elsewhere involving redbase shiners and steelhead illustrates how complicated possible interspecific competition can be. In a stream environment, Reeves et al. (1987) found that juvenile steelhead production was the same whether redbase shiners were present or absent when water temperatures were 12-15°C. When water temperatures were 10-22°C, a range that includes temperatures observed in tributaries to Lake Ozette and the lake itself, steelhead production decreased by 54% when redbase shiners were present compared to when they were absent. Hicks et al. (1991) also discussed Reeves work by saying that the steelhead were dominant in cool temperatures but the shiners were more active and

dominant in warm temperatures. They hypothesized that long-term increases in stream temperature could allow reidside shiners to displace steelhead.

Northern Squawfish (Ptychocheilus oregonensis)

Northern squawfish are apparently native to Lake Ozette, although this conclusion remains largely unstudied. In lakes, this species inhabits shallows in the summer or moves to the surface in the pelagic zone to seek warm water temperatures, whereas in winter, northern squawfish tend to inhabit deeper waters (Wydoski and Whitney 1979). Spawning habitat is the gravel areas of streams and gravel beach areas in lakes. Small squawfish feed primarily on insects, but as the fish get larger they become piscivorous. This species is known to prey on kokanee and juvenile sockeye salmon in Lake Ozette (Beauchamp et al 1995), and if sufficiently abundant, could be judged to be a very significant predator. The only available estimate of abundance is speculation by Beauchamp et al. (1995) that 5,000-15,000 large (≥ 300 -mm fork length) squawfish might reside in Lake Ozette. This species is commonly caught by recreational anglers, which would indicate that it is fairly abundant in the lake. Squawfish occur in nearshore and offshore zones of Lake Ozette, but those individuals nearshore do not appear to consume salmonid prey (Beauchamp et al. 1995, Dlugokenski et al. 1981), whereas large squawfish offshore consume both kokanee and juvenile sockeye salmon (Beauchamp et al. 1995). For every 1,000 squawfish (≥ 300 -mm fork length), an estimated 5,600 age-0 kokanee and sockeye salmon and 1,000 age-1 kokanee could be eaten (Beauchamp et al. 1995). The per-capita rate of predation by northern squawfish seems to be considerably lower than the predation rate estimated for cutthroat trout because only a small fraction (2-29%, depending on the season) of the squawfish population occupies the offshore zone where these prey are available (Beauchamp et al. 1995).

Peamouth (Mylocheilus caurinus)

Peamouth is a chub associated with lake and river systems in the Pacific Northwest. The species often is associated with the lake or river bottom but will feed in pelagic habitats. Young peamouth feed on zooplankton, and older fish feed on plankton, aquatic and terrestrial insects, snails, and sometimes small fish (Wydoski and Whitney 1979). The species exhibits diel vertical migrations in some systems (Northcote et al. 1964). In Lake Ozette, this species has little overlap with kokanee and sockeye salmon juveniles in nearshore habitats and is much less abundant than kokanee and sockeye salmon juveniles in offshore habitats (Dlugokenski et al. 1981, Beauchamp et al. 1995). Based on gill-net captures, small peamouth occur in Lake Ozette offshore areas at depths of 1-40 m, whereas large individuals tend to occur in nearshore areas. Benthic prey dominates the diet of peamouth throughout the year in Lake Ozette (Beauchamp and LaRiviere 1993). They eat some sockeye salmon eggs, but to what extent is unknown.

Threespine Stickleback (Gasterosteus aculeatus)

Threespine stickleback is a ubiquitous fish species usually associated in freshwater habitats with lake bottoms and aquatic vegetation. Its diet largely consists of zooplankton and aquatic insect larvae. Coastal cutthroat trout feed to a large extent on sticklebacks (Wydoski and Whitney 1979, Beauchamp et al. 1995). Populations of threespine stickleback often have large overlap in distribution and diet with sockeye salmon in offshore habitats (O'Neill and Hyatt 1987). At high population densities, reduced growth of both juvenile sockeye salmon and threespine stickleback may occur, but at low densities there appears to be little competition (Burgner 1987). The degree of habitat and dietary overlap between threespine stickleback and juvenile sockeye salmon has not been studied extensively in Lake Ozette, although Beauchamp and LaRiviere (1993) suspected that the stickleback population in Lake Ozette is low in abundance and that this species has little

spatio-temporal overlap with sockeye salmon juveniles. Their speculation was based on the failure to capture sticklebacks in minnow traps set in offshore habitats and the absence of sticklebacks in the stomachs of Lake Ozette cutthroat trout.

Largemouth Bass (Micropterus salmoides)

Largemouth bass have been introduced to Lake Ozette. Very little is known about their population size and distribution, and thus potential for predation on sockeye salmon remains poorly studied. Six largemouth bass (230-400 mm fork length) caught by Beauchamp and LaRiviere (1993) exclusively contained fish in their stomach, with juvenile yellow perch and sculpin identifiable.

Yellow Perch (Perca flavescens)

Yellow perch have been introduced in Lake Ozette and have become a fairly abundant species (Dlugokenski et al. 1981). In lakes in general, adult perch live near the bottom. Fingerling perch usually occupy shallow water, but move offshore as they mature. Spawning takes place near shore and adult perch may linger in shallow water for awhile after spawning. Young perch feed on zooplankton, whereas large perch are piscivorous (Wydoski and Whitney 1979). The distribution and diet of larval perch in Lake Ozette remains undocumented, although Dlugokenski et al. (1981) observed that perch smaller than 119 mm fork length (age 2) fed primarily on zooplankton. Young perch (<200 mm fork length) have been captured in offshore vertical gill nets in spring and winter months, whereas older perch (>150 mm fork length) have been captured exclusively in nearshore areas (Beauchamp and LaRiviere 1993). As perch mature in Lake Ozette they shift from zooplankton to a diet of insects and other benthic invertebrates, and as adults, they eat invertebrates and fish, including yellow perch (Beauchamp and LaRiviere 1993, Dlugokenski et al. 1981).

Prickly Sculpin (Cottus asper)

The prickly sculpin is a small fish species that typically inhabits the pools and quiet water of large coastal streams and shores of lakes. The young are pelagic for about a month and feed on plankton and aquatic insect larvae. Adults tend to feed on benthic organisms, but will feed on fish eggs and small fish when they are available. It can be a very abundant fish in lakes of western Washington (Wydoski and Whitney 1979). The distribution and abundance of prickly sculpin has not been assessed in Lake Ozette. It is known to be an important prey of cutthroat trout and northern squawfish in the lake based on examination of stomach contents of these two species (Beauchamp and LaRiviere 1993). Prickly sculpin prey on eggs of sockeye salmon in Lake Ozette (Dlugokenski et al. 1981), but to what extent remains unknown. The sculpin probably has minimal spatio-temporal overlap with juvenile sockeye salmon (Beauchamp et al. 1995).

Habitat Characteristics

Fish habitat in the Lake Ozette Basin has changed through time both through natural succession and through human activities. Defining the cumulative effects of these changes on sockeye salmon in the basin, especially coupled with other changes such as introduced species of fish, is extremely difficult. Nonetheless, there are indications that some life-history stages of sockeye salmon may be jeopardized by basin conditions that have resulted from local land uses, particularly logging and road development in support of logging.

Land Uses

The dominant land use in the Ozette Basin is timber production. The majority of land ownership in the basin is private (about 67%), and most of this private land is managed for timber production. Olympic National Park accounts for roughly 23% of the basin lands (including the lake itself), and another 10% is in State of Washington ownership, the latter also managed

primarily for timber production. The ownership figures presented here are based on data provided by the US Environmental Protection Agency to Olympic National Park (R. Hoffman, Olympic Natl. Pk, pers. comm., Jan. 1995). Tourism and some residential developments on the northeastern shore of the lake also are present, but these two uses combined are much less dominant in the basin in comparison to industrial forestry. Green Crow, MRGC, Cavanham Forest Industries (transfer underway to Crown Pacific), and Rayonier are the major owners of the industrial forest lands in the basin. Land west of the lake, the lakeshore around the lake, and the lake itself are under the stewardship of Olympic National Park. Ozette Reservation lands in the vicinity of Lake Ozette consist of 291 ha under the stewardship of the Makah. All forests on the reservation are in old-growth condition.

As summarized in Colson (1953), Native Americans have a long history of occupation of the area surrounding Lake Ozette. The Makah first appear in recorded history at the end of the eighteenth century when they were already settled in a territory extending some 24 km on either side of Cape Flattery, southward along the Pacific Coast and eastward along the coast of the Strait of Juan de Fuca. Even at this time they were presumed to have been long established in this area. The Makah lived in five winter villages, each an independent entity. In summer the people from these villages moved to three summer villages near the Cape and its offshore halibut fisheries. In fall they camped in small groups along the rivers running into the Pacific Ocean and the strait to exploit salmon fisheries. Most of the subsistence of the Makah came from the sea, where they fished for salmon, halibut, other fish and shellfish, and hunted for whale and seal. Early contacts between the Makah and Euro-Americans began in the late 1780s. In 1855, the Makah by treaty ceded the territory that they claimed to control and received in return a small reservation occupying a portion of the original area claimed. The majority of the Makah currently reside on a

portion of this reservation about 25 km north of Lake Ozette at the community of Neah Bay. A neighboring reservation of the Quileute Tribe is located about 15 km south of Lake Ozette at the mouth of the Quillayute River.

European settlement of the Lake Ozette Basin began during the mid 1800s, and by 1892, 33 Euro-American families occupied the area. Evans (1983) reported that these settlers grew crops, raised livestock, and seasonally logged their lands. Historic records indicate that logging activities on the Olympic Peninsula in general began in the late nineteenth century and accelerated in magnitude by the early twentieth century (Fish 1983). Because of its remoteness, intensive logging of the Ozette watershed lagged behind logging of many other areas of the Olympic Peninsula. In 1926, a road was extended from Clallam Bay, on the south shore of the Strait of Juan de Fuca, to the eastern shore of Lake Ozette, and active logging of the Ozette watershed began a short time later in the 1930s (Bortleson and Dion 1979). About 25 percent of the watershed was clear-cut logged between 1940 and 1973 (Bortleson and Dion 1979), and an additional 60 percent of the watershed was clearcut logged by about 1984 (Blum 1988). In 1940, the unlogged area west of the lake was added to Olympic National Park. The lake itself and a narrow strip of land along the east shore were added to the park several decades later.

Extensive road development accompanied logging in the Lake Ozette Basin. Traditionally the material for road beds was derived locally and consisted of very erodible material with high levels of fine sediments. The watersheds of Big River and Umbrella Creek, two major tributaries of Lake Ozette, for example, had an average density of logging roads in the late 1980s of 2.6 km/km² and 2.2 km/km² (Blum 1988). These figures correspond well with recent estimates, which incorporate road data from aerial photographs taken in 1991 and indicate a road density of about 2.2 km/km² for the Ozette Basin (McHenry et al. 1994). The presence of roads coupled

with clear-cut logging practices has resulted in high levels of fine sediments (see page 59) and some mass wasting in areas of the watershed. McHenry et al (1994) developed a watershed disturbance index for the Ozette watershed and four other watersheds on the Olympic Peninsula. The index integrates information on road density, the percentage of vegetation present in age classes less than 40 years old, and the presence of mass wasting. The average rating for locations in the Lake Ozette Basin placed this system in a category of high impact.

Over sixty thousand visitors to Olympic National Park annually travel to Lake Ozette, with most of the use concentrated in the vicinity of the lake and along trails between the lake and the Pacific coast. Visitor facilities are limited to a small campground, a boat launch, restrooms, and an information kiosk, all located at the northeast end of the lake. Two boardwalk trails lead to the ocean beach from the northeast end of the lake, and camping is allowed at several dispersed sites along the ocean shore. Boat traffic on the lake is not restricted, and fishing pressure is light. The National Park Service has limited residence facilities for park staff and maintains a visitor check-in station with park staff present at the northeast end of the lake.

Ozette River

The 7.6-km-long Ozette River is a low-gradient stream (Figure 10) free of major impediments such as slides and waterfalls as it flows from Lake Ozette to the Pacific Ocean. Total elevation change is about 9 m over the river's length. Large woody-debris jams are extremely numerous on the river, although major jams capable of impeding fish passage are considered to be nonexistent (Dlugokenski et al. 1981, unpubl. data collected by Washington Dept. Fish. & Wildl. as summarized in Meyer and Brenkman 1995). Large debris dams were partially opened historically (Bortleson and Dion 1979), but this practice no longer occurs.

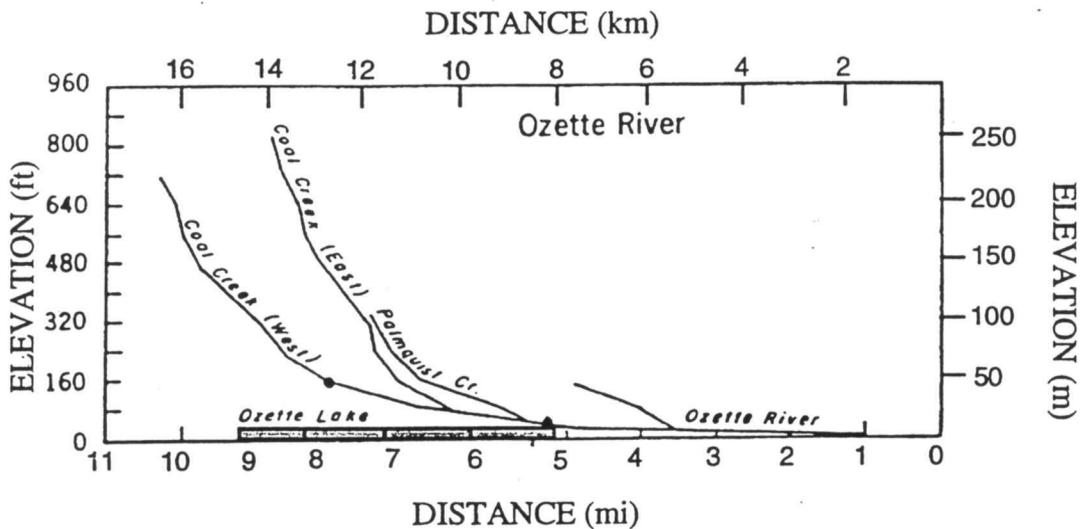


Figure 10. Gradient and stream length of the Ozette River and its major tributaries (adapted from Bortleson and Dion 1979).

The Ozette River experiences wide fluctuations in discharge, but the changes are more gradual than those observed in tributaries to Lake Ozette because of the buffering effect of the lake. Winter flows are in the range of 10 to 28 $\text{m}^3\text{sec}^{-1}$ and summer flows tend to be less than 9 $\text{m}^3\text{sec}^{-1}$ (Bortleson and Dion 1979, Figure 11). Blum (1988) analyzed flow measurements in the Ozette River from 1976 through 1987 relative to suitability of spawning habitat for sockeye salmon. Using a preferred discharge of $4.86 \pm 2.59 \text{ m}^3\text{sec}^{-1}$ for sockeye salmon spawning calculated according to methods of Swift (1978), Blum determined that during the sockeye salmon spawning and incubation period, daily flows in the Ozette River measured from 1976 through 1987 exceeded the upper range preferred by sockeye salmon 88% of the time.

Water temperatures in the Ozette River reach lows around 7°C in winter and early spring and maximums of about 20°C during late summer and early fall (Bortleson and Dion 1979, Meyer and Brenkman 1995, Figure 12, Table 12). During the period of peak adult sockeye salmon entry into the lake (mid-June through the first week of July), maximum daily temperatures can exceed 20°C (Meyer and Brenkman 1995), a temperature several degrees higher than the

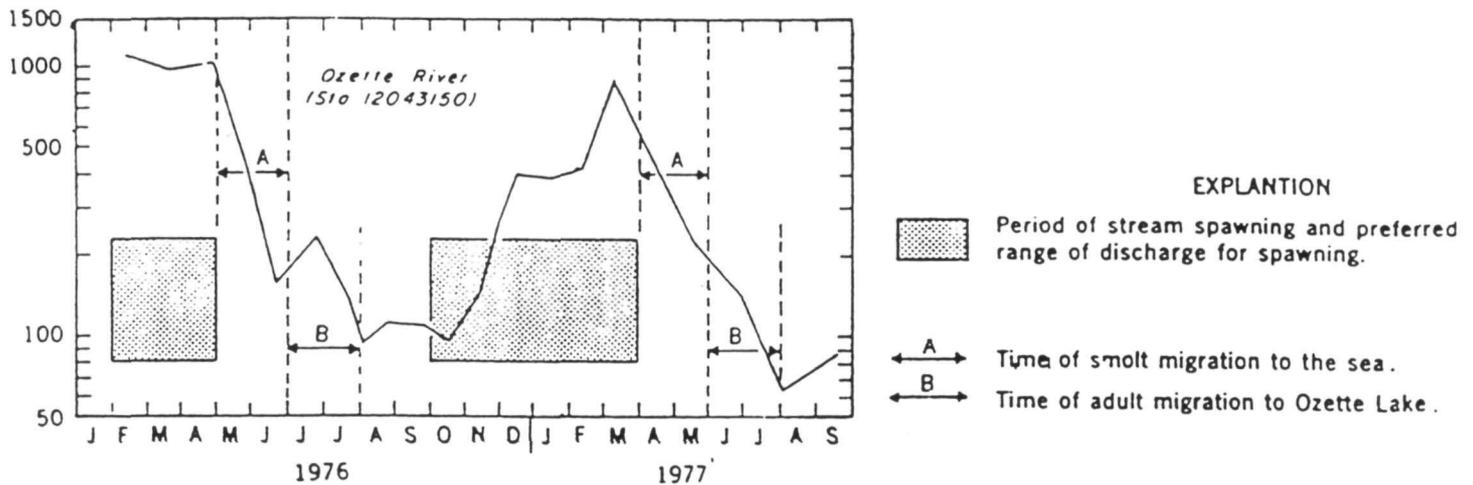


Figure 11. Discharge of the Ozette River (adapted from Bortleson and Dion 1979).

Table 12. Water temperatures measured in the Ozette River from July, 1993 through October, 1994 by Meyer and Brenkman (1995). Maximum and minimum temperatures were recorded with Ryan TempMentors. Other temperature data were collected with a Hydrolab Datasonde 3 multiparameter water-quality probe.

Date	Year	Temperature	Date	Year	Temperature
Jul. 25	1993	13	Jul. 25	1994	22 (max) 21 (min)
Aug. 17	1993	19	Aug. 17	1994	23 (max) 21 (min)
Aug. 24	1993	17	Aug. 24	1994	23 (max) 21 (min)
Sep.	1993	not available	Sep. 24	1994	20 (max) 18 (min)
Oct.	1993	not available	Oct. 19	1994	16 (max) 15 (min)
Nov. 2	1993	12	Nov. 16	1994	10
Dec. 11	1993	8	Nov. 30	1994	9
Dec. 16	1993	8			
Jan. 5	1994	8			
Feb. 2	1994	7			
Feb. 16	1994	7			
Feb. 22	1994	7			
Mar. 2	1994	8			
Mar. 30	1994	10			
Apr. 20	1994	11			
May 12	1994	15			
Jun. 15	1994	19 (max) 14 (min)			

TEMPERATURE IN DEGREES CENTIGRADE

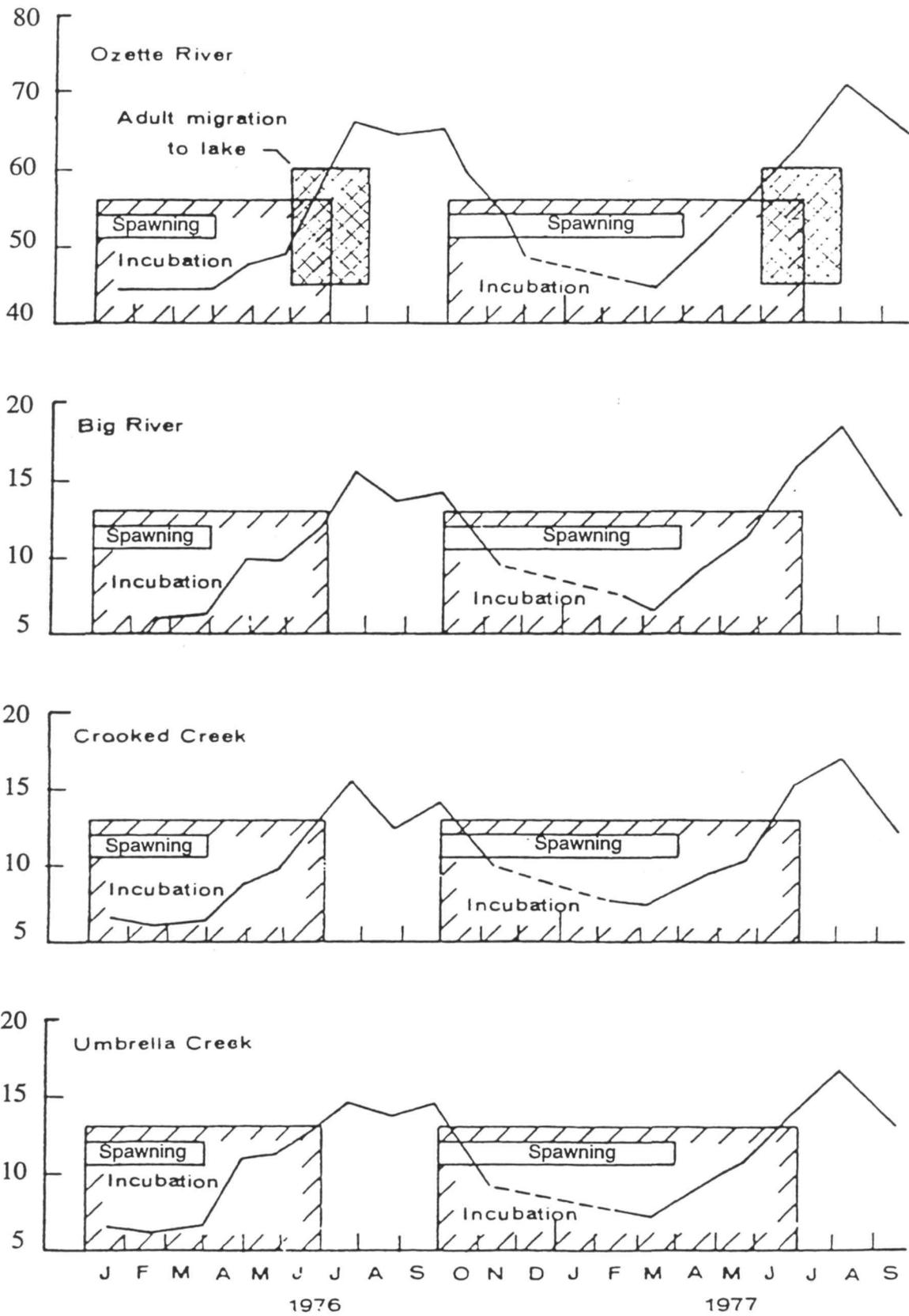


Figure 12. Water temperatures in the Ozette River and in selected tributaries of Ozette Lake (adapted from Bortleson and Dion 1979).

18°C that Brett (1971) described as generally limiting to sockeye salmon. Daily minimum water temperatures in the river begin to exceed 18°C sporadically before the end of June and regularly from July through September. Thus, adult sockeye salmon attempting to return to Lake Ozette from July and on through the run may be delayed by high water temperatures. These temperature data lend credence to LaRiviere's (1991) suspicion that 50 adult sockeye entering the lake on October 20, 1989 were delayed in the Ozette River by high temperatures.

Based on sampling in 1993 and 1994, other water-quality characteristics in the Ozette River appear to be favorable for use by sockeye salmon and other salmonid species. Concentration of dissolved oxygen ranges between 8.07 and 11.84 mg/L, pH ranges between 6.4 and 7.4, conductivity ranges between 31.3 and 43.0 $\mu\text{S}/\text{cm}$, and turbidity ranges between 0.4 and 14.2 nephelometric turbidity units (NTU) (Meyer and Brenkman 1995). This river remains clear even during storm events when other streams in the Ozette Basin are extremely turbid, although Coal Creek now contributes a sediment plume to the river during storm events (N. Currence, Makah Fish. Manage., pers. comm., Apr. 1996)

Tributary Streams

Lake Ozette is fed by numerous ephemeral and perennial streams. The total length of perennial tributaries as measured on topographic maps is about 130 km (Bortleson and Dion 1979). The three principal tributaries are Big River, Umbrella Creek, and Crooked Creek, all entering the lake's northeast shore. These three tributaries account for 58 percent of the drainage to the lake based on measures of stream length taken from topographic maps (Bortleson and Dion 1979). Falls impassable to migrating salmon are located on two of these tributaries, which restrict fish passage to as little as 45 km (35%) of stream length (Phinney and Bucknell 1975) or as much

as 110 km (85%) of stream length (Bortleson and Dion 1979). Most of the largest streams have a low-to-moderate gradient, averaging about 3 m decline in elevation per km of stream length. The tributaries and headwaters of these large streams have steep gradients, commonly 15 to 40 m decline per km, but gradients become much less steep as the streams near their confluence with the lake. The small streams that enter Lake Ozette, such as Siwash, Elk, and South creeks, have relatively steep gradients throughout most of their length (Figure 13). Although systematic surveys have not occurred to document distribution and density of woody debris in tributary streams, the qualitative assessment is that large amounts of woody debris are generally absent, and what is present is small in size. Woody debris has been salvaged from some tributaries (e.g., Big River) (N. Currence, Makah Fish. Manage., pers. comm., Dec. 1995).

As for the Ozette River, discharge of tributaries to Lake Ozette is low in summer and high in winter (Figure 14). Low summer discharge has the potential to interfere with migration of juvenile sockeye salmon into Lake Ozette for rearing, and high winter discharge has the potential to interfere with reproduction of sockeye salmon in the tributaries. Neither situation currently is an issue for sockeye salmon because a tributary-spawning component is largely absent from the Lake Ozette population (see page 17). Summer discharge was systematically measured in Big River and Umbrella Creek in 1976 and 1977 with stage recorders. With flows greater than $0.03 \text{ m}^3\text{sec}^{-1}$, these tributaries were judged to have adequate discharge for migration of juvenile sockeye salmon to Lake Ozette for rearing (Bortleson and Dion 1979). Winter discharge in 1976-77 was judged to be adequate for spawning in Big River from late November to late February. In Umbrella Creek, discharge was judged to be adequate for spawning from mid-December to mid-January and for about five weeks from mid-February to late March. This assessment was conducted during a winter when precipitation was well below normal, and adequacy was based on

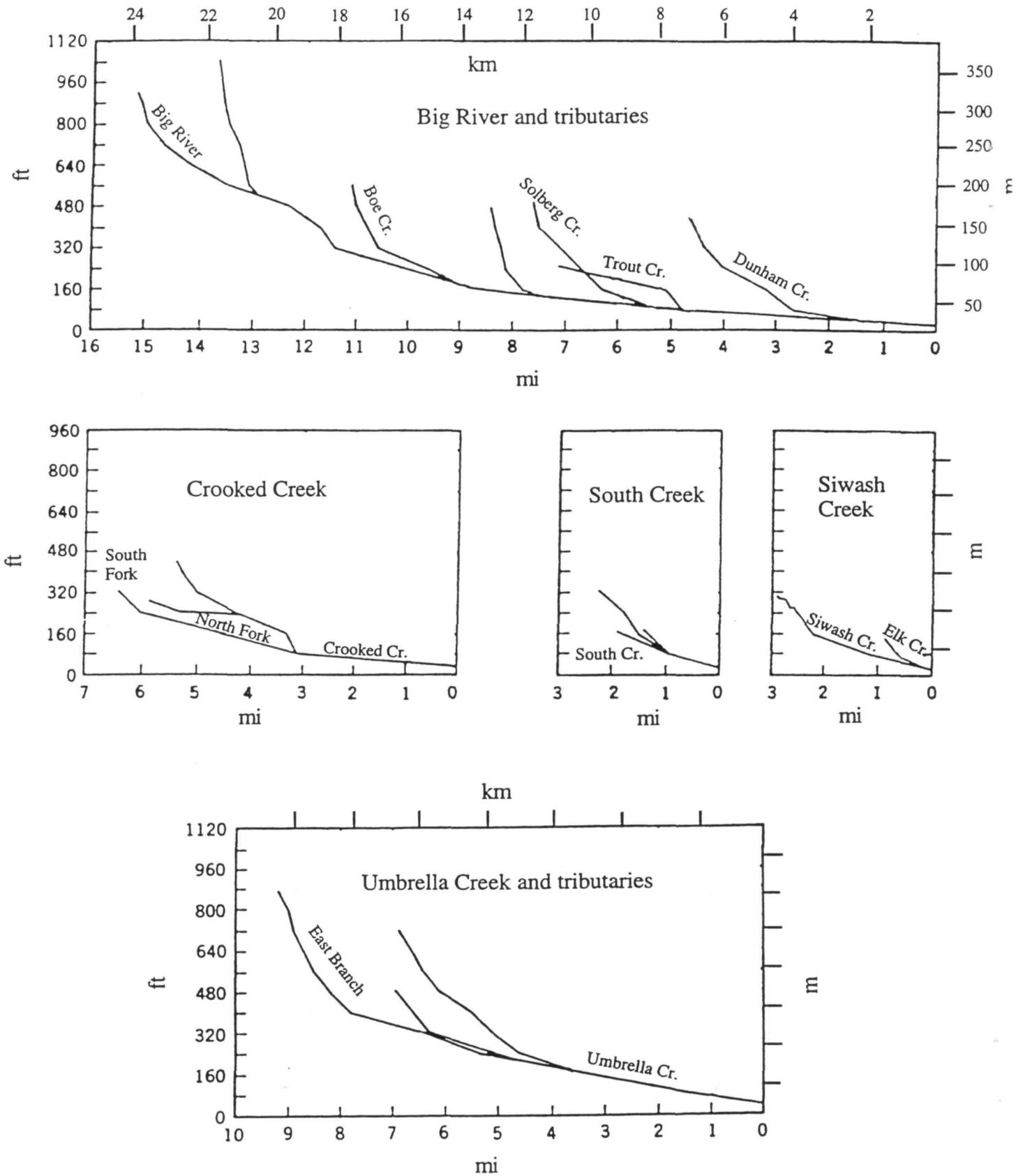


Figure 13. Gradient and stream length of several tributaries to Ozette Lake.

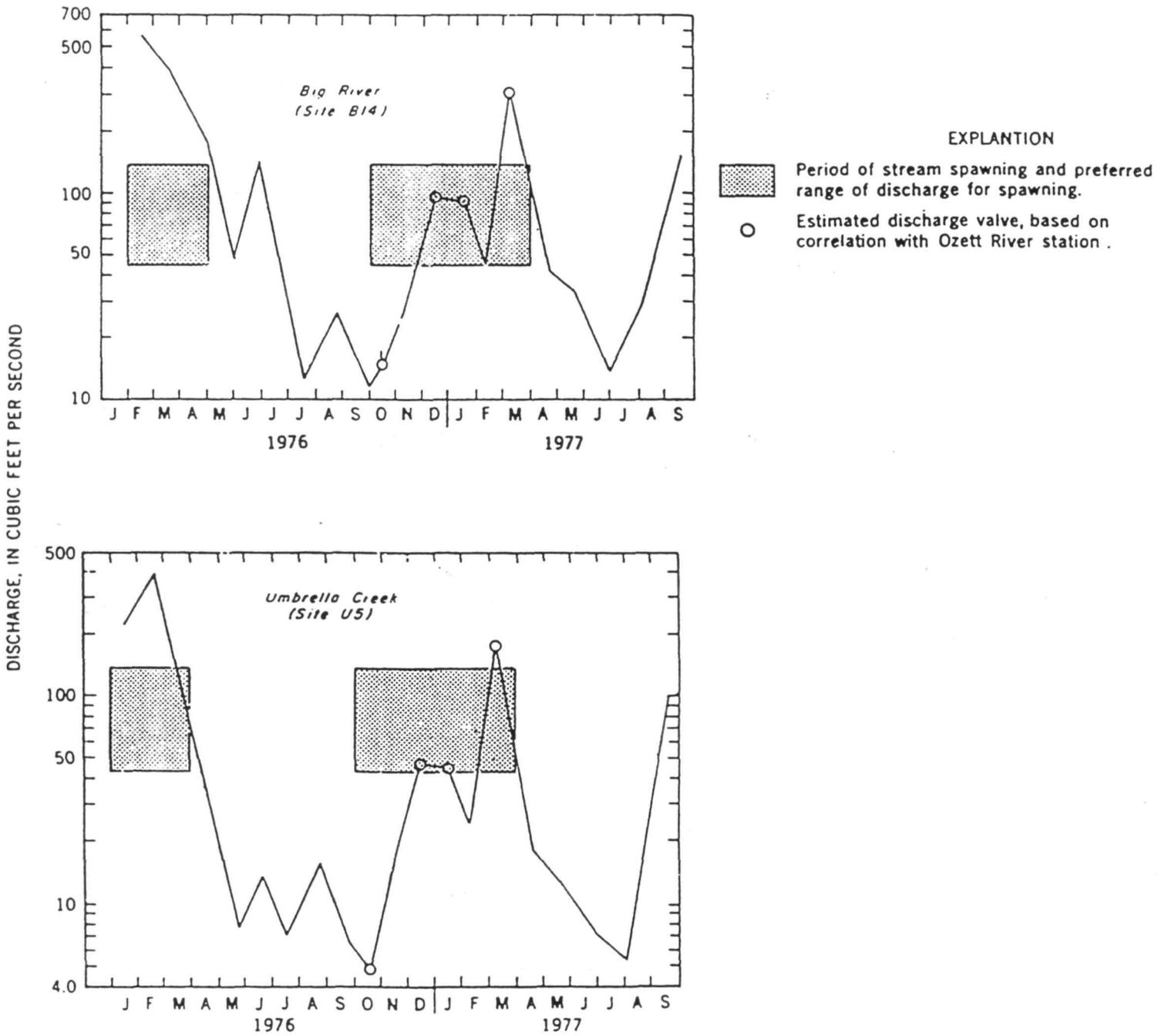


Figure 14. Discharge of Umbrella Creek and Big River (adapted from Bortleson and Dion 1979).

a comparison of preferred discharges for spawning calculated according to Swift (1978) and observed discharges.

High discharge events during winter months can destroy redds and limit availability of spawning sites, and Lake Ozette tributaries are subject to frequent and highly localized winter storms and flash floods. Blum (1988) analyzed flow measurements in Big River and Umbrella Creek from 1976 through 1987. Using preferred discharge ranges for spawning of sockeye salmon calculated according to Swift (1978) for Big River ($2.42 \text{ m}^3/\text{sec} \pm 1.17 \text{ SE}$) and Umbrella Creek ($2.27 \text{ m}^3/\text{sec} \pm 1.00 \text{ SE}$), Blum (1988) determined that from 1976 through 1987 during the sockeye spawning and incubation period, favorable flows were exceeded 78% of the time in Big River and 62% of the time in Umbrella Creek. Maximum peak discharges exceeding six times and four times the upper range of the preferred flows for incubation and spawning were recorded in Big River and Umbrella Creek, respectively (Blum 1988). Meyer and Brenkman (1995) observed rapid changes in discharge within the tributaries during 1993 and 1994 but were unable to measure the highest flows because the streams were not approachable during these events. On several occasions, tributaries overflowed their banks and spread across the forest floor.

High flows accompanying storms commonly result in high turbidity levels in Lake Ozette tributaries (Table 13). Turbidity can reach astronomical levels in Big River and Umbrella Creek as indicated by measurements on November 30, 1994 of 161 NTU and 185 NTU, respectively (Meyer and Brenkman 1995). These values are well above the level at which feeding of juvenile salmonids is impaired and gill damage occurs (Cook-Tabor 1994). No obvious problems to sockeye salmon appear evident based on measurements of dissolved oxygen, pH and conductivity in tributary streams (Table 13).

Table 13. Water-quality characteristics measured in selected tributaries of Lake Ozette on a monthly basis by Meyer and Brenkman (1995).

Characteristic and Stream	Range of values observed	
	Nov., 1993 through Mar., 1994	Apr. through Jun., 1994
Turbidity		
South Creek	3.7-6.2	3.0-6.9
Siwash Creek	4.9-22.0	0.8-2.5
Crooked Creek	2.6-41.0	0-4.2
Big River	2.1-57.3 ¹	0.7-19.7
Umbrella Creek	1.5-51.5 ¹	0.4-55.4
Dissolved Oxygen		
South Creek	8.7-12.7	8.2-10.1
Siwash Creek	10.0-11.1	9.5-11.4
Crooked Creek	10.0-12.0	8.5-11.6
Big River	8.4-11.6	8.7-11.2
Umbrella Creek	9.6-12.3	9.2-11.2
pH		
South Creek	6.0-7.0	6.2-7.0
Siwash Creek	6.2-7.3	6.6-7.1
Crooked Creek	5.6-7.2	6.3-7.1
Big River	6.1-7.1	6.5-7.0
Umbrella Creek	6.4-7.4	6.8-7.2
Conductivity		
South Creek	26.7-81.8	44.6-68.1
Siwash Creek	30.8-52.9	44.0-66.8
Crooked Creek	17.9-53.2	34.3-45.4
Big River	22.6-61.8	44.6-61.4
Umbrella Creek	24.2-79.4	50.0-83.8

¹Extremely high levels of turbidity were observed on 30 Nov. 94 in Big River (185 NTU) and Umbrella Creek (161 NTU) in connection with a major storm event.

Tributary reaches in the Lake Ozette Basin with low to moderate gradients tend to have streambeds of relatively fine materials (gravel and sand), whereas tributary reaches with high gradients tend to have streambeds of boulders and cobbles (Bortleson and Dion 1979). Fine sediments are consistently high in the tributary streams (McHenry et al. 1994), which can be partly attributed to the sandstones, siltstones, and mudstones present in the drainage basin.

McHenry et al. (1994) sampled spawning gravel from five watersheds of the northern Olympic

Peninsula, including the Lake Ozette Basin, to examine gravel quality for salmon spawning. Sampling was conducted during low-flow conditions (May to October) in 1991 and 1992 (Table 14). In Washington streams, Peterson et al. (1992) recommended target conditions for salmonids in which no more than 11% (volumetric) of the particle size distribution be comprised of sediment less than 0.85 mm in diameter. By this standard, all Lake Ozette tributaries measured exceeded target conditions. Fredle index values (Lotspeich and Everest 1981), an index of gravel quality that has been closely correlated to salmonid survival to the time of emergence in other systems (Chapman and McLeod 1987, Young et al. 1991), were low (mean=4.9, S.D.=2.8) throughout the five watersheds studied, with the lowest median value for the tributaries of Lake Ozette. Low values indicate poor conditions for incubation of salmon eggs.

Table 14. Percent of fine sediments in stream spawning gravel, with fine sediments defined as those < 0.85 mm diameter, for tributaries of Lake Ozette based on measurements taken under conditions of low flow in 1991 and 1992 (McHenry et al. 1994).

Tributary	Percent fine sediments (sieve wet values)
Big River at Dept. Nat. Resour. Site	15.7
Upper Big River	17.3
N. Fk. Crooked Cr.	23.9
S. Fk. Crooked Cr.	16.7
Crooked Cr.	14.0
Trout Cr.	14.0
Boe Cr.	14.4
Siwash Cr.	24.0
Umbrella Cr. below Hoko/Ozette Rd.	16.4
Middle portion of Umbrella Cr.	15.5
Umbrella Cr. at Makah hatchery	16.3
Ozette Basin Average	17.1

These data substantiate a situation that is generally visible from a basin perspective. Large deposits of sand are evident along the lower reaches of each of the lake's five principal tributaries and are especially evident along Big River and Crooked Creek (Meyer and Brenkman 1995). The latter two tributaries are especially vulnerable to sediment deposition because of their low gradients as they approach the lake. The low-gradient areas of Big River where fine sediment has deposited are occupied by extensive stands of reed canarygrass *Phalaris arundinacea* (Meyer and Brenkman 1995).

By some measures, suitable spawning habitat for sockeye salmon exists in Lake Ozette Basin tributaries. Bortleson and Dion (1979) estimated potential spawning capacity for Big River and Umbrella Creek using the peak-unit spawnable area obtained from equations using average channel width per Swift (1978) and visual estimates of the length of stream channel usable by sockeye salmon. The preferred spawning areas within the usable length of Big River and Umbrella Creek were $32,600 \pm 9,200$ and $26,000 \pm 7,000$ m², respectively. Bortleson and Dion (1979) also presented estimates of spawning area developed by the State of Washington Department of Fisheries based on field surveys -- 39,000 and 25,100 m² within Big River and Umbrella Creek, respectively. They extrapolated these estimates to potential spawning capacity of 46,000 sockeye in Big River and Umbrella Creek, with assumptions and estimates incorporated related to preferred stream discharge, availability of suitable streambed, redd size, utilization only by sockeye, a 1:1 sex ratio, and 100 percent use of the preferred area without overlapping redds (Table 15). Dluglozenski et al. (1981) estimated spawning potential for Crooked, Siwash, and Lost Net creeks at $2,000 \pm 560$ redds, assuming use of 3 m² per female sockeye salmon at optimum flows. Blum (1988) estimated spawning potential in the tributaries as 30,000 redds, but did not provide the basis for the estimate.

Table 15. Estimated potential of Big River and Umbrella Creek to support sockeye salmon redds (adapted from Bortleson and Dion 1979).

Potential capacity	Big River ¹	Umbrella Creek
Length considered suitable for use by sockeye salmon	from river km 4.8-14.5	from river km 0-6.4
Area of spawning gravel available (m ²) at preferred flow based on unit-spawnable-area equations by Swift (1978)	32,608±9,197	25,919±6,940
Number of redd sites at preferred flow assuming 2.5 m ² per sockeye and 100% use of potential area without overlap by sockeye	13,000±3,700	10,000±2,800

¹One portion of this river goes subsurface in late June.

Temperatures in Ozette tributaries fluctuate widely on a seasonal basis, with highest temperatures reached during summer months when air temperatures are high and stream discharge is low. Relative to sockeye life-history requirements (Table 16), water temperatures of Ozette tributaries do not appear to directly jeopardize sockeye salmon survival, primarily because

Table 16. Temperature requirements and limitations of sockeye salmon (1989).

Developmental Stage	Temperature (°C)	Citation
Adults		
Delay of adult immigration	21.1	Bell 1973
Optimal spawning	10.6-12.0	Reiser and Bjorn 1979
Recommended migration temperatures	7.2-15.6	Reiser and Bjorn 1979
Embryos		
Successful hatching	4.4-13.3	Reiser and Bjorn 1979
Juveniles		
High growth rate and low mortality	8.9-10.0	Donaldson & Foster 1941
Poor growth and high mortality	3.9-7.2 & > 23	Donaldson & Foster 1941
Preferred range	12-14	Brett 1952
Physiological optimum	15	Brett 1971
Optimal growth & food conversion efficiency	11.5	Brett 1971
Generally limited (max. observed in field)	< 18	Brett 1971
Upper lethal	24.4	Brett 1952

periods of high stream temperatures and sockeye presence do not coincide (Tables 17 and 18, Figure 12). The possibility of indirect effects of high water temperatures, particularly on food supplies and other relationships in the lake community, cannot be discounted, although it remains unstudied in this system.

Table 17. Water temperatures measured in several tributaries of Lake Ozette from December 1993 - November 1994 (Meyer and Brenkman 1995).

Stream	Range of temps. (°C)	Maximum temp. observed
Crooked Creek	2.6-20.3	Jul 20, 1994
Umbrella Creek	2.7-19.1	Aug 18, 1994
South Creek	3.2-18.4	Aug 3, 1994
Siwash Creek	3.7-17.4	Jul 20, Aug 2 & 3, 1994
Ozette River	6.7-19.0	Aug 17, 1993, Jul 20, 1994

Lake Ozette

Shoreline Characteristics

The shoreline of Lake Ozette is a dynamic area. Fluctuations in lake level, which are tied to annual weather patterns, have a large effect on the extent of nearshore lake bed that is inundated. Bortleson and Dion (1979) conducted a shore survey on August 25, 1976 to assess the suitability of nearshore lakebed materials in the shallows of the lake for spawning by sockeye salmon. Lake levels were low at the time of the survey, and a large area of beach was exposed. They concluded that the beach sediment along the 50 km of shore was highly variable

Table 18. Range of water temperatures observed in the Ozette River and tributaries to Lake Ozette in 1993 and 1994 (from Meyer and Brenkman 1995).

	Temperature Range (°C)
Adults return	
Ozette River	
July	16-23
Aug.	19-24
Sept.	18-21
Oct.	15-19
Spawning (Nov. thru Mar.)	
South Creek	3-9
Siwash Creek	4-10
Crooked Creek	3-9
Big River	3-9
Umbrella Creek	3-9
Ozette River	7-10
Incubation hatching/emergence (Dec. thru Jul.)	
South Creek	3-16
Siwash Creek	4-14
Crooked Creek	3-16
Big River	3-17
Umbrella Creek	3-16
Ozette River	7-19
Smolt migration in Ozette River (Apr. & May)	11-15

in size, ranging from silt to boulders. Meyer and Brenkman (1995) conducted visual surveys of the lakeshore in 1994 and concluded that much of the substrate along the shoreline is composed of fine sediment (silt and organics) and sand. This is especially true in Umbrella, Swan, and Ericsons bays. Long stretches of gravel and cobble, seemingly of suitable quality for sockeye salmon spawning habitat, exist along the western shore from Rocky Point to Allen's Slough, although in this stretch of beach, only the area north of Allen's slough consistently is used by spawning sockeye salmon. Scattered patches of gravel exist along the eastern shore in shallow water with sand immediately below. The site at Olsen's Beach on the eastern shore that is consistently used by spawning sockeye salmon is composed of a strip of gravel that grades into sand at water depths greater than about 3 m.

Sockeye salmon redd sites along the Lake Ozette shoreline occur at depths of 0.3 to 3.0 m (Dlugokenski et al. 1981, Meyer and Brenkman 1995) and vary in some attributes with location. Depth of seven redds at Olsen's Beach in 1994 averaged 1.3 m. Redds found in 1994 near Olsen's Beach and Baby Island were constructed in pea gravel and sand, and ranged from 15 to 20 cm in diameter. Most of these redds were located at shallow depths of 1 m or less, and several were constructed adjacent to clumps of emergent vegetation. Compared to redds observed at Olsen's Beach and Baby Island, redds observed along the west shore in 1994 were approximately the same size but appeared to be located in slightly shallower water and the substrate had a much higher percentage of large gravel and cobble (Meyer and Brenkman 1995).

Much of the upper shoreline is exposed during the summer, allowing the growth of grasses, shrubs, and other vegetation. Sedges (*Carex* spp.), herbs, reed canarygrass, and a native shrub, sweet gale *Myrica gale* are very abundant. Many of these species become inundated as lake levels rise in the winter. Reed canarygrass and sweet gale have been observed in 1.5-m-deep water at Olsen's Beach in areas where sockeye salmon are spawning (Meyer and Brenkman 1995).

Lake Levels

Changes in water levels of Lake Ozette are strongly correlated with annual precipitation cycles. Generalizing from measurements taken in 1976 and 1977 by Bortleson and Dion (1979) (Figure 15), lake levels are highest in winter and early spring and decline starting in March to lowest levels in August. Annual changes can be great. During 1976 and 1977, for example, the difference between highest and lowest lake stage from January through mid-August was 2 m and 1.5 m, respectively. Such fluctuations are sufficient to de-water redds deposited along shorelines. Olympic National Park personnel at the Ozette Ranger Station have recorded lake levels since 1981.

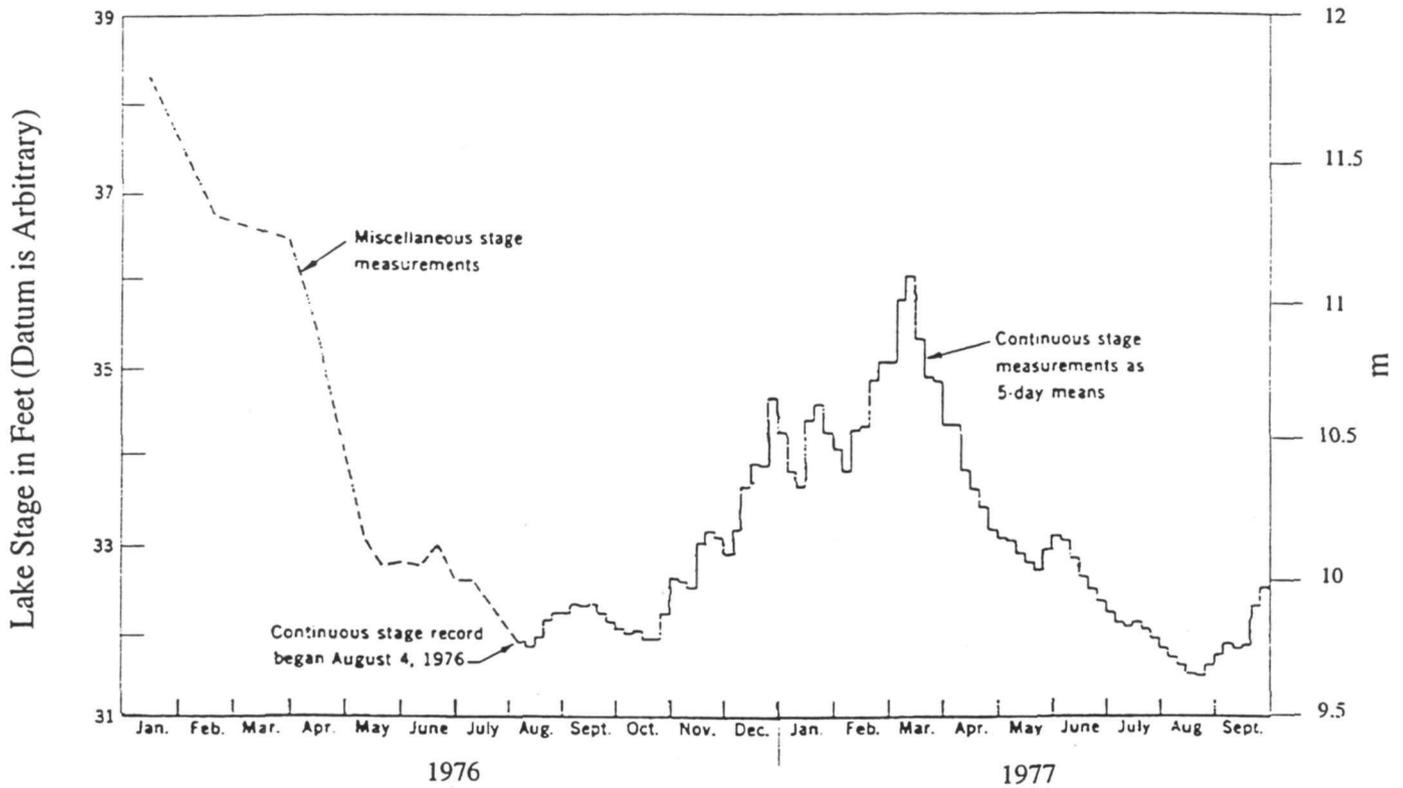


Figure 15. Hydrograph of Lake Ozette stage at the lake outlet to the Ozette River (from Bortleson and Dion 1979).

These records indicate annual lake level changes ranging from 0.8 to 2.7 m (average 1.8 m).

Meyer and Brenkman (1995) calculated that redds deposited in less than 1 m of water early in the year (i.e., at the end of the spawning period of sockeye salmon) commonly could be desiccated or isolated from the lake prior to emergence of sockeye salmon fry.

Temperature and Dissolved Oxygen

Temperature and dissolved-oxygen conditions do not appear to be a threat to sockeye salmon in Lake Ozette. The lake begins to stratify in April, is strongly stratified during the summer, begins to mix in October, and is isothermal by December (Meyer and Brenkman 1995). Whole-water-column temperature reaches a low in December through February of 7.0 to 8.5°C (Beauchamp and LaRiviere 1993, Meyer and Brenkman 1995; Figure 16). The surface

temperatures are warm in late summer, with temperatures close to 22°C possible in August from the surface to a depth of about 6 m (Meyer and Brenkman 1995), but cool water exists deep in the lake in which adult and juvenile sockeye could reside. Concentration of dissolved oxygen remains greater than 8 mg/L throughout the year and at all depths (Meyer and Brenkman 1995, Bortleson and Dion 1979). The lowest dissolved oxygen concentrations occur in the metalimnion from August through October (Meyer and Brenkman 1995).

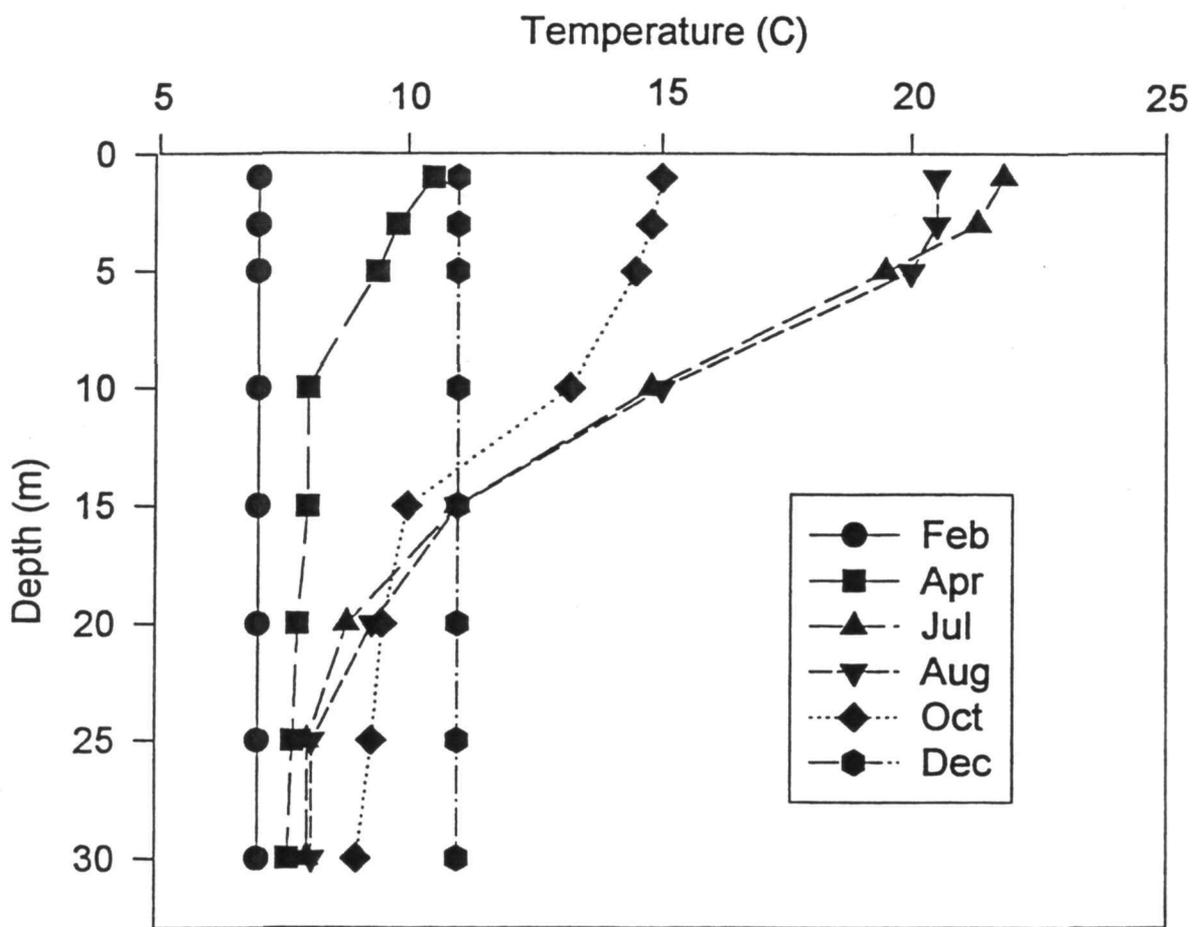


Figure 16. Seasonal temperature-depth profiles for Lake Ozette (adapted from Beauchamp et al. 1995).

pH and Conductivity

Sockeye salmon exist in lakes with comparable pH and conductivity conditions to those found in Lake Ozette (Foerster 1968). Based on recent pH and conductivity sampling by Meyer and Brenkman (1995), pH remains near neutral (range 6.7-7.0) in surface waters of Lake Ozette throughout the year. The pH tends to gradually decrease with depth throughout the year, although values remained within the range of 6.0-9.0 (Meyer and Brenkman 1995). Conductivity in the surface waters ranged from 33.7-43.2 $\mu\text{S}/\text{cm}$.

Turbidity and Clarity

Turbidity in Lake Ozette can vary widely by location, depth, and time (Meyer and Brenkman 1995). Turbidity tends to be low throughout the year with two exceptions; it increases slightly during May and June, possibly because of plankton blooms, and it increases, often radically, following storm events. For example, following heavy rain on March 1-2, 1994, Meyer and Brenkman (1995) conducted turbidity monitoring at the mouths of several major tributaries to the lake and at several locations on the lake. A plume of turbid water extended into the lake from the mouths of the tributaries and was pushed northward by winds. Turbidity in the mouths of Big River, Crooked Creek, and Umbrella Creek measured 34.7, 12.2, and 18.9 NTU. Turbidity in Swan Bay at the mouths of Big River and Crooked Creek was 34.7 NTU at a depth of 3 m and decreased gradually to 13.8 NTU at the bottom of the bay (13 m deep). In a review of studies that evaluated effects of turbidity on salmonids, Lloyd (1987) concluded that a reasonable standard for fish and wildlife protection in clearwater systems would be no more than 25 NTU above natural levels in streams and more than 5 NTU above natural levels in lakes. Washington State standards for turbidity specify that turbidity shall not exceed 5 NTU over background conditions. Unfortunately, background conditions in Lake Ozette have not been established. Certainly, the

patterns of high turbidity events in lake Ozette provide strong indication of the potential for damage to salmon redds in streams and along the Ozette shoreline and the potential for loss of spawning habitat by siltation. Rearing of juvenile salmonids may also be negatively affected by high turbidity levels. Cook-Tabor (1994) reviewed the literature regarding the effects of turbidity on salmonids and found several studies that point to probable effects. For example, Barrett et al. (1992) found that feeding reactive distances were reduced by 45-80 percent at 15 to 30 NTU, Lloyd et al. (1987) found that salmonids exhibit reduced ability to locate and capture prey at 25 to 70 NTU, and Sigler (1980) observed damage of gill tissues when juvenile steelhead and coho salmon were exposed to 25 NTU over a period of five to seven days. The high levels of turbidity in Lake Ozette tend to be most pronounced in Swan Bay, which is where Big River and Crooked Creek enter the lake (Meyer and Brenkman 1995). Juvenile sockeye residing in Swan Bay could not completely escape these high levels by swimming deep in the bay because, although turbidity declines with depth, levels above 13 NTU have been observed near the bottom of the bay.

Based on measurements at four sites in the lake in 1976 and again in 1993-94, Secchi disc depths in Lake Ozette range from 2.1 to 6.5 m, with the greatest visibility generally occurring in summer and fall. The average Secchi reading is around 3 m (Bortleson and Dion 1979). The lake water is a slight brown color (Bortleson and Dion 1979), resulting from the leaching of tannins from organic matter (Meyer and Brenkman 1995).

Nutrients

Based on nutrient sampling by Meyer and Brenkman (1995) and Bortleson and Dion (1979), Lake Ozette is an oligotrophic to mesotrophic system (Wetzel 1975). No major changes in nutrient concentrations are evident based on season or depth within the lake. Based on 1976 data, the nutrient concentrations during all seasons and for all depths within the lake tends to be

slightly low in comparison with concentrations evident in many of the other lakes in Washington (Bortleson and Dion 1978, 1979).

Phytoplankton and Zooplankton Communities

The amount of algae in water is often estimated as a function of the amount of chlorophyll *a* in the water (Wetzel 1975). Based on 1976 and 1977 data, chlorophyll *a* concentrations in Lake Ozette are lowest in winter and highest in summer (Figure 17). The average summer concentration (measurements from June-September 1976) is 3.5 $\mu\text{g/L}$. In the mid 1970s, the algal population in Lake Ozette was dominated by *Botryococcus* during all months except May. During May, the diatom *Asterionella* was the most abundant taxon (Bortleson and Dion 1979). Current information is not available to determine if these conditions still persist.

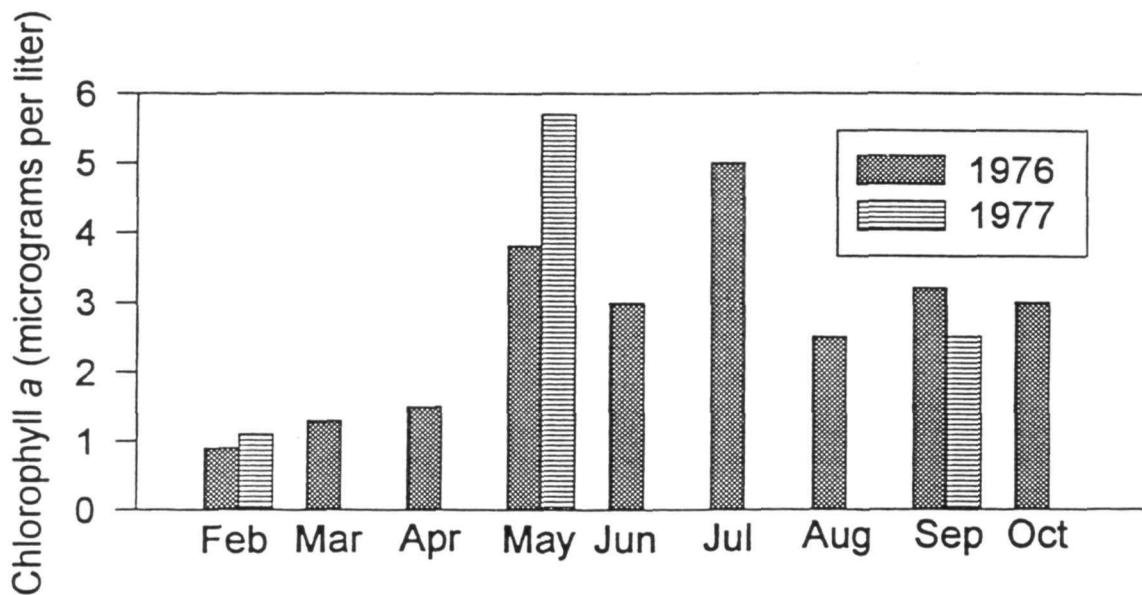


Figure 17. Chlorophyll *a* concentrations in Lake Ozette. Data depicted are averages of four sampling sites in 1976 and two sampling sites in 1977 (adapted from Bortleson and Dion 1977). Samples were collected from different levels of the upper lighted zone of the lake and composited prior to analysis for determination of chlorophyll *a* concentration.

All researchers who have studied zooplankton communities in Lake Ozette have concluded that sufficient food supplies are available for juvenile sockeye salmon during their period of lake residence (Bortleson and Dion, 1979, Blum 1988, Dlugokenski et al. 1981, Beauchamp et al. 1995). A general assessment is that none of these studies have been thorough enough to definitively describe species composition, density, and population cycles of zooplankton in the lake. An analysis of a small number of samples recently collected at three times of the year indicates strong patterns of seasonal succession in the zooplankton community and some interesting morphological characteristics for at least one species (R. Truitt, OR St. Univ., pers. comm., Jan. 1996). Based on sampling in the mid and late 1970s and again in the early 1990s, the standing crop of zooplankton follows the same trend as changes in the concentration of chlorophyll *a* -- low winter densities, increasing densities through spring and summer, and a decline in density in the fall (Beauchamp et al. 1995, Dlugokenski et al. 1981, Figure 18). A spring pulse in zooplankton standing crop occurs in May and June, coinciding with movement of sockeye salmon juveniles into offshore lake habitats to begin their rearing (Figure 18). The most abundant zooplankton include *Diaptomus*, *Epischura*, *Kellicottia* and unidentified cyclopoid copepods. Less common zooplankton include the cladocerans, *Bosmina* and *Daphnia*. (Beauchamp et al. 1995, Bortleson and Dion 1979). Dlugokenski et al. (1981) also identified the large-bodied cladocerans *Holopedium* and *Leptodora*. Of the common species, *Daphnia* is the largest and least evasive, and is more concentrated in the upper water column than the other large zooplankton species. These characteristics make it a high candidate for prey by planktivorous fish. With an average density of 7.4 copepods and cladocerans per liter of water, Lake Ozette has intermediate densities compared to several other lakes that produce sockeye salmon (Dlugokenski

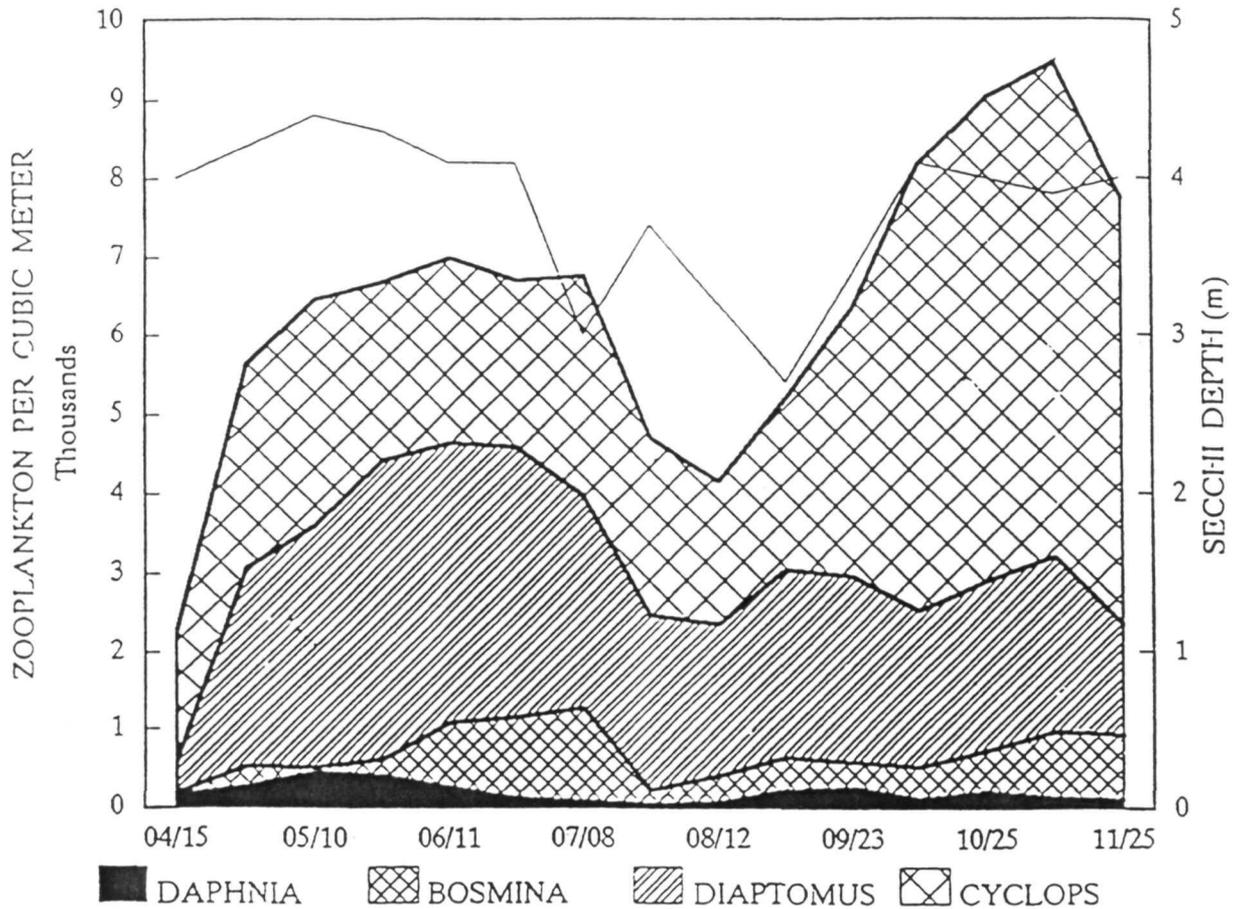


Figure 18. Temporal change in density of the major zooplankton species (hatched areas) and the coincident change in Secchi depth transparency (line and scale on the right vertical axis) (from Beauchamp et al. 1995).

et al. 1981). For the zooplankton community in general, Lake Ozette seems to have comparable or higher average densities compared to several other sockeye-producing lakes (Table 19).

Hatchery Operations

Release of sockeye salmon into Lake Ozette from other systems and a hatchery program have probably had some influence on population characteristics. The earliest recorded hatchery enhancement efforts for sockeye salmon in Lake Ozette appear to be a release in the 1930's of Quilcene-reared sockeye fingerlings derived from the Baker River population (U.S. Fish and Wildl. Serv. records cited in Dlugokenski et al. 1981). Size of the fingerlings ranged from

Table 19. Average densities of zooplankton in Lake Ozette and other sockeye-salmon producing lakes in Washington, Alaska, and Canada (adapted from Bortleson and Dion 1979).

Lakes	Zooplankton density (organisms/L)	Citation
Cultus, Canada	16.4	Foerster 1968
Karluck, Alaska	15.0	" "
Danlee, Alaska	13.4	" "
Osoyoos, Washington	10.2	Allen and Meekin 1972
Lake Ozette, Washington	9.9	Bortleson and Dion 1979
Lake Ozette, Washington	7.4	Dlugokenski et al. 1981
Lakelse, Canada	5.7	Foerster 1968
Bizhnee, Alaska	5.5	" "
Wenatchee, Washington	0.9	Allen and Meekin 1972
Port John, Alaska	0.7	Foerster 1968

2.5 to 7.6 cm. Kemmerich (1945) reports that sockeye from the Quinault system were stocked in Ozette, but details of the stocking are not documented. Quinault fry also were released into the lake in the spring of 1983 (Makah Fish. Manage. 1987b)

Since 1982, the Makah have operated a hatchery on a tributary of Umbrella Creek to incubate and rear sockeye salmon for release into Lake Ozette to supplement natural production. In 1990-91 the facility was rebuilt a short distance downstream of its original location (Makah Fish. Manage. 1991b). The current location is just above the confluence of Umbrella Creek (RM 4.5) and WRIA tributary #20.0056. The site, which is accessed via the 27E logging road off of the Hoko Ozette Road, is owned by Cavanham Forest Industries (tentatively Crown Pacific) and is leased to the Makah. Typical hatchery procedures are to collect sexually mature adult sockeye from lakeshore spawning habitat in December and January, artificially fertilize the eggs, rear the young to a fry stage, and release the fry in the lake. The hatchery program has a goal of 3,000,000 green eggs, but is currently working under an interim goal of 250,000 green eggs (Makah Fish. Manage. 1987b). Eggs have not been available from the Quinault Lake population of sockeye

salmon since 1983 due to a series of low returns of sockeye to Quinault Lake coupled with the end of the sockeye production program at the Quinault Tribal Hatchery (Makah Fish. Manage. 1987b). Fertilized eggs and fry typically are held at the Umbrella Creek incubation facility until they attain a target size of 400 fry per pound. Fry are released into the lake in June or July (Makah Fish. Manage. 1987b). Fry cannot be reared all summer at the facility due to high water temperatures and low water supply. The average number of fry released annually over the 13 years of operation of the Umbrella Creek facility is about 50,000 (Table 20). Although the hatchery strives to make all releases of juvenile sockeye into the lake, releases of fry have occurred directly into Umbrella Creek in the spring of 1988, an accidental release, and again in 1992, an intentional release (Makah Fish. Manage., unpubl. data). Some of these fish have returned to the stream as adults (see page 21).

The hatchery operation is limited by the low numbers of adults available for broodstock, especially females, and the difficulties of navigating the lake to capture adults during frequent winter storms. In some years, adult sockeye salmon have been captured as they return to the lake and held in net pens, anticipating they would reach sexual maturity. Mortalities of the adults and failure of many of them to mature in the pens have severely limited the success of this procedure. For example during the winter of 1991-1992, 43 of 56 adults held in the net pen died, in part because of apparent stress the fish experienced when the pen was towed back to its original anchorage following a wind storm in August, 1991 (Makah Fish. Manage. 1992). The current practice is to capture adults on their spawning grounds, transport them to the hatchery, and hold them until they mature.

Table 20. Releases from Umbrella Creek Hatchery in the Ozette River Basin.¹

Brood Year	Release Year	No. Released	Stock
1982	1983	120,000	Lake Quinnault sockeye
1983	1984	10,000	Ozette lakeshore sockeye
1984	1985	0	No eggs available
1985	1986	21,400	Ozette lakeshore sockeye
1986	1987	12,400	Ozette lakeshore sockeye
1987	1988	118,300	Ozette lakeshore sockeye accidentally released into Umbrella Cr.
"	"	15,000	Ozette lakeshore sockeye
1988	1989	158,245	Ozette lakeshore sockeye accidentally released to Umbrella Cr.
"	"	41,522	Ozette lakeshore sockeye
1989	1990	0	Not able to capture broodstock
1990	1991	2,915	Ozette lakeshore sockeye males x Siwash Cr. kokanee females
"	"	9,504	Ozette lakeshore sockeye
1991	1992	11,483	Ozette lake sockeye males x Siwash Cr. kokanee
"	"	7,645	Umbrella Creek sockeye
"	"	29,058	Ozette lakeshore sockeye
1992	1993	0	Entire lot destroyed because of IHN epizootic
1993	1994	39,040	Ozette lakeshore sockeye
1994	1995	44,411	Ozette lakeshore sockeye

¹Sources of information are Makah Fish. Manage. 1987b for brood years 1982-1986 and Makah Fish. Manage., unpubl. data provided by J. Hinton for brood years 1987-1994.

Egg handling and rearing procedures at the hatchery have evolved over the years of hatchery operation. During the first year when Quinnault stock were introduced, streamside incubators were used. Fry were allowed to freely swim into a "start" box, also positioned streamside, and were fed initially there. Juveniles were reared in the start box until being transferred to a net pen in the lake, where they underwent some additional rearing and were released into the lake. During the first couple of years that Ozette Lake broodstock were used, the juveniles were released from a bridge just upstream of the mouth of Umbrella Creek and were not reared for any time in the net pen in the lake. Starting in the late 1980s, the hatchery facility was expanded to allow the juveniles to be held longer on site. Thereafter, juveniles were released in June directly into the lake. The hatchery also began to use stacked vertical incubators (Heath Trays). Current procedures are to transfer eyed eggs to a "nopad" incubator. Fish can then freely

leave incubators and move to a rearing tank, where they are fed. Fry are netted and briefly held in a 100-gal container and transported to Lake Ozette in a boat (17-ft Boston Whaler), where they are released.

In 1990 and 1991, the hatchery experimented with the production of sockeye salmon x kokanee hybrids. Two factors motivated the Makah to pursue this practice: a desire to restore a tributary-spawning component of the sockeye run and low captures of female sockeye salmon from the lakeshore for brood stock. Pure sockeye crosses also were conducted in conjunction with the hybridization program. The hybrids exhibited poor embryo survival (about 70 percent loss) and poor fry survival (about 60 percent loss). In 1990 for example, eggs from 81 ripe female kokanee collected from Siwash Creek were fertilized with milt from five lakeshore-spawning male sockeye. Total green-egg take was 21,173. In late July, 1991, 2,915 fin-clipped hybrid fry were released into the southern part of Lake Ozette along with pure sockeye reared separately and simultaneously (Makah Fish. Manage. 1991a). In July, 1992, 11,483 hybrid juveniles were released into the lake. The Makah discontinued the hybrid program because of poor survival of eggs and fry, concerns about genetic integrity of sockeye salmon and kokanee stocks in Lake Ozette, and concerns about the possibility of retarded saltwater adaptability of hybrid smolts as noted in studies conducted elsewhere by Foote et al. (1992).

The Makah have considered expansion of the hatchery program to increase the artificial production of sockeye salmon. This has not occurred for several reasons, including policy and biological concerns of the tribe and the National Park Service centered around the hatchery concept, costs, and very limited availability of Lake Ozette broodstock. An evaluation of competition and predation as limits to juvenile kokanee and sockeye production in Lake Ozette by Beauchamp et al. (1995) was conducted in response to the considerations of large-scale hatchery

production and the possible fate of large numbers of sockeye fry released in the lake. Their studies indicated that, if northern squawfish and cutthroat trout populations are sufficiently abundant, a question that remains unresolved, these piscivores could severely crop hatchery-produced fry. The tribe has a proposal to study piscivore population levels in the lake but has not proceeded because of funding limitation. The most recent proposal considered by the tribe is an offer by a private company (Redhook, Inc.) to develop a captive broodstock of sockeye salmon from Lake Ozette consisting of four year classes. These fish would be held at a facility in Nebraska, and the stock would be used to produce eggs for shipment back to the tribe for incubation and fry rearing at the Umbrella Creek Hatchery (proposal from Redhook, Inc. to Hatchery Manager, Makah Fish. Manage., dated 27 July 1995). Funding for this project has not been identified, nor have biological concerns been resolved.

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SECTION II:
Panel Reports: The Sockeye Salmon *Oncorhynchus nerka*
Population in Lake Ozette, Washington, USA

Summary

A panel of four prominent salmon biologists from the Pacific Northwest and Alaska joined federal and state agency staff, tribal staff, and other individuals (Table 21) at a meeting at Olympic National Park on May 8, 1996 to discuss research and management options to restore sockeye salmon in the Lake Ozette Basin. Robert Burgner served as the panel facilitator. Section I of this report was distributed to the four panel members in advance of the meeting to provide background information. After a lengthy discussion involving all participants, the panel met in a closed session to develop and express opinions about research and management options to pursue to restore sockeye salmon in Lake Ozette. Following the meeting, panel members prepared individual reports of their opinions, except that Burgner and Adkison submitted a joint report. The reports were outstanding in quality and contained consensus on several points. A summary of these reports is provided in this section, followed by each report in its entirety. The reports are presented in the order in which they were received at Oregon State University.

Current Population Abundance

The four members of the panel were unanimous in expressing great concern about the abundance of the Lake Ozette sockeye salmon and future outlook for this population. Adkison and Burgner noted that the population has declined 90% to 98% over the last 45 years based on a comparison of historical catches versus current returns. They commented that the population will soon be extinct, probably within the next thirty years, if this trend continues and further speculated that the population is almost certainly an evolutionarily significant unit as defined under the Endangered Species Act (ESA). Their assessment was that the population in its current

Table 21. Participants in the May 8, 1996 meeting to discuss Lake Ozette sockeye salmon.

Panel Membership

Milo Adkison, National Biological Service, Anchorage, Alaska
Robert Burgner, University of Washington, Seattle (Panel Facilitator)
Lawrence Lestelle, Poulsbo, Washington
Harold Geiger, Alaska Department of Fish and Game, Juneau

Other Participants

Katherine Braun, Olympic National Park, Port Angeles, Washington
Scott Bosse, Olympic National Park, Port Angeles, Washington
Ned Currence, Makah Tribe, Neah Bay, Washington
Ken Currens, Northwest Indian Fisheries Commission, Olympia, Washington
Denise Dailey, Makah Tribe, Neah Bay, Washington
Dan Drange, Olympic National Park, Port Angeles, Washington (Previously Makah Tribe)
Brian Edie, Washington Department of Fish and Wildlife, Olympia, Washington
Jeff Haymes, Quileute Tribe, LaPush, Washington
Cat Hawkins Hoffman, Olympic National Park, Port Angeles, Washington
Joe Hinton, Makah Tribe, Neah Bay, Washington
Roger Hoffman, Olympic National Park, Port Angeles, Washington
Ruth Jacobs, Oregon State University, Corvallis, Oregon
Mark LaRiviere, Tacoma Public Utilities, Tacoma, Washington (Previously Makah Tribe)
Gary Larson, National Biological Service, Corvallis, Oregon
Steve Meadows, Quileute Tribe, LaPush, Washington
John Meyer, Olympic National Park, Port Angeles, Washington
Jim Traub, Olympic National Park, Port Angeles, Washington
Bob Truitt, Oregon State University, Corvallis, Oregon
Brian Winter, Olympic National Park, Port Angeles, Washington
John Wullschleger, Olympic National Park, Forks, Washington
Jim Springer, Washington Department of Natural Resources

condition probably qualifies for “threatened” status under the ESA, and if it declines as they expect it will, it will likely qualify as “endangered” status in the near future. Geiger characterized the future for Lake Ozette sockeye salmon as “rather bleak”, noting that the available information shows a population with a strong downward trend in abundance and a population whose status is inadequately monitored. The decline, combined with the small number of breeding fish left, led him to speculate that the population will be virtually extinct in the coming decades unless

effective action is taken soon. Lestelle referred to the abundance of the population as collapsed from levels that existed a half century ago. He focused his report on recommending the development of an approach for diagnosing and prescribing rational treatments for the population.

Population Limiting Factors

Although the four panel members expressed strong concern about the condition of the population, none felt comfortable singling out a specific set of limiting factors. The panel acknowledged that a variety of factors, many of them related to local 20th-century land uses, may have caused or contributed to the collapse of the population, but the necessary information to define the relative importance of various factors to the decline was lacking. Geiger went so far as to speculate that a large part of the decline of this population seemed to be the result of land-use practices. The overriding opinion was that the decline of Lake Ozette sockeye salmon was likely due to the cumulative effects of a number of concurrent or back-to-back events. Relying on extensive personal knowledge of other Olympic Peninsula watersheds, Lestelle discussed some of the factors to illustrate one possible scenario of how cumulative effect could have influenced the Lake Ozette population. This scenario included extensive changes in the freshwater environment of Lake Ozette starting with land uses primarily for homesteading and commercial logging, coupled with several other possible concurrent events that could have altered survival of sockeye salmon such as tribal fishing, unusually large floods, and adverse ocean conditions. These and other possible changes likely severely reduced the resilience and sustainability of many salmonid populations in the Ozette system, not just sockeye salmon. Furthermore the effects of these types of factors would likely have operated in a multiplicative manner, i.e., they would have compounded over the life cycle of the animal. Ultimately certain life-history types could have

disappeared from the population or other factors, predation for example, could have assumed a level of pressure sufficient to prevent the population from rebounding to previous levels of abundance even if other factors could be removed. Adkison and Burgner ventured to list seven plausible contributing factors, but these were extremely broad subjects (Table 22). In line with Lestelle's perspective, Adkison and Burgner's seventh factor and the one they felt was the most likely explanation for the population decline and lack of recovery was "a combination of many factors". Several factors were judged to be unlikely limiting factors -- nutritional problems, recent overfishing, and competition for food resources.

Table 22. Possible factors contributing to the decline and current low abundance of Lake Ozette sockeye as presented in panel report submitted by Adkison and Burgner.

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- Unlikely Contributing Factors
 - Competition, intra- and interspecific
 - Plausible Contributing Factors
 - Introduced species
 - Predation
 - Loss of the tributary populations
 - Decline in quality of beach-spawning habitat
 - Temporarily unfavorable oceanic conditions
 - Excessive historical harvests
 - Introduced diseases
 - A combination of many factors¹
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¹Panel members explicitly stated that this was the most likely explanation for the population decline and lack of recovery.

Principles for Management

The following information was presented in Adkison and Burgner's report as a consensus view of the panel on principles for management.

1. The objective of management should be the sustainability of the wild stock.
Sustainable populations are self-perpetuating, maintain genetic and life-history diversity, and are productive enough to sustain some harvest.
2. As uncertainty is high and likely to remain so for quite some time, management actions require monitoring, periodic re-evaluation of directions, and an overall adaptive response. Actions should be designed to achieve the objective given above.
3. It is likely that an effective strategy will require a watershed-based approach. Past and current land-use practices in the basin may have contributed to the decline of sockeye and could hinder restoration efforts.
4. Restoration of this stock will require participation of all parties whose actions might affect this population. Cooperation and coordination are essential. Each of the parties involved should have clearly defined roles and responsibilities.
5. Achieving restoration will require a larger financial commitment than is presently being made. Some of this will be the direct costs of monitoring, management actions, and evaluation. Some will be indirect costs in the form of restrictions on activities which might impact the sockeye population.
6. The restoration effort requires continuity to be effective. This means continuity of objectives and of approach, robust to the vagaries of funding cycles and political change. Continuity of personnel would contribute to a continuity of approach.
Continuity of strategy does not preclude an adaptive development of tactics.

Research Priorities

A list of research priorities was presented in Adkison and Burgner's report as a consensus view of the panel on research priorities and also was contained in Geiger's report (Table 23). The

reader should refer to their report for additional explanations of the subjects presented. The only qualifying comments to this summary is the caution in Lestelle's report that any recommendation for monitoring and evaluating beyond the number-one priority (adult counts at weir), may be "putting the cart before the horse". In elaborating on this caution, he reiterated the consensus view of the panel that monitoring and evaluation (including research) should be based on a formal planning process (see below)

Table 23. Research priorities for Lake Ozette sockeye salmon per Adkison, Burgner, and Geiger.

Priority 1. Maintain weir counts of adults and improve their quality.

Priority 2. Monitor fate of hatchery fish.

Priority 3 (order of presentation here does not imply rank)

Juvenile monitoring.

Total predator impacts on juveniles.

Spawning-ground conditions in the lake.

Improve census of spawners.

General Principles to Guide the Formulation of Restoration Efforts

It was clear that none of the panel membership had any quick fixes to recommend that would reverse the decline in abundance of Lake Ozette sockeye salmon. Meeting participants were urged by the panel to view resource management more holistically than done in the past. Lestelle, Adkison, and Burgner referenced the work of Lichatowich et al. (1995) as a source of statements of general principles for restoration that aimed toward the development of such a holistic approach. Five major principles as presented by Lestelle are: 1) restoration actions should be based on an ecosystem strategy, 2) restoration actions should seek sustainability, 3) salmon species can serve as indicators of watershed or ecosystem health, 4) restoration efforts needs to

employ the scientific method, 5) restoration efforts should be driven by a planning/decision process that is based upon learning by doing, referred to as adaptive management.

Recommendations that flow from these principles aimed at restoration of Lake Ozette sockeye salmon to a more productive state (as presented by Lestelle) are:

1. Establish a planning process that promotes learning and accountability in pursuing actions consistent with clearly formulated rationale and new information as it develops.
2. Define and refine project objectives over the course of the project.
3. Use existing information and new information as it develops to “diagnose” the condition of the populations of interest (i.e., sockeye salmon in this case).
4. Based on the diagnosis, identify and describe one or more possible strategies and associated actions.
5. Analyze potential risks and benefits on the one or more courses of action being considered.
6. Monitor and evaluate.

The reader should refer to Lestelle’s report or the joint report of Adkison and Burgner for additional information on these principles and recommendations. Three publications accompanied Lestelle’s report that contained additional information to assist in formulating restoration efforts (RASP 1992, Mobrand et al. 1995, Lestelle 1996).

Ongoing Activities

Monitoring of different life stages of sockeye salmon in the Lake Ozette Basin and a small hatchery program are the major ongoing efforts directed at this species. At the time of the May 8th meeting, the Makah and National Park Service were developing plans for monitoring the 1996

adult run, and specific questions were asked of the panel about the value of this effort.

Furthermore, the Makah had considered at various times expanding or eliminating the hatchery program. The panel was asked to specifically comment on any positive and negative aspects of the hatchery program, and also to comment on a recent proposal to the Makah for an enhancement program involving the use of captive broodstock.

Population Monitoring

The panel unanimously agreed that maintaining weir counts of adults and improving the quality of these counts was the highest priority. Monitoring and evaluation of juveniles, distribution of spawning adults, and hatchery-produced fish were also judged to be high priority by Adkison, Burgner, and Geiger. Lestelle expressed reservations about recommending at this time any other priority, other than maintaining monitoring of adults at the weir, because such advice would be inappropriately presented in advance of the development of a formal planning process, a recommendation that all panel members supported.

Enhancement

All members of the panel commented on hatchery enhancement and the possible use of a captive broodstock. The general sense was that modest enhancement efforts may have some benefits to wild spawning stocks as an interim measure, but each panel member was adamant that poorly planned enhancement could pose a threat to wild stocks in a number of ways. All cautioned about genetic problems of a captive brood stock or an unreasonably large enhancement program. Geiger's perspective was that any plan that calls for using small numbers of hatchery-produced fish or captive brood stock as the basis of large population size increases should only be considered as a last resort to save the population from extinction. This sentiment was clearly echoed by Adkison and Burgner who stated, "Artificial production should be viewed as a

desperate stop-gap measure to maintain the population while the factors preventing the wild population from being self-sustaining are fixed.” Lestelle felt that if safeguards could be built into the enhancement efforts and survivals could be expected to be improved over natural levels, then the greatest benefit of applying this tool would be as an aid to learning in building a successful restoration program. Monitoring and evaluating must be built into the current enhancement program, if it is to continue. The panel specifically advised the Makah to discontinue the use of a ventral-fin clip to mark hatchery fish, a practice known to decrease survival of juvenile salmonids, and instead rely on thermal marks or coded wire tags. The general recommendation was that the issue of enhancements needs to be formally brought into a planning process, and a policy on enhancement needs to be developed, including monitoring and strict controls on family size, breeding protocols, and disease control in the hatchery. Development of a captive broodstock was not advised at this time.

The panel discussed whether the hatchery program (if it continues) should focus on increasing lake spawners or establishing a population of tributary spawners. Panel member’s views were variable on this topic. Adkison and Burgner questioned the value of efforts to produce stream-spawning sockeye, especially, as is currently the case, in the absence of substantial evidence that large stream-spawning populations formerly existed. They were concerned that if successful stream-spawning populations were established, but the beach-spawning populations continued their trend to extinction, the native sockeye salmon would still be lost from the system. If strong evidence developed that large runs of stream-spawning sockeye formerly existed, re-establishing such populations could be justified as restoring some of the original characteristics of the system, but not at the expense of efforts to maintain and rebuild existing wild populations. Lestelle tended to lean toward efforts to increase life-history diversity,

if possible, because he tended to believe that one reason the population had crashed was the demise of certain life-history types. He felt that the lake-spawning population may be faced with continued decline in the quality of its spawning environment. If so, the establishment or re-establishment of tributary spawners may be important. Geiger did not specifically comment on this topic.

Experimentation Possibilities

Several interesting perspectives related to experimentation and different forms of habitat or population supplementation were raised by Adkison and Burgner. It was noted that since the majority of sockeye salmon in Lake Ozette return at an age of four, the population to some extent consists of four temporally isolated subpopulations. An experimental treatment might be applied to one brood year without much risk to the others.

Related to spawning areas, one outcome of a planning process might be a decision to direct actions toward supplementing existing spawning areas or re-establishing other lakeshore areas that were historically used. It was noted that it would be wise to try risky techniques to supplement existing spawning grounds on only one spawning ground. Supplementing former spawning grounds, although it has some negative aspects, would be an attractive alternative because new populations might be established and unoccupied habitat allows experimentation with untried techniques without risk to existing populations.

Streamside incubators in Umbrella Creek were once used in the hatchery program operated by the Makah. The question was asked if incubation boxes could be developed that would work on beach spawning sites.

Looking Forward

In one sense, the greatest current threat to the sockeye population is lack of continuity in efforts to restore the population. Ozette sockeye salmon are a valuable component of the cultural and natural system that we inhabit with these fish. A sufficient number of us recognize this value and also recognize that these fish are invaluable indicators of the sustainability of our own style of existence. Many of us, thus, feel compelled to take positive action toward restoration. Losing this population would be one more example of human failure to sustain our culture coincident with the sustainment of our natural world. It's intriguing to imagine restoring this population because many of the attributes of the system these salmon inhabit make restoration seem manageable. These sockeye salmon apparently are not subject to any major commercial or recreational harvest during their ocean residence, they only have a short dam-free and fishing-pressure-free distance to migrate to their spawning habitat, the watershed they inhabit is reasonably small and situated in a temperate climate zone, water supplies are very abundant, rates of forest growth are high, residential and recreational facilities are scarce, Lake Ozette and major portions of the Ozette River are part of a large national park with policies that specify protection of native wildlife, and local Native Americans have strong cultural ties to these fish and are willing to postpone harvest until population abundance increases. These are strong positive attributes lacking for many other salmon populations. The problematic attributes of the watershed are not insignificant -- a complexity of land ownership encompassing tributary habitats, extensive past and present commercial forestry, heavy winter rainfall, seasonally poor conditions for collection of data, and several non-native aquatic and terrestrial species. Yet, we can restore this population if we will commit and coordinate toward this goal with an adaptive planning and

management process, including setting of objectives, assessments of risks and benefits of actions followed by associated actions, monitoring, and periodic re-assessment of direction.

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Panel Reports

Management and Research Priorities for Lake Ozette Sockeye*

A report following the May 8th, 1996 review of population status at the Olympic National Park in Port Angeles, Washington

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Overview

The Lake Ozette sockeye salmon population is in serious trouble. Based on historical catches of up to 17,000 and current returns varying between 250 - 2,000, **this population has declined 90% to 98% over the last 45 years.** If this trend continues (there is little reason to expect it will not) **this population will soon be extinct, probably within the next thirty years.** The persistence of this population at low levels during the last 20 years should not be a cause for optimism. Extinctions happen by fits and starts, with periods of seeming stability interrupted by precipitous declines to a new, lower abundance.

Rescuing this population will require a serious and concerted effort by a number of parties, many of whom are currently not much involved in the process. It is essential that all parties participate. For example, it is likely that any effective solution will require reducing sedimentation due to logging, and almost certainly the viability of the population depends on continuing the commitment by the tribes to forgo harvesting sockeye salmon. In order for this multi-party approach to work, all parties must have an incentive to participate. The strong potential for listing this population under the Endangered Species Act (ESA) provides that incentive.

This population is almost certainly an evolutionarily significant unit (ESU) as defined under the ESA. In its current condition, it probably qualifies for “threatened” status. If it declines as we expect it will, it will likely qualify as “endangered” in the near future. **Either designation would impose onerous financial and regulatory burdens on most land-owners and government agencies in the watershed.** It is in all parties’ best interests to try to prevent this from happening.

The causes of the decline are uncertain, and may remain uncertain for some time. Because of this uncertainty, it is difficult to devise effective approaches to rebuild the population. Two stop-gap measures, artificial propagation and predator control, are available; however, both are risky and should be implemented cautiously if at all. Current population levels do allow use of slower-acting but less expensive and restrictive options than if the population consisted of a few individuals. **We recommend using an adaptive approach employing experimentation and evaluation of several tactics.**

Current Status of Lake Ozette Sockeye Salmon*

Catches in the period 1949-1951 ranged between 14,500 and 17,600, indicating that the population was at least this large, likely about 20,000. Following this period, catches declined steadily and ceased in the early 1970s. Current abundances fluctuate between 250 and 2,000. Thus, **the population has declined 90%-98% over the last 45 years.** This decline may have begun even earlier than 1950, as the earliest recorded catches give evidence of a declining trend. Thus, population abundance might have been higher than 20,000 in the past.

Over the last 20 years, abundances have fluctuated considerably but there is little evidence of an overall trend downward. This implies that the decline between 1950 and 1977 was very precipitous - more than 95% over the space of 25 years. Although the apparent current stability is promising, it should not be interpreted to mean that the population is not in imminent danger. Extinction proceeds by fits and starts; once a population is reduced to low abundance, its condition usually deteriorates (Gilpin and Soule 1986). Temporarily favorable environmental conditions can mask a deterioration in habitat quality or in the fitness of the population. Once the environment reverts to normal or a new stressor appears, a rapid decline can occur. It is very discouraging that no indication of an upward trend in the population has been seen despite 20 years of almost no fishing pressure.

There is no reason to suppose that the overall downward trend for the population has been permanently arrested. Aside from fishing, very few of the potential stressors on the population have been eliminated. In particular, logging activity continues at a high level and sedimentation problems are as bad as ever. New stressors may exist; for example, there is some thought that marine mammal populations at the outlet of the Ozette River may have increased. **A new episode of decline is likely in the near future, and emergency measures should be prepared to deal with such a scenario.** A decline similar to that seen between 1950-1977 would rapidly extirpate this population.

Hypotheses for Decline of Sockeye Salmon

The review panel identified the following possible factors contributing to the decline and current low abundance of Lake Ozette sockeye. We feel research to identify the major factors is important. However, this research is not an end in itself and should only be undertaken as part of a strategy to enhance the prospects for population recovery. We were concerned that an excessive focus on identifying the specific causes could be counterproductive. Certainly, strategies targeted at the major sources of mortality will be the most effective. However, not taking action because the major factors causing the decline have not been conclusively identified, or one party refusing to modify their

* Information in this report is based on Jacobs et al. 1996 and presentations given May 8th, 1996 at the Olympic National Park in Port Angeles

practices because another party may be having a larger impact, could hinder recovery efforts.

Unlikely Contributing Factors:

1. Competition, intra and interspecific

Competition does not appear to be a limiting factor since the Lake Ozette juvenile sockeye exhibit exceptional freshwater growth and their plankton food is in ample supply. Kokanee may not have been present before being planted into the lake in the 1950's, but there is little indication that their populations are a problem as food is abundant and they use different spawning areas than sockeye. It is curious that kokanee maintain stream-spawning populations in the face of extensive habitat degradation.

Plausible Contributing Factors:

1. Introduced species (kokanee, exotic plants, etc.)

Exotic plants have been observed intruding on beach spawning areas and changing the character of much of the lake habitat. The plants may make the habitat less suitable for egg incubation, or facilitate predation. Several exotic fish species have been introduced. The current population of kokanee may or may not be native, but is not thought to compete strongly with sockeye.

2. Predation (pelagic cutthroat and squawfish, sculpins and other egg predators, marine mammals)

According to Beauchamp et al. (1995), cutthroat alone might consume most of the fry produced. Egg and alevin predators (such as sculpins or birds) or marine mammals could also be a problem. Predation is a plausible mechanism for keeping a population at low levels once another factor has driven it there.

3. Loss of the tributary populations.

Severe degradation of the habitat quality in the tributaries has occurred as a result of logging. Accounts of tributary populations are sparse, and they have not been seen in recent years. However, logging in the earlier half of the century may have been intense enough to have destroyed these populations. Habitat recovery is long down the line.

4. Decline in quality of beach spawning habitat.

Increased sediment influxes into the lake as a result of intensive logging could be silting spawning grounds. The northern spawning areas are thought to be the most silted and are not currently used. It's also thought that salmon digging nests favorably condition

the substrate for future years; thus, recent low abundance of spawners may result in gradual erosion of the quality of a spawning ground. Intrusion of exotic vegetation is another plausible mechanism.

5. Temporarily unfavorable oceanic conditions.

Many northwest salmon populations are in difficulty, and a part of recent poor survival is thought to be due to an unfavorable ocean climate. However, for Lake Ozette one year's (suspect) data indicates high ocean survival, and the decline in this population occurred before the oceanic conditions were thought to have shifted (mid 1970s).

6. Excessive historical harvests.

Harvests of 15-17,000 occurred in the early 1950's. Catch estimates for prior years don't exist. These historical catches may have been excessive. They could well have eliminated certain sub-populations, or reduced the overall populations to levels where compensatory mechanisms such as predation prevent recovery.

7. Introduced diseases.

Populations of sockeye and kokanee from other drainages have been introduced at various times in the past. Non-native fish species have been introduced as well. It is possible that a disease or parasite has also been introduced. A novel disease could well result in an initially precipitous population decline, followed by a period of stability with low numbers of individuals exhibiting some degree of immunity to its effects.

8. A combination of many factors.

The reviewers felt this was the most likely explanation for the population decline and lack of recovery.

Principles for Management

What follows reflects a consensus view of the reviewers.

1. The objective of management should be the sustainability of the wild stock. Sustainable populations are self-perpetuating, maintain genetic and life history diversity, and are productive enough to sustain some harvest.
2. As uncertainty is high and likely to remain so for quite some time, management actions require monitoring, periodic re-evaluation of directions, and an overall adaptive response. Actions should be designed to achieve the objective given above.

3. It is likely that an effective strategy will require a watershed-based approach. Past and current land-use practices in the basin may have contributed to the decline of sockeye and could hinder restoration efforts.

4. Restoration of this stock will require participation of all parties whose actions might affect this population. Cooperation and coordination are essential. Each of the parties involved should have clearly defined roles and responsibilities.

5. Achieving restoration will require a larger financial commitment than is presently being made. Some of this will be the direct costs of monitoring, management actions, and evaluation. Some will be indirect costs in the form of restrictions on activities which might impact the sockeye population.

6. The restoration effort requires continuity to be effective. This means continuity of objectives and of approach, robust to the vagaries of funding cycles and political change. Continuity of personnel would contribute to a continuity of approach. Continuity of strategy does not preclude an adaptive development of tactics.

Research Priorities

What follows reflects a consensus view of the reviewers.

Priority 1. Maintain weir counts of adults and improve their quality. This information is basic, and is the clearest indication of any difficulty or recovery the population may be experiencing.

Priority 2. Monitor fate of hatchery fish. Artificial production is a major component of current efforts to maintain this population. If it is to continue, we need to know whether it is succeeding, and if it is not, why it isn't. Potential changes in practices will need to be evaluated for performance as well. The current system of marking a large portion of hatchery fish using ventral fin clips should be replaced by thermal marks (possibly natural) or coded wire tags, since fin clips are known to decrease survival.

Priority 3. Juvenile monitoring. This includes abundance and condition of smolts and/or fry. Such information is invaluable in focusing research efforts at either freshwater or the ocean, and in discriminating among proposed mechanisms. For example, smolt size and weight strongly suggest that freshwater food limitation is not a factor maintaining the low abundance of this population. Better smolt numbers might eliminate freshwater mechanisms entirely as suspected causes for the decline, although such numbers may be difficult to get.

Priority 3. Total predator impacts on juveniles. The study by Beauchamp et al. (1995) strongly suggests that freshwater predators may be taking most of the juvenile sockeye.

However, accurate abundance estimates for the predators do not exist. Little is known about marine mammal takes at the river mouth or predation on eggs and emerging fry by sculpins and water birds in lake beach spawning areas.

Priority 3. Spawning ground conditions in the lake. Sedimentation of spawning beds, particularly in the northern part of the lake, may contribute to the decline. We need to determine if former spawning grounds have become unsuitable for embryo survival, what the status and outlook is of the currently-occupied grounds, and whether improvement of spawning beds is feasible.

Priority 3. Improve census of spawners. While tributary streams were intensively surveyed in the 1970's, we are not confident that all spawning populations are known. Intensive surveys of the lakeshore and other areas (even a one year effort) would be valuable. Lakeshore surveys should be concentrated in the following areas: where there is subsurface flow near the mouths of tributary streams, where runoff from hills adjacent to the lakeshore may provide subsurface water flow, and where wave action produces within-lake currents, particularly at exposed prominences or in straits between land masses (e.g. Baby Island). There are hints of outlet spawners, hints of late runs of spawners, etc. in the historical records. Abundances on the major spawning grounds are unknown. In addition, there is some suggestion that the two major spawning populations in the lake may differ in timing of spawning, which might suggest they are distinct. A genetic comparison of the different spawning groups would also be useful.

Treating the Symptoms

What follows are two short-term methods for maintaining population abundance while the factors causing the decline of this population are identified and remedied. **As a permanent strategy, neither is consistent with the objective**, which is to restore a self-sustaining sockeye salmon population to Lake Ozette. However, they do provide tools to arrest any precipitous decline in abundance that may occur in the near future. Whether they are required immediately is debatable. However, **experimentation should immediately begin to develop the most effective ways to implement these approaches should a crisis develop**.

A. Artificial Production

The available documentation of hatchery goals indicates a large-scale production objective. **A fishery based on artificial production is not sustainable, and would reduce the viability of the wild population**. Hatcheries produce more fish per spawner than wild reproduction (theoretically). Thus, when hatchery and wild fish are commingled wild fish are usually overharvested. Hatcheries also can result in genetic damage to the wild stock by using foreign broodstock, by causing artificial selection for undesirable traits, or through excessive success; the relatively few hatchery fish can

produce most of the next generation, which means soon the population is composed of highly related individuals and inbreeding depression may result (Ryman et al. 1995). **Artificial production should be viewed as a desperate stop-gap measure to maintain the population while the factors preventing the wild population from being self-sustaining are fixed.** Presently desperate measures are not called for.

One of the major worries of the review panel was the possibility that a hatchery program, once established, would shift goals from temporary conservation to permanent production of fish for a fishery. Hatchery production of salmon for a fishery has a history of getting out of control (Hilborn 1992, Meffe 1992). Artificial production of fish tends to gather support from consumers of the resource. In large part, this is because the product of hatcheries is highly visible (smolts) while the damage caused by hatcheries (overharvest of wild-produced fish, genetic damage, etc.) is less visible. Hatcheries are also strongly supported by those who would be impacted by other types of remedial actions. In many cases, hatchery operations tend to grow to consume most of the budgets for restoration of salmon production, which results in underlying problems not being addressed. A constituency for hatchery production should be discouraged; except for a limited ceremonial take, **harvest of sockeye should not be permitted until the hatchery has been closed down.**

The current hatchery program is limited by the amount of eggs available, and is in effect a modest supplementation program for the lake spawning fish. It should probably be continued at the present level in the near term. However, there are some indications that supplementation of the lake spawning populations may not be working. In general, **the hatchery program suffers from a lack of monitoring and evaluation.** Without some indicators of performance, improvements in using artificial propagation will be entirely based on guesswork. Although current practice informally considers the effects of hatchery practices on the wild stock, we felt that **a formal policy governing broodstock collection and disease control would be useful.**

For future consideration, there are numerous alternative ways in which the supplementation program could be directed. Here are several discussed by the review panel. Further development of a supplementation strategy is required, as previous planning efforts have been misdirected at production for fisheries.

1. Captive broodstock: this is an expensive option more appropriate to cases such as Redfish Lake, in which a very few individuals remain and their outlook in the wild is almost certain immediate extinction. Currently there is a proposal to create a captive broodstock for Lake Ozette, with the motivation being to provide a large dependable supply of eggs to the hatchery. This scheme has the potential to genetically harm the wild population, in that if successful the relatively few individuals in captivity will be producing most of the next generation of salmon in Lake Ozette and, over time, the population would be composed mostly of closely related individuals. In addition, rearing salmon throughout their entire life cycle in captivity greatly increases the possibility of inadvertent selection for disadvantageous traits.

2. Establishing stream-spawning populations. There is some debate as to whether stream-spawning populations ever existed in Lake Ozette, and, if so, how abundant they may

have been. Accounts of fish racks near stream mouths are suggestive but not conclusive; they may have been targeting adjacent beach spawners, kokanee, or other species. Regardless of the historical circumstances, it seems clear that if these populations existed they are now extinct and that their former habitat is heavily degraded. Currently, sporadic efforts are being made to establish a population in Umbrella Creek using hatchery-reared offspring of beach spawning populations. Although there have been a few returns, we are dubious about the potential for long-term success; beach-spawning fish are usually morphologically, behaviorally, and genetically quite distinct from stream spawners (Blair et al. 1993). If wild beach-spawning populations attain high abundance, recolonization of stream habitat may eventually occur.

However, we question the value of efforts to produce stream-spawning fish, especially if there is little evidence that large stream-spawning populations formerly existed. If successful stream-spawning populations were established, but beach-spawning populations continued their trend to extinction, we would still have lost the native sockeye salmon. This would not be consistent with the goals of the ESA, the Olympic National Park, nor likely of the Makah and Quileute tribes. The only possible benefit of these artificial populations would be to support a fishery; as such, they would be equivalent to hatchery production for the same purpose. If there were strong evidence that large runs of stream-spawning sockeye formerly existed, re-establishing such populations could be justified as restoring some of the original characteristics of the park. However, such efforts should be a second priority. They should not siphon resources from efforts to maintain and rebuild existing wild populations.

3. Experimenting with one cycle and/or one spawning area. Since the majority of sockeye salmon in Lake Ozette return at an age of four, the population to some extent consists of four temporally isolated subpopulations. An experimental treatment might be applied to one brood year without much risk to the other three. As an example, many of the current hypotheses for why sockeye abundance remains low despite little or no human harvest involve compensatory mechanisms such as predation, or insufficient spawners to maintain the condition of spawning beds, etc. (Peterman 1987). This implies that if the population could be increased, survival would increase as well and abundance would increase dramatically. Risky intensive population augmentation might be applied to one cohort only, then attempted on the other three only if proven effective. A similar experimental strategy could be applied using single spawning areas.

4. Supplementing existing spawning areas versus re-establishing historically-used areas. Several current spawning locations are known. Several others have been used historically, but are currently empty. Supplementing existing spawning grounds involves a risk of detrimentally affecting a healthy population. However, it has the potential of overcoming local compensatory mechanisms, such as egg predators or insufficient spawners to maintain the condition of the gravel. It would be wise to try risky techniques on only one spawning ground. Supplementing former spawning grounds is an attractive alternative. New populations might be established. Additionally, working with unoccupied habitat allows experimentation with untried techniques without risk to self-perpetuating populations. However, it may be a waste of effort if the spawning ground is vacant because it's no

longer suitable, or may redirect effort from populations which would be viable with a little attention.

5. Alternatives to hatcheries. Initially, artificial production of sockeye in Lake Ozette used streamside incubators rather than the current hatchery. There is some concern as to whether the current system of transportation to and release in the lake causes excessive mortality of fry. Could incubation boxes be developed that worked on beach spawning sites? Such methodology would be invaluable in trying to augment a specific spawning area or re-establish a population in a vacant area. Net pen rearing in the lake was also tried; in principle it's a low-impact method for increasing fry survival. This technique might be improved and made practical.

B. Predator Control

Large cutthroat trout are estimated to consume between 85% and 170% of the mixed pool of sockeye and kokanee age 0 fry in Lake Ozette (Beauchamp et al. 1995). These numbers are highly speculative, but indicate that reducing freshwater predation could be effective in boosting sockeye production. Predator control is in disfavor in wildlife management, where it was formerly extensively practiced. It is often expensive and unsuccessful. Where predators are successfully depleted, there are often unintended and counterproductive consequences. For example, the removal of a predator may result in stronger intraspecific competition, or it may result in a great expansion in abundance of a competitor species, or may permit a different and more effective predator to move in. It is within the realm of possibility that removing many of the large cutthroat trout could result in a large increase in the abundance of yellow perch or stickleback, or result in large numbers of squawfish or smaller cutthroat trout moving to the pelagic zone to feed on sockeye. Any predator control program instituted should be moderate in scope, and monitored closely for evidence of these sorts of counterproductive consequences. One fairly inexpensive option would be to increase sport angling take of large cutthroat, possibly through a combination of increased bag limits and targeted advertising.

Treating the Underlying Problems

Uncertainty and an Adaptive Approach

There is currently great uncertainty as to the causes of the population decline. This uncertainty will likely continue to exist for some time. There are two inappropriate reactions to this uncertainty. The first is to do nothing until the problem is conclusively identified. Understandably, when one group is asked to take an expensive remedial action under such uncertainty they often resist, pointing out that the action may be ineffective and action by others might be more effective. The legal system often supports this stance, requiring that proof of damage be given before someone is forced to incur the costs of

remediation. As proof is frequently slow in coming, the consequences on the impacted population may be disastrous. The second inappropriate response to uncertainty is to make an irreversible commitment to the approach that seems best at the time. This may result in ineffective or even counterproductive actions, with severe consequences as well.

The approach most likely to be beneficial is an adaptive one, combining risk-averse and reversible actions with monitoring and periodic re-assessment of direction. This is the type of approach we recommend for restoring Lake Ozette sockeye.

This adaptive process should consist of the following steps (Lichatowich et al. 1995):

1. Defining objectives.
2. Diagnosis. Evaluate the situation based on current data. Identify problems to be addressed.
3. Identify potential treatments and experiments.
4. Evaluate the risks and benefits of each proposed action. This is the stage where actions which may have long-term adverse consequences and experiments that are unlikely to clarify uncertainty are identified.
5. Select and implement actions. A decision analysis based on the results of step 4 would be useful. Here is where the potential long-term costs and benefits would be compared.
6. Monitor and evaluate the outcome of each action.
7. Repeat steps 1-6 on a regular basis! An annual technical review would likely be the best approach, with policy reviews (step 1) possibly less frequently.

For example, in step 1 the short term goal might be to develop the most effective methods of augmenting the abundance of beach spawning populations. Step 2 might identify early freshwater survival as the largest mortality component, but be unable to distinguish the effects of egg predators from fry predators. Step 3 might suggest lakeshore incubation boxes and net pen rearing as two possibly effective treatments. Step 4 might conclude that both were at significant risk of not working, which would result in the loss of any eggs taken for the experiments. Step 5 might conclude that the best way to proceed would be to deploy lakeshore incubation boxes on only one occupied area and on one vacant area, while placing half of the emerging fry from each area in a net pen. Step 6 might involve comparing egg-to-fry survival from incubation boxes and natural redds, marking pen-reared fry through chemicals in their food, and estimating survival and condition from captured smolts at the lake outlet. Step 6 would involve analyzing the results of the experiment, and then the entire process would be repeated to see whether either or both treatments should be expanded to more spawning areas.

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Recommendations to Preserve and Restore the Lake Ozette Sockeye Population:

A Report following the May 8, 1996 review of population status at
the Olympic National Park in Port Angeles, Washington

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PURPOSE

This report is submitted to the National Biological Service, Forest and Rangeland Ecosystem Science Center, at Oregon State University. It contains the authors recommendations and conclusions about a sockeye salmon population that originates in Lake Ozette, which is located in the Olympic National Park in the state of Washington. The report is largely based on information presented during a review of the population status of Lake Ozette sockeye salmon. This review occurred on May 8, 1996, in Port Angeles, Washington.

SUMMARY

The future for Lake Ozette sockeye salmon appears rather bleak. The available information shows a population with a strong downward trend in abundance, and a population whose status is inadequately monitored. Historical population sizes are not known, but total harvest exceeded 10,000 three times in the 1940s and early 1950s, when recordkeeping began (Jacobs et al. 1996). By the mid 1970s harvests had fallen to a few tens of fish for ceremonial purposes, and the breeding population was reduced to less than 3,000 animals. In the absence of any other information, we might speculate that historical population sizes might have averaged at least 10,000, and probably more. In 1992 the estimated number of spawners had dropped to approximately 2,200 animals; since then, the estimated spawning population size has remained below 500 animals (Jacobs et al. 1996). Using the last three years of information, this population appears to have experienced a population decline of over 95%. This decline, combined with the small number of breeding fish left, leads me to speculate that this population will be virtually extinct in the coming decades unless effective action is taken soon.

Assuming the will and resources exist to carry out corrective actions, we still lack the information to identify the basic problems. Based on the information I have reviewed and the conversations at the May meeting in Port Angeles, I strongly recommend a program of improved stock monitoring, combined with an ongoing planning process to steer a restoration effort. As part of that planning process (1) the objectives of all interested parties need to be articulated and integrated, (2) the role of enhancement needs to be reviewed to ensure it is fully compatible with these objectives, (3) population and enhancement monitoring projects must be solidly supported and the resulting information fed back into the planning process, and (4) restoration actions must be altered based on updated information.

Enhancement may play a useful role in reducing compensatory mortality, which has been identified as a possible obstacle to production (Beauchamp et al. 1995). Enhancement may also be useful in helping to seed tributary spawning areas. However, without appropriate safeguards, enhancement could lead to inbreeding depression, further loss of stock productivity (Kapuscinski and Jakobson 1987, Waples and Do 1994), and unsustainable harvest rates on the remaining wild fish. Poor use of enhancement will hasten the decline of this stock. I recommend that a formal policy be developed that specifies an egg-take schedule based on measured abundance of spawners. I further recommend that this formal policy prohibit directed harvest of hatchery-produced salmon. If the larger goal is to restore Lake Ozette sockeye salmon, this enhancement policy must ensure that effective population size (Kapuscinski and Jakobson 1987) be maintained, that unexpected failures at the hatchery not result in an unacceptable loss to the population, and that harvest of hatchery-produced salmon not be allowed to drive wild or naturally spawning salmon to extinction.

A CONSENSUS OF OPINION AMONG THE REVIEWERS

The reviewers at the May 8 meeting were Robert Burgner of the University of Washington, Milo Adkison of the National Biological Service, Larry Lestelle of Moberland Biometrics, and myself. We struggled with what conclusions to draw. The lake system does not appear to be food limited, and land-use practices seem to be at least partly responsible for the decline of the sockeye population. Even though we could bring closure to some issues about the population, we did not have the information before us to precisely diagnose problems and recommend solutions. At the meeting we all agreed that we should recommend a course of research activities that will help identify problems and lead to solutions; we agreed we would outline principles that we think are necessary to preserve and restore the stock; and we all agreed that the most important action to recommend at this time is the establishment of an ongoing, dynamic planning process.

The principles that we recommended to guide a restoration effort are (1) a commitment to the sustainability of the wild stocks, (2) a commitment to a planning process linking objectives to actions through a planning process, (3) a commitment to coordination and cooperation among all interested parties, (4) a need for a definition of rules and responsibilities among interested parties, (5) a need for a commitment to continuity, (6) a need for brood stock and genetic guidelines in support of Principle 1, and (7) a need for an analysis and improvement of land use around Lake Ozette.

RESEARCH PRIORITIES

Any management agency charged with reversing the decline of Lake Ozette sockeye salmon must first know the size of the spawning population. This most basic piece of information is vital for many reasons, two of the most important being (1) that it allows those attempting to restore the lake to at least responsibly speculate about the effects of any actions to reverse the decline, and (2) to know if the population reaches a crisis size from which it must be pulled back from biological extinction with heroic measures. Besides its large value to the restoration process, this estimate of spawning numbers is available at relatively low cost. At the May 8 meeting the review team reached consensus that this piece of information should be given the highest priority.

Because enhancement has the potential to either help with the restoration of this system or to hasten its decline, the second most important research priority is to improve the monitoring of the fate of hatchery fish. At the May 8 meeting the review team reached consensus that hatchery-monitoring information should be given the second highest priority. Researchers will need a means to identify fish of hatchery origin and find ways to measure survival of hatchery fish at as many lifestages as possible. Lake managers will

need to know where fish of hatchery origin are spawning and make inferences as to their contribution to the breeding population.

At the May 8 review, we learned hatchery fish have routinely been marked by removal of various combinations of fins. Fin clipping increases mortality, and the number of marks is very limited. I recommend that hatchery operators be given adequate resources to develop more modern hatchery marking methods. There are many new cost-effective ways to identify hatchery fish. For example, otolith marking (Brothers 1990) is now the standard marking method in many hatchery applications in Alaska (Hagen et al. 1995). Perhaps Lake Ozette hatchery salmon possess a natural mark in the otolith. If so, this would be an inexpensive way to identify hatchery-produced salmon without applying a mark that will lower survival. In any event, I am sure there are several cost-effective means of recognizing these fish that are workable if hatchery operators or lake managers are given the resources to develop them.

At the May 8 meeting the review team reached consensus that several other important pieces of information should be given the third highest priority. We recommend the census of spawning populations for site-specific abundance, timing, and location; improved juvenile monitoring; the monitoring of predator abundance, predator food consumption, and an estimate of total predation on sockeye salmon; and monitoring of spawning gravel conditions. We agreed that resources should be first directed to lake sites and then tributary sites, as resources permit. We also agreed that research planners must use care to only collect information that will be of sufficient quality for the application.

Estimated survival at each lifestage for each spawning aggregation would be ideal. Realistically, not all of these estimates can be generated. Some lifestage survival estimates may be prohibitively expensive or consume resources that would be better spent on other efforts. Perhaps this would be true of some embryo-stage survival estimates. Given realistic funding levels, other lifestage estimates would be so imprecise as to be unusable. This might be true for the fry-stage survival estimates. Because there are complex tradeoffs when using monitoring resources, the managers of Lake Ozette need a planning process that can evaluate what data-gathering projects work and what information is useful. This process must be flexible and be able to adapt based on the most current information.

An Examination of Land-Use Practices

A large part of the decline of this population seems to be the result of land-use practices. Focusing only on fishery information, population biology, and demographics may not lead to effective restoration solutions. It may be that no fishery or population actions will be effective if land uses that are fundamentally incompatible with salmon survival are ongoing. To the extent possible, as part of the planning process, an analysis of the entire

watershed should be undertaken with an emphasis on what land-use options exist at this time.

ENHANCEMENT

Modest enhancement efforts may help protect wild spawning stocks by lowering depensatory sources of mortality. However, poorly planned enhancement poses a threat to the remaining wild stock in a number of ways.

A captive brood stock program or other kind of large-scale enhancement may hasten the decline of this stock by draining it of its genetic variation. A captive brood stock may also serve as a dangerous kind of displacement behavior, helping to create a public perception of doing something, while valuable opportunities for truly effective actions pass by. In my view, a captive brood stock program would be a poor use of resources at this time.

Captive brood stock programs may eventually be needed as a last result to hold off biological extinction, while waiting for genuinely effective improvements to the stock's productivity to work. But these programs will be of no value — despite huge expense — without making genuine improvements to the stock's productivity.

Enhancement that simply replaces wild fish with hatchery fish would ultimately lead to the loss of this population of sockeye salmon. Large-scale enhancement would create a strong incentive for harvest rates that are too high for wild stocks. Given that this sockeye population seems to be declining with no harvest at all, directed harvest of a hatchery-produced run would almost certainly drive naturally spawning salmon to extinction. Once this is allowed to happen, eventually a single remnant hatchery population would be lost through mechanical failure of hatchery equipment, epizootic, loss of funding, or some other mechanism.

Without evaluation of the survival rates and a purposeful march toward proven hatchery practices, the ultimate survival of the hatchery-produced fish might be very low. If this is the case, enhancement could be just another source of mortality for this population. Again, any enhancement program must include an evaluation program that monitors the survival of each release.

Without policy safeguards, enhancement can create high levels of inbreeding (Waples and Do 1994). This, in turn, will lead to loss of genetic fitness and a lowering of stock productivity (Nelson and Soule 1987). — which is already at an unacceptably low level in this population.

Effective Population Size

Populations of all animals respond to changes in the environment by drawing on their store of genetic variability. The genetic variability is the source of the population's "options" for change. The amount of genetic information that a population can hold can be indexed by a quantity known as the *effective population size* (Wright 1931). When the population size becomes small, the probability that some genes will be lost due to chance goes up and the genetic variability in the population goes down. It is possible for populations to appear large but be genetically small. Suppose a population consists of 100 organisms organized into 50 mating units. At one extreme each family might have two offspring, and the effective population size would be at its maximum for a stable population. At the other extreme one family unit might have 100 offspring and all other families might have zero. In the latter case the genetically effective population size is at its minimum for a stable population. If only two animals are the parents of the next generation, the population will contain relatively little of the original genetic variation. This, in turn, will make the population less able to respond to a changing environment.

To illustrate how the concept of effective population size can be used to look at an enhancement strategy, suppose the population is down to its last 100 animals. Further, suppose that if effective action is not taken the wild families have a mean of 2 and a variance of 4 offspring per pair, while hatchery fish have a mean of 15 and a variance of 30 offspring per pair. Alternatively, with some kind of effective action to restore the population, the family size of wild salmon will have a mean of 8.5 and a variance of 17. For the moment, ignore pathology considerations, genetic selection in a hatchery environment, and a number of other realistic concerns. Instead, let's focus on just the effective population size in a single generation.

Let k_i stand for the number of offspring in the i^{th} family. Then let \bar{k} and $v(k)$ be the mean and variance of the family size. Crow and Morton (1955) called the ratio $R_k = v(k)/\bar{k}$ the index of variability and described its calculation. This quantity describes the extent that population increases come uniformly from either all families or from only a few. For populations that are expanding or contracting, Kimura and Ohta (1971) give the following formula for one form of the effective population size that is called the variance effective population size,

$$N_e = \frac{(N_{t-1}-1)\bar{k}}{R_k + 1}$$

This equation can then be used to show the population's capacity to retain genetic variability, using hypothetical parameter values and enhancement actions that involve egg takes from wild populations and mixing of hatchery and wild juveniles.

If the entire population is allowed to spawn in the wild without some action to improve survival, the breeding population would stay the same, but the effective population size in the next generation would decline:

$$N_t = \frac{(100-1)2}{4/2+1} = 66.$$

Similarly, suppose all of the fish are placed in the hatchery. In this case the actual population will increase to 15 (100/2), or 750 because of the increased survival in the hatchery environment. In this case the effective population size will be given by

$$N_t = \frac{(100-1)15}{30/15+1} = 459$$

However, if half of the population is placed in the hatchery and half is left in the wild, the mean family size will be given by $\bar{k} = (50(2) + 50(15))/100$, or 8.5. But now, because of the fact that wild families generally have family sizes less than 8.5 and hatchery families generally have family sizes larger than 8.5, the variance among families will increase to approximately¹ 54.

Then with half the families in the hatchery and half in the wild, the average will be 8.5 offspring per family for the 50 families, and the breeding population would be 425 animals. However, the effective population size will be given by

$$N_t = \frac{(100-1)8.5}{54/8.5+1} = 114.$$

Notice that most of the population increase came from just a small fraction of the breeding population in the hatchery. When the population increases this way it will behave as if it were still a small population from the point of view of maintaining genetic variation.

If managers could find a way to improve conditions for wild salmon to the point where the family size was 8.5 offspring per family, the breeding size would still be 425, but the effective population size would be over twice as large:

$$N_t = \frac{(100-1)8.5}{17/8.5+1} = 280.$$

When the population drops to very low levels, “splitting the difference” — that is putting half of the wild fish in a hatchery and leaving the rest in the wild — might seem like the most prudent course of action. But this action can be more harmful than many other

¹ Arrived at by simulation using a normal approximation with $N(2,4)$ and $N(15,30)$.

options if the variance of family size is allowed to increase too rapidly. From the point of view of preserving genetic variation in the wild stock — and improving the stock's productivity — both the average family size and the variance of family size must be considered together.

The above example of an effective population size is intended only to illustrate the principle and to highlight the genetic problems of a captive brood stock or large-scale enhancement program, when the variance of family size is not controlled. A full analysis requires consideration of the risk of extinction without enhancement and the cost to the population if the enhancement does not work. Again, enhancement often fails because of mechanical failure, disease outbreak, or unobservable genetic selection, and so forth.

Any plan poses a danger that calls for using small numbers of hatchery-produced fish or captive brood stock as the basis of large population size increases. Waples and Do (1994) provide a fuller discussion of these problems. There is a large amount of literature on this problem that is beyond the scope of this review. However, I hope I have helped make the case that this issue needs to be formally brought into a planning process, and a policy on enhancement needs to be developed. This policy must address the total number of salmon that may be brought into the hatchery and the total number that are left to breed in the wild. Most importantly, the plan should call for strict controls on the family size and breeding protocols in the hatchery.

PLANNING PROCESS

At the May 8 review, the review team members struggled with the possible causes of the Lake Ozette sockeye population decline when recommending actions. We realized we did not have enough information about the population, we did not understand the objectives of all parties, and we did not fully understand what all of the options were. We agreed that effective action can only come from a planning and controlling authority that will process information, implement actions, seek new information, and then alter the corrective actions based on constantly updated information.

At the May 8 meeting the review team developed and recommends the following elements for the planning process:

First, the objectives. The process should start by defining the objectives of the restoration. In the small time we spent talking about objectives at the May 8 meeting, I understood some of the current objectives to be incompatible. Interested parties need to first determine their own objectives, state them to the other interested parties, and then work to produce a consistent list of objectives for the larger process.

Second, a diagnosis of the problem. The reviewers attempted to discuss the current situation in terms of hypotheses. As I mentioned above, we were able to reach some conclusions, such as the lake is not food limited. However, a full diagnosis will require more information.

Third, identification and selection of all potential courses of action. Some courses of action will be beneficial over a wide variety of diagnoses, and others may be helpful under one diagnosis but harmful under another. In any event, the purpose at this stage of the planning process is to identify all options.

Fourth, an analysis of the potential risks and benefits of each course of action.

Fifth, evaluation of how the recommended actions support the objectives.

Sixth, the selection of a treatment or other action.

The planning process must be dynamic so that each time effects cascade from the selected actions, these effects are monitored and measured. Monitoring, as a basis for selection of new treatments or actions, is what will be used for the next round of diagnosis and will be used to reevaluate the objective to ensure they are realistic and attainable.

CONCLUSION

I have been somewhat short of specific conclusions on what the biological problems are and what to do about them. That is because I think the actual diagnosis and recommendations for action should come from an ongoing and directed planning process with the authority to act. However, I don't want my lack of a commitment to a particular diagnosis to be misunderstood as some kind of evidence that the potential problems are too diffuse to identify and solve. We have good reasons to conclude that land-use issues are a large part of the reason for this sockeye population's decline, and to further conclude that land-use issues remain an important part of the problem in bringing about a recovery. We also have good reasons, for example, to conclude that nutritional problems and recent overfishing are not part of the problem. I am not trying to simply argue for more study. I am hoping a planning process can be put in place with the authority to act on the positively identified sources of mortality — as well as sources only suspected of causing mortality. Unless this process is put in place and effective actions follow, I predict this population is doomed within a fairly short period of time.

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**Recommendations for Developing an Approach for
the Restoration of Ozette Sockeye Salmon**

**Submitted by Lawrence Lestelle
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Recommendations for Developing an Approach for the Restoration of Ozette Sockeye Salmon

Introduction

This document provides my recommendations regarding efforts to replenish sockeye salmon in the Ozette River, Washington. These recommendations are given at the request of the National Biological Service as part of its work to review restoration efforts for Ozette sockeye salmon and to formulate a recommended approach for future direction.

I was invited, along with several other biologists from the Pacific Northwest and Alaska, to review information on the status of the population, then to submit my opinions regarding future restoration efforts. The panel of biologists heard oral presentation at a meeting convened at the Olympic National Park Headquarters in Port Angeles on May 8, 1996. Following that presentation, the panelists discussed the nature of the problem and a course for proceeding. Much of the content of my recommendations is consistent with that being submitted by the other panel members, though my emphasis may differ.

The Ozette sockeye salmon population and the fishery it supported have collapsed from levels that existed a half century ago. Whereas historic run sizes appear to have at least sometimes, perhaps often, exceeded 30,000 fish, they now typically range between 300 and 1,000 fish. Nehlsen et al. (1991) concluded that there is a moderate risk of extinction to the population as it now exists.

The task before the panel is analogous to a team of doctors reviewing the case history of a patient in need of further treatment. The medical team is asked for its recommendations for treating a certain patient. Of course, it would be foolish to recommend any treatment without first formulating a clear and rational diagnosis. In medicine, we would all agree that prescriptions should be founded on an understanding of the nature of the ailment and what treatments have been applied thus far. The job of restoring depleted fish populations is no less complicated, although we biologists too often fly more by the seat of our pants in formulating management strategies and restoration plans.

My recommendations focus on the job of diagnosing and prescribing rational treatments for the patient, Ozette sockeye salmon. I give no recommended treatment. We members of the panel, either individually or collectively, could not make a well founded diagnosis with the information presented and time provided. I believe it would be a disservice to attempt to do so. It would only perpetuate the notion that if the parties involved (i.e., Makah Tribe, National Park Service, etc.) could consult with the right "experts", the appropriate treatment might be found and the problem solved. I personally do not believe there exists such a group of experts. Instead, the answer, I

believe, will be found in the parties committing to a process of learning and management, consistent with achieving realistic objectives for the river system and its fish populations. My recommendations address such a process and some principles to help move the project in that direction.

I have organized the following discussion into three parts. The first explains how I perceive the nature of the decline of Ozette sockeye. Its cause is likely due to the cumulative effects of a number of concurrent (or back to back) events. Next, I describe five principles that I believe are helpful in guiding the formulation of restoration efforts. I provide my recommendations in the final section. The elements that the team developed jointly are woven into what I refer to as principles and into my recommendations, though I have expanded on these somewhat from our discussions in Port Angeles.

I am also forwarding four documents that I believe the parties will find useful in more fully explaining some of the concepts discussed here. The first of these is a document that we recently submitted to the Bonneville Power Administration. We refer to it as a primer for using a methodology developed over the past five years for formulating an ecosystem strategy to restoration. The document describes a number of concepts more fully than I can here. The other three documents are Lichatowich et al. (1995), a report dealing with supplementation in the Columbia Basin (RASP 1993), and a report on restoration planning in the Grande Ronde watershed (Columbia River).

Nature of the Decline: Concurrent Events and Cumulative Effects

How we view the nature of the decline of salmon populations is fundamentally important to how we attempt to restore them. I discuss this point at some length in the following to emphasize and clarify why it is crucial that we approach restoration activities in a manner differently than we often have in the past.

The decline of Ozette sockeye salmon has followed the same pattern as scores of other wild salmon populations in the Pacific Northwest. The declines can usually be correlated with the extent of intervention of 20th century society into the life histories of these animals. This observation may seem so obvious as to be trivial, but it deserves attention because biologists frequently ignore or gloss over it. The causes of the declines are clearly multi-faceted, having many sources. We have too often looked for the single overriding cause, or at least for a facet of the problem that we think poses the greatest threat. Solutions are then sought as kinds of “silver bullets”, like the use of hatcheries, the closure of fisheries, predator removal, or the placement of woody debris into streams.

I am not implying that restoration cannot employ these actions--it may. But consider how we have too often looked at the causes of salmonid declines. Huppert and Fight (1991) concluded that “some stocks are habitat-limited while others are limited by fishing mortality.” They suggested that when stocks are low due to insufficient escapement, that habitat improvement measures have

little effect on stock size. Similarly, the problem of Hershel and his band of sea lions at the Ballard Locks might be viewed as a form of fishing mortality; hence unless predator losses are diminished there can be no value in improving habitat. In the same manner, Reeves et al. (1989) concluded that unless “optimal escapement” is expected within five years that it is difficult to justify habitat improvement actions. They suggest that the solution to diminished runs is to reduce fishing or dam passage mortalities (or, perhaps, predator losses).

These views have been widespread. They explain why much of the region has been locked in debate over *which* of several possible problems is *the* principal problem with natural salmon production. The whole idea of “limiting factors analysis” is often thought of as an analysis to identify the “most limiting factor”, in order to address it. The point is that such a narrow view of diagnosing salmon declines fails to see how cumulative impacts affect resiliency, sustainability, and ecosystem stability.

In contrast, Bella (1995) suggests that our inability to better understand why salmon populations are declining is that our theoretical frameworks have not enabled us to grasp the severity of cumulative impacts. He asserts that subtle interactions of many diffused impacts have escaped notice using conventional analytical approaches. Such pervasive misperceptions, he notes, explain the decline of salmon stocks in spite of the scientific effort to protect them. Similarly, Frissel et al. (in press) conclude that today’s salmon crisis is due largely to an overly simplified view of how natural systems function and a failure to recognize the collective consequences of many changes in the environment. Mobrand et al. (1996) suggest that our conceptual framework for understanding salmon population dynamics has relied on a one-dimensional view of population performance, i.e., on habitat capacity. They suggest that we have failed to incorporate different aspects of mortality and related effects on life history diversity and sustainability.

The review of Jacobs et al. (1996) shows that a variety of factors have been considered as possibly causing or contributing to the collapse of the population. These include, among others, degradation of spawning habitat, excessive harvest, introduction of nonnative fish and plant species to Lake Ozette, disruption of competitive relationships within the lake’s fish community, and limitations of lake productivity. The relative importance of these factors to the decline is not known. But it is clear: dramatic changes have occurred to certain conditions that affect survival and abundance; these changes now prevent the population from rebounding to past levels. These changes may include many of the factors cited by Jacobs et al.

I discuss some of these factors in the remainder of this section to illustrate how I perceive that cumulative effects have potentially affected the Ozette population. Other scenarios than the one I describe exist. The point is that many factors have likely interacted to produce the conditions that currently exist.

There should be no doubt that the freshwater environment of Ozette sockeye has been changed dramatically over the past century. These changes have likely severely reduced the resilience and sustainability of many salmonid populations in the Ozette system, not just sockeye salmon.

Wholesale changes to the watersheds that drain to the lake began with homesteading around the turn of the century, then accelerated rapidly with the advent of commercial logging. While it is unclear to me exactly when logging took place in certain stream systems, it appears that in general it proceeded rapidly from the 1940s on (Jacobs et al. 1996).

The original timber type and geology of this area does not appear to be unlike that of much of the coastal area of Washington State. Its character appears to be similar to that of the lower Quinault River and Raft River located to the south, where I spent 16 years of my career. Much of this area is relatively flat or has low hills with steep draws in the headwaters of its streams. The original timber type in the Ozette likely consisted of a large amount of exceptionally large western red cedar, as existed on much of the land to the south.

Logging of old growth cedar in these areas typically resulted in severe disturbance to stream systems. I spent a number of years reviewing logging actions on the Quinault Reservation and researching their effects (Lestelle et al. 1976; Zasoski et al. 1977; Lestelle and Blum 1989). A report prepared by myself and John Blum in 1989 made an assessment of logging damages to the fisheries resources in this area. We documented numerous examples of severe habitat degradation due to heavy siltation and compaction associated with yarding large, extremely heavy cedar logs and the associated removal or destruction of in-stream structure that provided some measure of stability to streams over the centuries. Cedar windfall, which had accumulated in stream channels over time, would be pulled out during yarding operations because these logs were still commercially valuable. I personally observed many cases where streams located in cedar forests were changed from stable channels with high quality habitat to ones having extremely poor conditions for the survival of adult spawners, incubating eggs, emergent fry, and other life stages. I envision that such was the case on much of the land draining to Lake Ozette.

One approach that Blum and I used to examine the effects of logging was to compare trends of salmon catches in four rivers within the Quinault area. The rivers, from south to north, were the Moclips, Quinault, Raft, and Queets. All drain directly to the Pacific Ocean. All have been fished by the Quinault Tribe for centuries. These fisheries were conducted using gillnet from the early part of this century with fishing grounds established for each family who took part. Catch records have been maintained since about 1935. We assumed that catch trends in these rivers would reflect actions that took place within these watersheds (either from land use activities or the river fisheries themselves) and not from ocean fisheries up to the time when ocean fisheries escalated. Mortality in the ocean likely operated in the same manner on the populations from these rivers. Also, ocean fisheries from the 1930s through the 1950s did not appear to change much; effort levels burgeoned soon thereafter. Based on my knowledge of how the Quinault Tribe conducted its fisheries, I further assumed that these river fisheries were operated more or less in similar ways.

I believe the results of our comparisons between these rivers are telling. We found that catch trends of coho salmon paralleled the extent of logging that occurred in these watersheds during the 1940s through the 1950s. In the Queets River, where only a very small amount of logging took place until the 1960s, catch levels were stable, showing neither decline or increase. In

contrast, precipitous declines occurred in the Quinault, Moclips, and Raft rivers during the 40s and 50s where logging was rapidly liquidating old growth. We concluded that catch trends likely reflected the extent of logging that was occurring in each watershed during the period when ocean fisheries were relatively stable. The catches of coho salmon, it appeared, were good indicators of the changes that occurred to stream habitat.

I examined the catch data for coho salmon in the Ozette system to see if its pattern is like that of Quinault, Moclips, and Raft, or instead, like that for the Queets. I used the Ozette data in Jacobs et al.. The Ozette pattern shows a dramatic decline during the period when logging was likely occurring at a high rate, while the Queets pattern is stable (Fig. 1). I suggest that this picture is an indicator of how coho salmon habitat was changing in the Ozette system during this period. If this is true, then it also likely reflects how the spawning environment for stream spawning sockeye (to the extent they were present) was also changing.

Based on comments by several of the biologists at the workshop who are knowledgeable of Ozette streams, it appears that the effects of logging on stream stability may still be strongly evident. I posed a question to those present: How would the workshop participants judge the quality of potential sockeye spawning habitat in the basin with respect to density-independent survival on a relative scale, where a value of 1 would represent the highest quality of incubation habitat in nature and a value of 0 would be a total loss (100% mortality). For stream habitat, John Meyer and Ned Currence gave values of 0.1 and 0.2 respectively. Such poor survival was attributed to streambed instability and sedimentation. They guessed that prior to alteration from logging that relative survivals would have been close to a 1 on this scale. While these judgements are not empirical data, they show that experienced biologists see potential spawning habitat within Ozette streams as severely degraded. We use such an approach to document how biologists view past and present watershed conditions, based on their knowledge of on-the-ground conditions and relevant literature (see Lestelle et al. 1996).

The onset of logging apparently also resulted in changes to lakeshore spawning areas as a result of siltation from the inflow of nearby tributaries (Jacobs et al. 1996). These changes, together with known encroachment by exotic aquatic plants in these areas, appears to have affected both the quality and quantity of lake spawning beds. Posed with the same question as given above, Meyer and Currence gave values for relative survival in lakeshore spawning beds of 0.25 along the western shore and 0.20 along the eastern shore. Historic values, they said, would have approached a value of 1. In other words, they were of the opinion that the quality of lakeshore spawning beds has declined significantly, that there is some difference between the western and eastern shores, and that relative quality of these areas is better than in potential spawning streams. The exercise is useful in that it reveals how these biologists compare these habitats.

Concurrent to the rapid changes within the watersheds draining to Lake Ozette, other events that affected survival of sockeye salmon were occurring. One of these was tribal fishing within the Ozette River. In 1949, close to 20,000 adult sockeye were caught. This fishing was occurring in a relatively small river at a time (late spring and early summer) when freshets would not have been

Ozette and Queets Rivers Coho Catches 3 Year Means and Harvest Trends

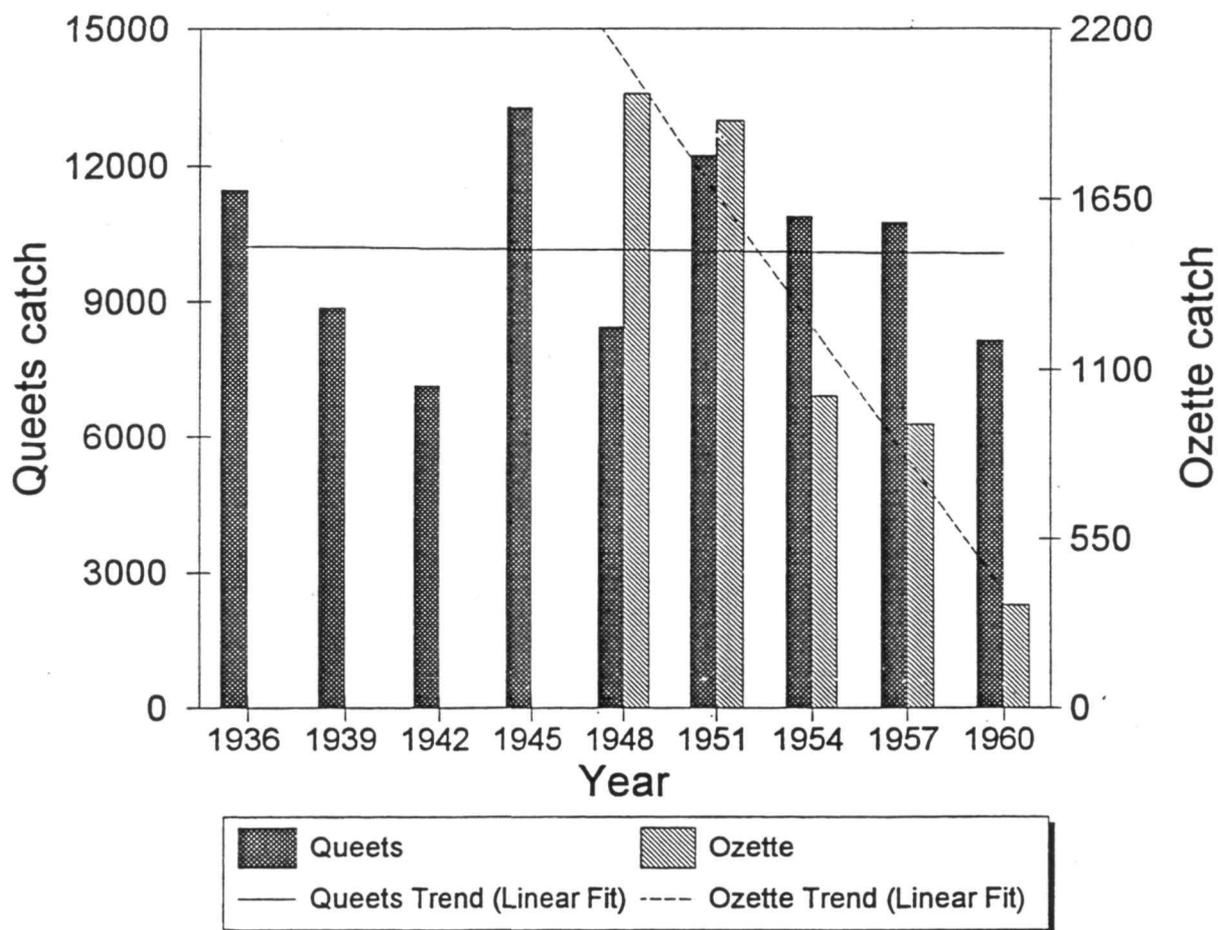


Figure 1. Reported gillnet catches of coho salmon in the Ozette and Queets rivers, 1936-1962. Ozette data begin in 1948; two years with zero catches listed (1959-60) were excluded from analysis. Data points represent three year averages, corresponding to the 3-year cycle for coho salmon in these rivers. Data sources: Washington Department of Fisheries (Brix and Kolb 1971 and Ward et al. 1976).

substantial and fishing gear could have been maintained without frequent washouts. The reader should be careful to avoid concluding that I am saying that overfishing was occurring. My point is not to say that fishing was *the* problem. Instead, it should be recognized that fishing was a real source of mortality, which was occurring at the same time that habitat was declining in quality. I believe it is reasonable to assume that the in-river exploitation rate was at least 0.4 or higher during the late 1940s and 1950s (i.e., at least 40% of the in-river run was likely being harvested). Moreover, gillnet fisheries are frequently size selective, as I believe they are for many in-river fisheries on the coast. Such selectivity can result in a reduced number of eggs for each spawner successful at reaching the spawning grounds (see Ricker 1981).

Other events were likely occurring as well while habitat quality was declining and harvest was taking place. Gilbertson (1981) presented evidence that unusually large floods occurred in the Washington coastal area in the late 1940s and 1950s (see also the discussion on this in Houston 1983) for the period 1911 to 1978. These floods coincided with the marked decline in the abundance of adult sockeye salmon in the Quinault River (on a brood year basis). It is noteworthy that Ozette sockeye showed substantial decline at the same time that Quinault sockeye trended downward (Fig. 2).^{1/} These same floods may have occurred in the Ozette area, which would have had similar adverse effects as suggested for Quinault, especially given the likely magnitude of logging-related changes that may have already been present.

Additional changes may have occurred in ocean conditions during this same period. Conditions for ocean survival appear to be cyclic (see Lawson 1993 and Lichatowich 1993).

The effects of the types of factors described above would likely have operated in a multiplicative manner, that is, they would have compounded over the life cycle of the animal. Factors that operate through density-independent processes can be easily conceptualized to operate in this manner. All too often biologists have ignored how such changes have been operative in salmon populations. Cumulative impacts of this kind reduce the sustainable loss rate (say, through harvest) that a population can experience without going to extinction or at least moving to a different state of nature. Such cumulative effects could have resulted in the loss of certain life history types within the population (like tributary spawners). They may have also resulted in a situation whereby predation now prevents the population from rebounding to previous levels of abundance (as discussed by Peterman 1977 and Peterman 1987). If the latter has happened, moving back to a former state of nature is not likely to happen in the near future, even with the kind of supplementation effort that the parties could feasibly mount.

^{1/} Quinault sockeye did not decline largely as a result of wide scale logging; these fish spawn upstream of Lake Quinault where logging has not occurred on the scale that it did downstream of the lake. However, changes still occurred to the watershed landscape due to land clearing associated with homesteading and farming along the river, combined with flood protection measures. These actions are believed to have destabilized river channels upstream of the lake and, in turn, affected sockeye salmon spawning areas (see Gilbertson 1981).

Ozette and Quinault Sockeye Catches River Gillnet 1936-1982

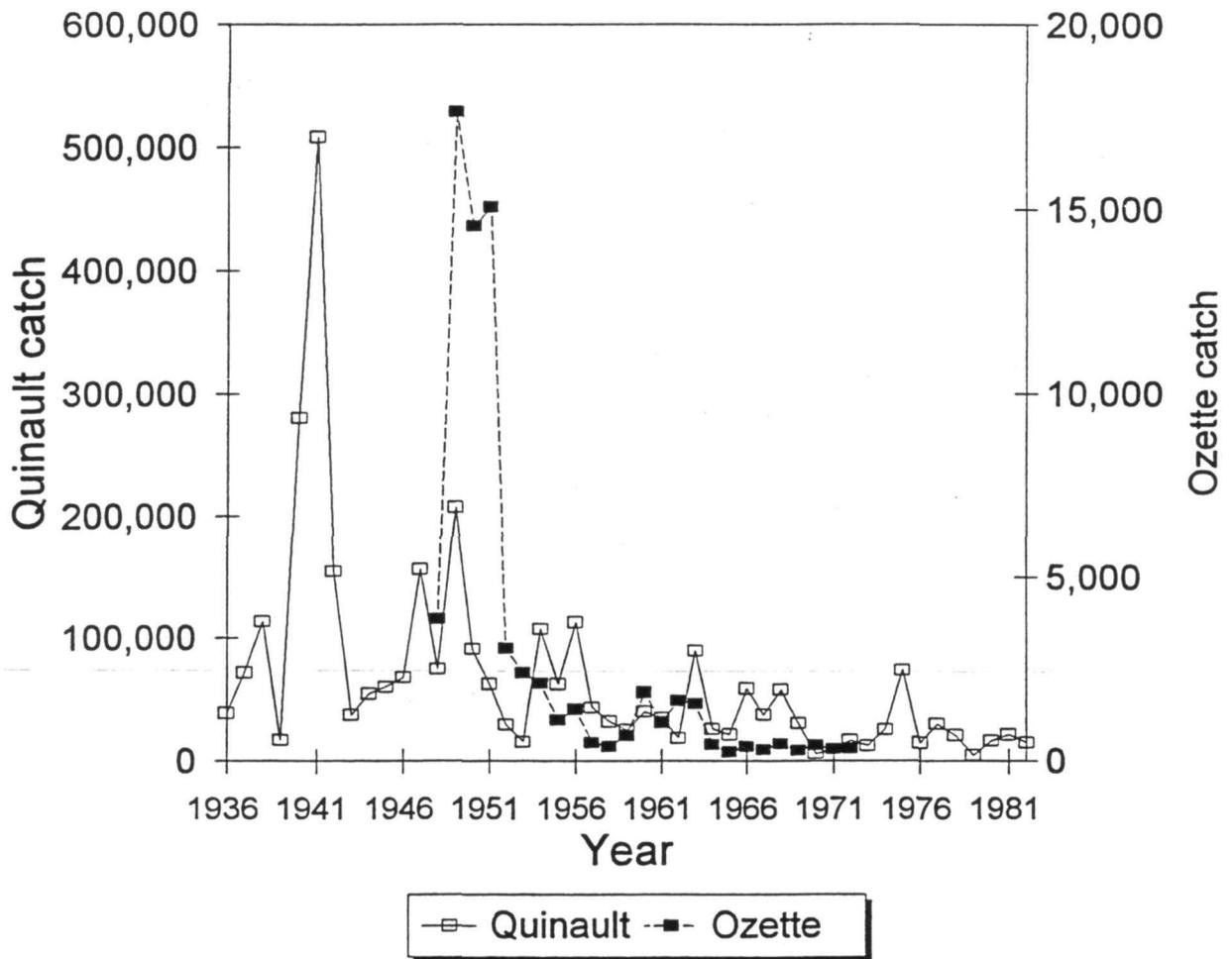


Figure 2. Reported gillnet catches of sockeye salmon in the Ozette and Quinault rivers, 1936-1982. Ozette data shown cover the years 1948-1972. Data sources: Washington Department of Fisheries and Quinault Indian Nation (Ward et al. 1976 and Gilbertson 1981).

General Principles to Guide the Formulation of Restoration Efforts

There are no quick fixes to reverse the declines that have occurred to the large number of salmon populations across the Northwest. As stated earlier, such techniques as supplementation and other technologies may be of use in addressing some of the factors affecting salmon performance—but new ways of looking at problems and solving them are needed. Many recent publications describe an emerging emphasis in management that calls for looking at resource management in a more holistic manner than we have in the past (e.g., Doppelt et al. 1993; Lee 1993; Lichatowich et al. 1995). The recent move towards "watershed analysis" within Washington State and by federal agencies is in response to the recognition that a new approach is needed.

A set of principles, or premises, have been proposed for proceeding toward the development of such a holistic approach, but one that also addresses the specific needs of salmonid species (Lichatowich et al. 1995; Lestelle et al. 1996). The recommendations that I present are founded upon these principles. I briefly describe each principle below; more complete descriptions can be found in the source documents.

1. *Restoration actions should be based on an ecosystem strategy.* Actions aimed at restoring depleted salmon populations should be built on, or be consistent with, ecosystem-directed strategies that promote or maintain ecologically healthy watersheds. Specific actions, aimed at improving habitat or to supplement natural populations, are best thought of as being tactics. Tactics address local, immediate, or short-term needs. In contrast, strategies address comprehensive and broad concerns often having a longer time horizon. Management actions are more likely to succeed if they are directed by, and consistent with, such an overall strategy—and one based on sound scientific principles. Management actions have too often been the result of tactical-level planning without the benefit of clearly formulated watershed strategies (Doppelt et al. 1993).

A management strategy based upon an ecosystem perspective provides a scientific basis for evaluating, coordinating, and prioritizing watershed actions in a consistent manner. Also, a true ecosystem strategy needs to incorporate human economies and values, as well, because people cannot be separated from nature (Grumbine 1994).

2. *Restoration actions should seek sustainability.* A primary management goal should be to ensure the sustainability of valued renewable natural resources. The most important challenge facing environmental management is to foster a balance between short-term human needs and ecosystem sustainability (Ruckelshaus 1989; Lee et al. 1992). Attempts at quick fixes usually do not address long-term sustainability due to the nature of cumulative effects described earlier.

Human communities generally desire that resource-based values and objectives associated with the water and land of a watershed be sustainable, even within the context of watersheds that have undergone major changes to accommodate human needs. The concept of sustainability must also recognize that ecosystems are constantly evolving. Management for sustainability must be

concerned, however, about the direction and rate of this evolution. All valued resources may not be concurrently sustainable in all watersheds.

In my view, the involvement of the parties at Ozette demonstrates a commitment to sustainability; this should continue and be explicitly stated in the objectives for the project.

3. *Salmon species can serve as indicators of watershed or ecosystem health.* Certain species or populations that are dependent on the relative stability of ecological processes over a large portion of a watershed can be used to help diagnose conditions for sustainability. The shift, described above, away from single species management of the past toward a more holistic approach poses a problem: How do we assess the condition of ecosystems, given their inherent complexity? The use of appropriately selected indicator or diagnostic species provides a way of coping with this complexity (Soulé 1987; Lee 1993).

Desired conditions for a watershed or ecosystem may be achieved through actions guided by the needs of populations that fill representative (umbrella species) or key (keystone species) functional roles within the ecosystem. This approach may be the most effective way currently available to achieve ecosystem sustainability (Olver et al. 1995; Walker 1995).

Migratory salmonid species, like sockeye or coho salmon, are highly suited to serve as diagnostic species. The characteristics of these species that make them useful in this regard include their dependency upon the stream system of the watershed and their sensitivity to varied habitat conditions across many life stages; their role in connecting ecosystems--marine to freshwater, lake to stream, and terrestrial to aquatic. They appear to fit well the definition of keystone species, given their potential role in the food web and in nutrient cycling. Their cultural significance to tribal communities is well known. Salmon also symbolize the vitality of the Pacific Northwest to many human communities.

I suggest that sockeye salmon are well suited to be used as a diagnostic species for formulating an overall watershed planning effort for the Ozette system. Consideration should be given to including coho salmon as well, given the likelihood of a wider distribution within the system.

4. *Restoration efforts need to employ the scientific method.* A management approach that seeks to follow the principles outlined above needs to employ the scientific method to improve understanding of the effects of human actions on ecological conditions and relationships over time. Kai Lee, in his highly stimulating recent book (1993) on resource management, states:

"Today, humans do not know how to achieve an environmentally sustainable economy...Human action affects the natural world in ways we do not sense, expect, or control. Learning how to do all three lies at the center of a sustainable economy."

If natural resources are to be managed in a sustainable manner, then actions need to be guided through a process that incorporates scientific learning.

Fundamental to this method of learning is the use of an explicitly conceptual framework within which information about the system of interest is gathered, analyzed and organized. A logical linkage between actions and events within the watershed and their effect on values and objectives must be presumed and explicitly addressed.

The scientific method promotes learning and assures accountability. Hypotheses and assumptions that are critical to the effectiveness of actions can be identified and tested. The scientific framework is the basis for providing useful and credible information to decision makers.

5. *Restoration efforts should be driven by a planning/decision process that is based upon learning by doing, referred to as adaptive management.* This approach to planning and decision making allows action in the face of scientific uncertainty (Walters 1986; Lee 1993). It serves two important functions: it provides assurance that actions are progressive—those actions that are effective are continued and those shown ineffective or damaging are discontinued; it also provides the means for an open decision making process whereby constituents (the public) have the opportunity to remain informed and participate. Both scientific information and community ("stakeholders") values must be effectively incorporated into the decision process.

Recommendations

1. *Establish a planning process that promotes learning and accountability in pursuing actions consistent with clearly formulated rationale and new information as it develops.*

Such a process should facilitate and promote the use of adaptive management for the project. Without this type of planning, projects can too easily "lock onto" a view of the world that stymies learning and prevents adapting actions as new information becomes available. Too often, it seems, the term "adaptive management" is just tacked onto a project to give it the right appearance. True adaptive management can only occur if the project is being shaped by an on-going and iterative planning sequence. This type of planning is never completed until the project is terminated.

I suggest that the parties consider adopting the planning process outlined in Lichatowich et al. (1995). It consists of a sequence of steps that requires consideration of new information and new thinking over the course of the project. It contains many of the elements that I describe in subsequent recommendations.

Use of a planning process like the one cited above will also require that the parties develop an effective vehicle for working together. This will require that roles and responsibilities be clarified and schedules for the various aspects of the project be established.

2. *Define and refine project objectives over the course of the project.*

Existing objectives are a good place to start. It wasn't clear to me what these objectives are for the parties. The steps in the planning process should lead the parties to refining objectives as it

becomes clearer what kinds of outcomes are realistic, both in the short and long-term. Some of these objectives should be measurable to determine whether the project is moving in the right direction. The objectives should also consider those outcomes that the parties are trying to avoid. The concept of "risk" involves, in part, the risk that objectives will not be achieved.

3. *Use existing information and new information as it develops to "diagnose" the condition of the populations of interest (i.e., sockeye salmon in this case).*

The diagnosis is critical component of the project. This isn't to say that the diagnosis is always accurate. It may not be. But, it is the basis for documenting how the parties perceive the problems that they are addressing by taking certain management actions. The diagnosis should be based on existing studies, information applied from outside sources, and from local knowledge about the conditions of the resource. The diagnosis contains many assumptions. But, the important point is that it documents those assumptions, rather than leaving them hidden as is so often the case.

One way to perform the diagnosis is using a technique referred to as Patient-Template Analysis (PTA). It requires that a comparison be made of healthy-sustainable conditions for the population (the template), as apparently existed prior to rapid watershed alterations beginning last century, to those now existing (the patient). True, historic conditions may not be clearly known. But the use of this technique requires that a consideration be made for at least one plausible scenario. More than one possibility may exist, leading perhaps to more than one diagnosis.

In performing such a diagnosis, one is also required to clarify the theoretical or conceptual framework that is used to consider population condition. This should in some way describe the theoretical basis for how one looks at the relationships between environmental condition and population performance. Is this theoretical basis consistent with what we know about the species and with the scientific literature about the responses of such populations?

One conceptual framework that I have found very useful is described in some detail in Lestelle et al. (1996). It is built on considering relationships between environmental condition and what we refer to as population performance. How the population performs, that is how it expresses itself through various life histories (such as lake spawning or tributary spawning) is in some fashion related to mortality processes operating on the population. These processes are affected by both the quality and quantity of habitat that members of the population utilize. How we view these relationships should affect how we diagnose the condition of the population and how it may respond to various types of actions. The point of this type of framework is not to "model" the population, nor to "predict" outcomes to specific actions. Instead, it is meant to be a catalyst for thinking. It should bring insights that may otherwise go unconsidered. It should also help to consider whether proposed actions can be supported by plausible and reasonable assumptions about how the population may respond.

Concepts related to population performance are described in Lichatowich et al. (1995) and

Lestelle et al. (1996). These concepts allow one to consider the cumulative effects of many changes to the population.

4. *Based on the diagnosis, identify and describe one or more possible strategies and associated actions.*

The strategy should deal more broadly with the course of treatment being considered; actions are those specific activities that would be implemented. Actions should be consistent with the strategy, as well as with the diagnosis.

5. *Analyze potential risks and benefits on the one or more courses of action being considered.*

This recommendation is not aimed at modeling and prediction per se. It is meant to require that some form of assessment be made about possible outcomes and how these relate to the objectives. Are the assumptions that need to be made to result in achieving project objectives plausible and reasonable? What alternative assumptions can be made? What monitoring measures can be implemented to identify surprise outcomes or those that are inconsistent with objectives?

The consideration of risk should also lead the parties to establish rules or criteria for actions. If supplementation is being pursued, what are the rules for broodstock capture, holding, and spawning? Similarly, what guidelines or rules are being followed with respect to pathogen control?

6. *Monitor and evaluate.*

In my view, the past actions that have been taken as part of this project have not been well monitored. If adaptive management is indeed to become more than just a phrase, then the parties need to be committed to monitoring and evaluating. I don't believe this type of project should proceed unless these elements are an integral part of the program.

At the workshop, we discussed possible priorities for monitoring and evaluating (including research). The number one priority was placed on maintaining monitoring of adults at the weir. I agree that this should continue. However, beyond that, I have reservations about recommending any other priority items. It is too easy to suggest things at this point, but I fear it may be putting the cart before the horse. Cost and feasibility need to be carefully considered. And most importantly, I believe that the monitoring and evaluation plan should be *based on* the preceding steps in the planning process. In some ways, it would be like us recommending a course of action based on the very sketchy and cursory "diagnosis" that we may have performed at the workshop. I would encourage the parties to commit to the principle of using the scientific method, which certainly is built on monitoring and evaluation, but to build the M and E plan in the context of the other planning steps.

Final Remarks

A few comments are in order about the potential role of supplementation in possible restoration efforts for Ozette sockeye salmon. I don't consider the continued use of this approach to be immediately obvious, based principally on whether the parties can be successful at doing what is necessary to avoid making matters worse for the population.

I think supplementation can offer benefits if approached carefully. The question is whether supplementation conducted the way it has been done (and may continue to be) can have a lasting, net positive effect, or whether it may exacerbate the problem. How likely is it that the survival of the progeny of spawners taken for broodstock will survive at a higher rate than those that would be produced if spawning occurs naturally? And, how is long-term fitness likely to be affected by a significant supplementation effort? These questions need to be addressed (see RASP 1993). I think it is a mistake if any of the parties believe that this approach could *quickly* turn the population upwards. I am not optimistic in this regard. If safeguards can be built into the project and survivals can be expected to be improved over natural levels, then I suggest that the greatest benefit of applying this tool would be as an aid to learning in building a successful restoration program. However, if the quality of the freshwater environment continues to decline, or ocean survival conditions turn worse, then supplementation is likely the only way of preventing extinction until conditions can be improved.

The team discussed whether supplementation (if it continues) should focus on increasing lake spawners or establishing a population of tributary spawners. There was not agreement on this matter. I tend to lean toward using the approach to increase life history diversity, if possible, because I tend to believe that one reason the population has crashed has been the demise of certain life history types. Dr. Burgner may have different views about whether tributary spawners existed within the recent past in this system. He is far more knowledgeable than myself on this matter. Still, I am inclined to feel that the lake spawning population may be faced with continued decline in the quality of its spawning environment. If so, the establishment (or reestablishment) of tributary spawners may be important. Limited results from supplementation to date suggest that this may be possible. It may be easier to improve habitat quality within tributaries as compared to the lake.

My final remarks are that I hope the parties proceed with a project to "restore" Ozette sockeye to a more productive state. I believe that such a project is fully warranted given its history and its values to the parties.

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