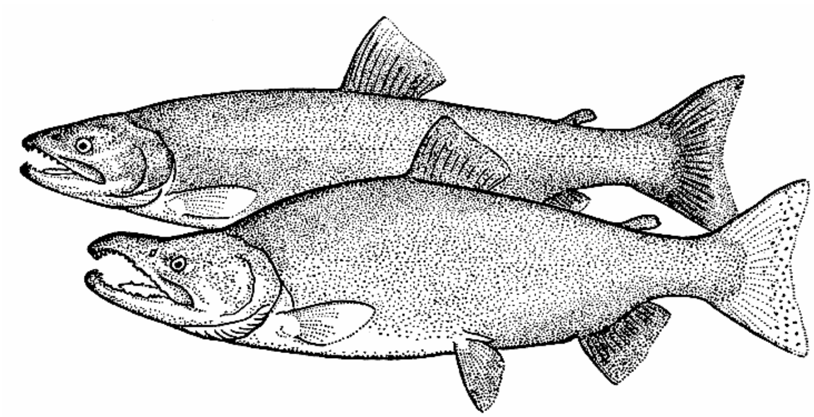
COSEWIC
Assessment and Status Report

on the

Sockeye Salmon
Oncorhynchus nerka

Sakinaw population

in Canada



ENDANGERED
2003

COSEWIC
COMMITTEE ON THE STATUS OF ENDANGERED WILDLIFE IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION DES ESPÈCES EN PÉRIL AU CANADA

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Cover illustration:
Sockeye Salmon — Mature Sockeye Salmon (female above, male below) (reprinted from Scott and Crossman, 1973).

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COSEWIC
Assessment Summary

Assessment Summary – May 2003

Common name
Sockeye Salmon (Sakinaw population)

Scientific name
Oncorhynchus nerka

Status
Endangered

Reason for designation
The Sakinaw population has unique genetic and biological characteristics (early river-entry timing, protracted lake residency before spawning, small adult size, low fecundity, large smolts). The lack of success with previous attempts to transplant sockeye to Sakinaw Lake and other lakes suggests that Sakinaw sockeye are irreplaceable. The Sakinaw population has collapsed primarily due to overexploitation, including directed and incidental catches in mixed-stock fisheries at levels above those that can be sustained. In addition, water flow and water level have at times been insufficient to allow adult fish to enter the lake. There are also ecological impacts on the lake habitat from logging, residential development and water usage. Because very few fish remain, the population is at high risk of extinction from even minor impacts from fishing, poaching, impediments to spawing migration, predation, habitat degradation and water usage.

Occurrence
British Columbia Pacific Ocean

Status history
Designated Endangered in an emergency listing in October 2002. Status re-examined and confirmed in May 2003. Assessment based on a new status report.

COSEWIC
Executive Summary

Sockeye Salmon
Oncorhynchus nerka

Species information

Sockeye salmon is one of seven species of the genus *Oncorhynchus* native to North America. In the ocean, adults have a slender, streamlined, silvery body and grow to an average of 3 kg. They undergo a distinctive transformation of external colour and body shape during their migration from the ocean back to the freshwater ecosystem from which they originated. The head becomes pale green in colour and the body becomes scarlet. Males also develop a hump, teeth and a sharply hooked jaw. The adults die soon after spawning but their progeny remain for several years in the freshwater environment (usually a lake) before migrating to the ocean. Dependence on nursery lake habitat, which is discontinuous by its nature, requires precise homing that divides the sockeye salmon species into isolated populations. The isolated populations typically evolve unique migratory, spawning and rearing behaviours as adaptations that improve survival in the natal freshwater environment. This differentiation into finely tuned, locally adapted populations accounts for the high productivity and commercial importance of the species; it also means that these populations would be very difficult, if not impossible to replace should they be lost.

This status report evaluates the distinct population of sockeye that inhabits Sakinaw Lake, British Columbia (henceforth called Sakinaw sockeye). Protein electrophoresis and molecular DNA analyses indicate that Sakinaw sockeye are genetically distinct and substantially reproductively isolated from other BC sockeye salmon populations. Sakinaw sockeye also have different life history characteristics including early, but protracted, timing of river-entry, extended lake residence prior to spawning, small body size, low fecundity and large smolt size, indicating that Sakinaw sockeye are evolutionarily distinct from other sockeye populations.

Distribution

Sakinaw sockeye are endemic to Canada, in the sense that they reproduce and rear for two or three years (over half their life) exclusively within Sakinaw Lake, situated on the Sechelt Peninsula in Georgia Strait, British Columbia (BC). Because they are anadromous, they also share marine migration corridors and foraging habitat in the north Pacific Ocean with many other sockeye salmon populations. A few non-anadromous individuals have been found in Sakinaw Lake, but it is not yet known whether these are male progeny of anadromous females (i.e., “residual sockeye”, and part of the anadromous gene pool) or members of a genetically distinct, self-perpetuating population of smaller bodied, exclusively freshwater sockeye (called “kokanee”). As a species, sockeye salmon occur in North America from the Columbia River (Oregon, Washington, and Idaho) north to Kotzebue Sound, Alaska, and in Asia, from the southern Kuril Islands north to the Anadyr River. Populations have declined in abundance or become extinct in the southern parts of their range on both sides of the Pacific Ocean. Migratory (anadromous) sockeye no longer occur naturally in California or Japan, although non-migratory kokanee populations exist.

Habitat

Sakinaw sockeye require suitable spawning and juvenile rearing habitat within Sakinaw Lake, and foraging habitat for smolt and immatures in the north Pacific Ocean to attain adult size. Like other anadromous populations, they also require unobstructed passage between these habitats. Sakinaw Lake has a surface area of only 6.9 km^2, a mean depth of 43 m and a mean euphotic zone depth of just over 15 m. Chemical, temperature and salinity conditions are rare and unusual because Sakinaw Lake is meromictic with a 30-m freshwater layer overlying warm, anoxic salt water; this prevents seasonal mixing and results in strong thermal stratification. In summer, the epiliminion extends to 7 m depth and becomes too warm for sockeye, but below this there is cool, well-oxygenated habitat that is rich in zooplankton and very suitable for rearing juvenile sockeye. Primary productivity in Sakinaw Lake is higher than in other coastal BC lakes but lower than in most lakes of the Fraser River system including Cultus Lake.

The availability of suitable spawning habitat probably constrains maximum population size more than the availability of lake rearing habitat. Unlike most sockeye salmon populations, Sakinaw sockeye spawn almost entirely within the lake itself on five beaches near creeks or other sources of ground water. The shoreline perimeter is 35 km but most is unsuitable for spawning because eggs and alevins require clean, well-oxygenated, gravel substrates during their development until they emerge as fry.

Sakinaw Lake has an elevation of only 5 m and drains directly into Georgia Strait by a short stream. A dam on the outlet controls water storage and adult sockeye gain access to the lake through a fishway. Seaward migrating “smolts” must pass through the Georgia and Johnstone straits to reach the north Pacific Ocean where they spend two summers before returning to Sakinaw Lake by the same route. In the ocean, sockeye salmon typically inhabit cool (2-7ºC) surface waters (less than 15 m) and those from British Columbia generally remain north of 48ºN and east of 160ºW.

Biology

Most Sakinaw sockeye spawn in late November; all die after spawning and their carcasses are eaten or decompose in the lake. The females construct nests (called “redds”) in gravel substrate and bury their eggs immediately after fertilization. Eggs and alevins remain buried during the winter. Free-swimming fry emerge in early May and move to limnetic habitat where they feed primarily on zooplankton. The timing of fry emergence is likely synchronized with spring plankton blooms. Synchronization requires that for each lake, the spawning time and/or embryonic development rate be genetically adapted to ambient temperature regimes in the spawning environment.

As with fry emergence, each sockeye salmon population usually has its own life history adaptations that determine the age (size) and seasonal timing for smolting, a physiological adaptation to the saline marine environment and seaward migration. Most Sakinaw sockeye become smolts in April of their second year, and exit the lake via a short (<500 m) creek into Georgia Strait. Although Sakinaw sockeye smolts are large (100 –150 mm) at age 1+ relative to other sockeye populations, some remain in the lake for another winter and become even larger smolts, migrating at age 2+. It is presumed that Sakinaw sockeye smolts migrate northwest through Johnstone Strait into the Gulf of Alaska, together with smolts from other sockeye populations in the Fraser River. The timing of sea entry can greatly determine the mortality imposed by seasonally migrating (warm-water) marine predators.

Most Sakinaw sockeye mature at age 4 after spending two winters at sea. During the return migration, individuals migrate southeast through Johnstone and Georgia straits, but are thought to turn northeast at the end of Sabine Channel to reach Sakinaw Lake. They enter Sakinaw Lake in June through September even though peak spawning does not occur until late November. As a result, they are small at maturity compared with other sockeye populations in Canada, and their fecundity is at the low end of the species' range, averaging only 2,500 eggs.

Population sizes and trends

Sakinaw sockeye abundance has declined dramatically since 1987. From 1947 (when records began) to 1987, the estimated number of (maturing) adults entering Sakinaw Lake averaged about 5,000 individuals (range 750 to 16,000) with no declining trend. From 1987 to 2002, numbers declined, averaging just over 1000 adults per year between 1988 and 1992, less than 200 between 1993 and 1996, and less than 50 between 1997 and 2001 (between 1999-2002, less than 80). In 2002, adult sockeye were carefully enumerated; only 78 were counted entering the lake, and only 44 were observed on the spawning grounds.

A statistically robust estimate of decline rate from regression analysis using 1-generation smoothed estimates of mature abundance (based on annual counts of mature adults between 1988 and 2002, and smoothed to 1990-2001) reveals a decline rate of 33% per year, which implies a reduction of 99% over 3 generations. Using only endpoints, there has been an 87% or larger reduction in the number of adult Sakinaw sockeye estimated to enter the lake over the last 3 generations (1991-2002; 4 years per generation).

Limiting factors and threats

The persistence of the Sakinaw sockeye population is threatened by two primary factors: mortality from fisheries, and degradation of freshwater habitat. At present, fishing mortality is probably the single greatest threat. Sakinaw sockeye continue to be killed in fisheries, and given their very low abundance, even modest fishing mortality may jeopardize the viability of the population. Over-fishing can also be considered the proximate cause of decline in the sense that fishing effort was not reduced significantly until 1998 despite the observed decline in spawning escapements to Sakinaw Lake that began in 1987. Sakinaw sockeye are captured during their migration to Sakinaw Lake through Johnstone and Georgia straits together with sockeye and pink salmon from more productive salmon populations, in what are termed 'mixed-stock fisheries'. The fact that Sakinaw sockeye are vulnerable to these fisheries, and that escapements decreased rapidly during a short period of consistently high fishing effort, strongly suggests that fishing mortality was excessive.

The vulnerability of Sakinaw sockeye to overfishing likely increased as their productivity was eroded by habitat degradation within Sakinaw Lake. The most significant degradation of habitat within Sakinaw Lake was probably due to logging activities in the first half of the 20th century. The lake was used as a log dump, millpond and booming ground. To assist in transporting logs to the ocean, the lake's outlet was dammed sporadically to raise water level, and this likely reduced the access for migrating sockeye. These practices largely ended by 1952 when a permanent dam with a fishway was built. Residential development and recreational boating subsequently increased. Stream flows were diverted to prevent flooding and a boat ramp was constructed through the middle of one of the major spawning beaches. Again, most of this degradation occurred prior to 1987. The BC Fish and Wildlife Branch attempted to augment the natural population of sea-run cutthroat trout in Sakinaw Lake by stocking a quarter million juveniles between 1965 and 1989. The consequences for Sakinaw sockeye are unknown but cutthroat trout are predators of juvenile sockeye. Sockeye migration into the lake may also have been adversely affected by reduced summer flows resulting from increased human utilization of water throughout the drainage.

There is little possibility that neighbouring sockeye populations could rescue Sakinaw sockeye naturally, within a human lifetime or perhaps longer, given the extremely restricted gene flow and the degree of local adapation. It is also doubtful that humans could successfully transplant sockeye into Sakinaw Lake should Sakinaw sockeye go extinct. Several previous attempts to plant sockeye from other populations into Sakinaw Lake have almost certainly failed because there is no genetic signature of the donor populations. Thus, the extinction of Sakinaw sockeye should be considered irreversible.

Fisheries and Oceans Canada (DFO) is taking several conservation actions. Fishing effort has been reduced significantly since 1995 in Georgia Strait and since 1998 in Johnstone Strait following fleet reduction and fishing restrictions imposed for conservation reasons. Area 16 (including Sabine Channel adjacent to Sakinaw Lake) was closed to commercial fishing in 2002 to protect Sakinaw sockeye; this closure did not reduce food and ceremonial fishing by First Nations however. DFO is also co-ordinating habitat restoration activities including the clearing of logging debris from spawning beaches, modifications to the fishway to improve water flow for migrating adults, and increased surveillance to discourage poaching and natural predation at the fishway where adults are most vulnerable. Hatchery supplementation was also initiated in 2000. However, it is not known whether hatchery supplementation can restore an endangered salmon population, and thus, contributions by naturally breeding adults remain a prudent component of any recovery plan.

Special significance of the species

Sockeye salmon are economically the most important species of Pacific salmon, contributing to commercial, recreational, and aboriginal catches along the Pacific coast of North America. The number of extant populations has declined in the southern parts of the species' range. Currently, ESUs of North American sockeye salmon are considered endangered in four locations: two in Canada (Sakinaw Lake and Cultus Lake, BC) and two in the United States (Ozette Lake, Washington and Snake River, Idaho). The Sakinaw Lake population is one of only two anadromous lake-type sockeye salmon populations situated in the 200-km length of Georgia Strait (the other is Village Bay Lake on Quadra Island, 100 km distant at the extreme northern end of the strait). The conservation of Sakinaw sockeye is a high priority for the Sechelt Indian Band because these fish return to reproduce within the band's traditional territory. Sockeye salmon may also play a significant role in maintaining the productivity of the Sakinaw Lake ecosystem, including a variety of animal and plant life, by importing marine-derived nutrients. The juveniles contribute to the complexity of the lake's food web, consuming invertebrates and serving as prey for native fish, birds and mammals. Returning adults are consumed by many species, including river otters, bears and lampreys, and the carcasses provide food for bald eagles and other species. Thus, Sakinaw sockeye play a significant role in the ecology of the Sakinaw Lake ecosystem.

Existing protection or other status designations

The federal *Fisheries Act* has long required that DFO authorize proposed alterations to habitat. In addition, provincial and municipal governments regulate many land and water use activities that can affect fish populations. DFO is mandated to manage fisheries to conserve the resource for the benefit of all Canadians. To date, none of these protections have prevented the collapse of Sakinaw sockeye. However, mixed stock fishing effort was significantly reduced in 1998 and DFO has recently assigned a recovery team to co-ordinate restoration activities. These actions are consistent with the federal *Oceans Act* (1997) that requires DFO to manage Canada's marine resources to conserve biological diversity and natural habitats. In fall 2002, COSEWIC conducted an Emergency Assessment and listed Sakinaw sockeye as *Endangered* (25 October 2002). NatureServe lists sockeye salmon as *Secure* (G5) as a species, but *Critically Imperiled* in Idaho (S1), *Imperiled* in Washington State (S2), *Apparently Secure* (S4) in Oregon, *Secure* in Alaska (S5) and *Under Review* in California and British Columbia.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) determines the national status of wild species, subspecies, varieties, and nationally significant populations that are considered to be at risk in Canada. Designations are made on all native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fish, lepidopterans, molluscs, vascular plants, lichens, and mosses.

COSEWIC MEMBERSHIP

COSEWIC comprises representatives from each provincial and territorial government wildlife agency, four federal agencies (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership), three nonjurisdictional members and the co-chairs of the species specialist groups. The committee meets to consider status reports on candidate species.

DEFINITIONS

Species	Any indigenous species, subspecies, variety, or geographically defined population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.
** Formerly described as "Not In Any Category", or "No Designation Required."
*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

Sockeye Salmon
Oncorhynchus nerka

Sakinaw population

in Canada

2003

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SPECIES INFORMATION

Name and classification

Sockeye salmon, *Oncorhynchus nerka* Walbaum 1792, is in the order Salmoniformes, family Salmonidae, and is one of seven Canadian species in the genus *Oncorhynchus*, of which five are Pacific salmon and two are trout (Smith and Stearley 1989, Stearley and Smith 1993). Common names include “blueback salmon”, “red salmon”, and “saumon rouge” or “saumon nerka” when anadromous, and “kokanee” or “little redfish”, among others, when non-anadromous (Scott and Crossman 1973).

Description

Oncorhynchus species are distinct from other salmonids in having 12 or more rays in their anal fin. Sockeye salmon are unique from other *Oncorhychus* salmonids by having 28 to 40 long, slender, closely spaced gill rakers on the first arch, relatively few (45-115) pyloric caeca, and fine black speckling on their back (Hart 1973, Mecklenburg et al 2002). At sea, both sexes are metallic dark blue to greenish blue on the head and back, with silver sides fading to white below. At spawning, they become red with olive green heads. Males are more brilliantly coloured and develop elongate hooked jaws and humped backs at maturity (Figure 1). Sockeye salmon can reach a total length of 84 cm and weigh up to 7 kg, but their spawning size varies with age of maturity; both age of maturity and size at age vary widely among populations (Foerster 1968). Precocious males (“jacks”), which spend only one winter at sea, are common in some populations (Burgner 1991). Kokanee typically mature at a smaller size and may lack brilliant colouration because they feed on small freshwater zooplankton throughout their life.

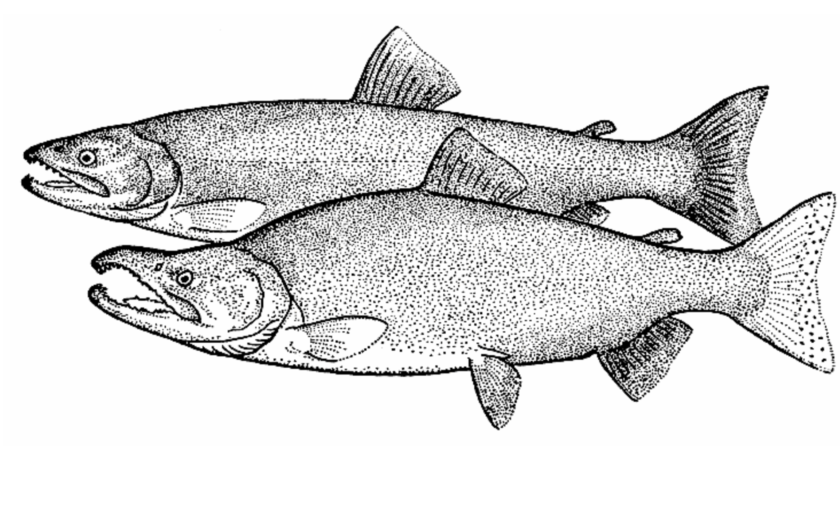

Figure 1. Mature sockeye salmon (female above, male below) (reprinted from Scott and Crossman 1973).

Nationally significant populations

Like most salmon, sockeye salmon exist as reproductively isolated populations; however, sockeye salmon populations are discrete at a much smaller geographical scale than most other salmon (Wood 1995). This is because juvenile sockeye salmon typically rear in nursery lakes, which by their nature are discontinuous and geographically isolated, and often very different in physical and biotic characteristics (e.g., temperature and water flow regimes, nutrients, light penetration and primary productivity, competitors and predators, parasites and diseases, and factors that challenge anadromous migration). Reproductive isolation among sockeye salmon populations inhabiting different lake environments promotes the evolution of unique adaptations to the local freshwater environment. Consequently, sockeye populations can differ considerably in life history traits and phenotypic characters (reviewed by Foerster 1968, Burgner 1991). The special significance of fine scale population structure and local adaptation in sockeye salmon is reflected in decisions by the US National Marine Fisheries Service (NMFS) that individual nursery lakes may be Evolutionarily Significant Units (ESUs): e.g., Redfish Lake (Snake River), Osoyoos Lake (Okanogan River), Lake Wenatchee, Quinault Lake, Ozette Lake, Baker Lake (Baker River), and Lake Pleasant (Gustafson et al. 1997). Two of these, Redfish Lake and Ozette Lake, have been listed under the US Endangered Species Act as Endangered and Threatened, respectively.

The sockeye population in Sakinaw Lake (henceforth Sakinaw sockeye) warrants similar designation as an ESU (or Nationally Significant Population). An ESU is defined as a population or group of populations that (1) is substantially reproductively isolated from other conspecific population units, and (2) represents an important component of the evolutionary legacy of the species (Waples 1991). As described by Gustafson et al. (1997), designation of an ESU follows a two-part test: reproduction isolation, and local adaptation (evolutionary legacy). Sakinaw Lake sockeye qualify under both parts of this test.

Evidence for Sakinaw sockeye reproductive isolation — Several surveys of genetic variation in allozymes (Wood et al. 1994), microsatellite DNA (μsatDNA, Nelson et al. 2003) and mitochondrial DNA (mtDNA, Murray and Wood 2002, Wood unpubl. data) demonstrate significant reproductive isolation between Sakinaw sockeye and other anadromous sockeye populations in the region (Figure 2). Pairwise-F_{ST} statistics[1] based on comparisons of allele frequencies at 10 μsatDNA loci between Sakinaw Lake sockeye and the nearest other sockeye populations range from 0.06 (Koeye Lake, Area 9) to 0.13 (Heydon Lake, Area 13 and Nimpkish River (Woss Lake) in Area 12) (Table 1, above diagonal; some of these lakes are shown in Figure 7). These values (0.06 – 0.13) are large relative to those observed in other species over comparable distances and suggest that successful reproduction following immigration into Sakinaw Lake from other populations has been very rare; estimates of historical gene flow are less than 4 and 2 successful migrants per generation, respectively, under the usual assumptions for calculating gene flow based on allele frequencies at equilibrium between genetic drift and migration (Wright 1951).

[1]F_{ST} statistics are a measure of genetic differentiation among populations commonly used to infer gene flow.

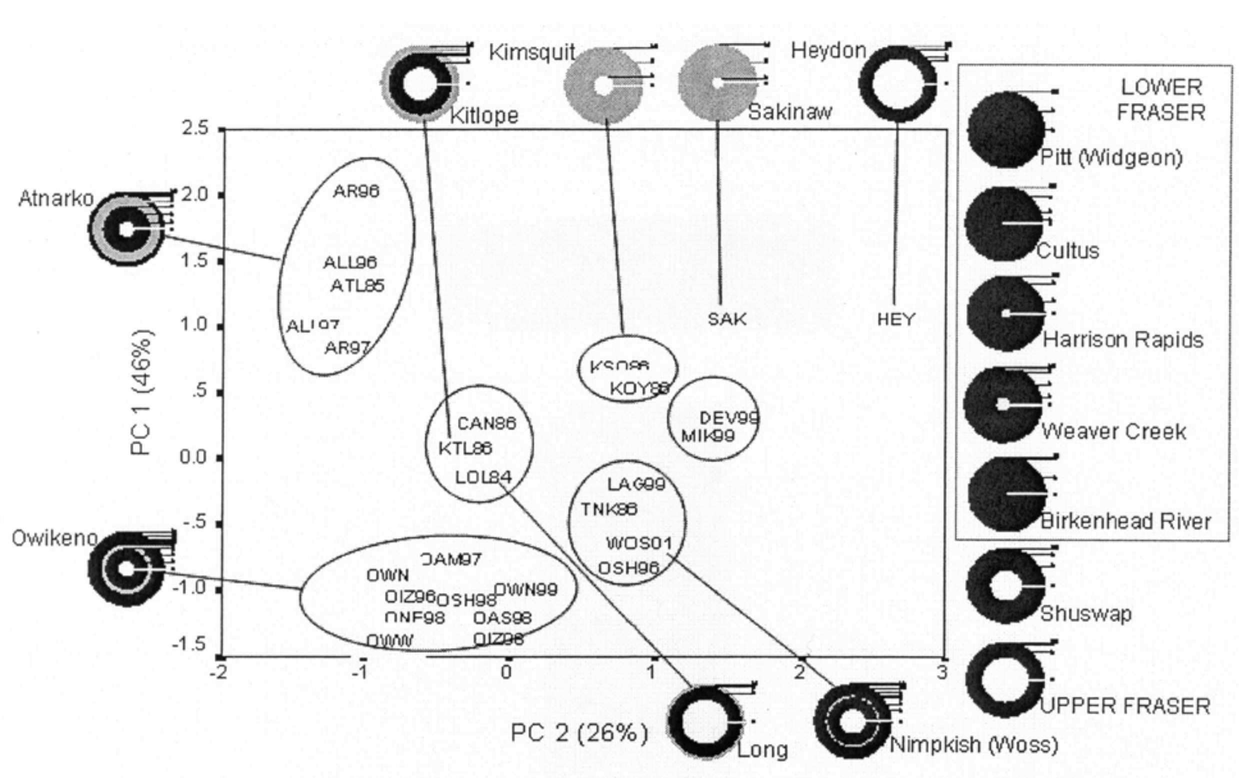

Figure 2. Principal components analysis of Cavalli-Sforza and Edwards' genetic distance between central coast sockeye populations based on differentiation at 10 microsatellite DNA loci (from Nelson et al. 2003). Pie diagrams indicate relative frequencies of mitochondrial DNA haplotypes (haplotype #1 is shown as white, haplotype#5 as grey, all others as black). Fraser River populations are included for comparison because they were the source of attempted transplants to Sakinaw Lake (from Murray and Wood 2002).

With one exception, pairwise-F_{ST} statistics based on comparisons of mtDNA haplotype frequencies (Table 1, below diagonal) range from 0.33 (Atnarko river system, Area 8) to 0.60 (Heydon Lake), indicating even lower rates of gene flow (0.5 to 0.2 female migrants per generation) than those based on allele frequencies in nuclear DNA. The exception is Kimsquit Lake which is indistinguishable using mtDNA; however, a very large difference in allele frequency (16% versus 66%) at the *PGM-1* locus, and smaller differences at two other allozyme loci (Wood et al. 1994), together with the μsatDNA differences in Table 1 (F_{ST} =0.09), confirm that this is a coincidental result of random genetic drift rather than continuing gene flow between Kimsquit and Sakinaw lakes.

Evidence for local adaptation — Sakinaw sockeye are distinct from other sockeye populations in the Pacific Northwest (data summarized by Gustafson et al. 1997) in terms of their early and protracted river-entry timing, extended lake residence prior to spawning, small body size and low fecundity at spawning, large size at smolting and unusual incidence of age 2+ smolts despite large size at age 1+. These characteristics are described further in the 'Biology' section.

Table 1. Pairwise Fst statistics for mitochondrial DNA (below diagonal, from Murray and Wood 2002) and microsatellite DNA (above diagonal, from Nelson et al. 2003).

Population		Sample size		Population number																				
No.	Name	mtDNA	msatDNA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	UPPER FRASER	158	--	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	Shuswap	19	--	0.06	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3	Birkenhead River	25	--	**0.36**	**0.39**	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	Weaver Creek	23	--	**0.25**	0.04	**0.45**	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	Harrison Rapids	25	--	**0.22**	0.07	**0.18**	**0.10**	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	Cultus	25	--	**0.36**	**0.24**	**0.48**	**0.15**	**0.25**	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	Pitt (Widgeon)	13	--	**0.53**	**0.40**	**0.84**	**0.20**	**0.43**	**0.52**	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8	Sakinaw	27	113	**0.51**	**0.56**	**0.79**	**0.55**	**0.61**	**0.60**	**0.86**	0	**0.13**	**0.13**	**0.08**	**0.09**	**0.06**	**0.12**	**0.09**	**0.11**	**0.10**	**0.13**	**0.11**	**0.10**	**0.09**
9	Heydon	24	34	**0.10**	**0.11**	**0.60**	**0.22**	**0.35**	**0.30**	**0.60**	**0.60**	0	**0.14**	**0.11**	**0.12**	**0.13**	**0.17**	**0.15**	**0.15**	**0.09**	**0.16**	**0.11**	**0.11**	**0.12**
10	Nimpkish	24	50	**0.17**	0.03	**0.47**	0.04	**0.18**	**0.23**	**0.32**	**0.47**	**0.11**	0	**0.06**	**0.03**	**0.08**	**0.10**	**0.11**	**0.11**	**0.08**	**0.11**	**0.04**	**0.10**	**0.10**
11	Long	25	51	-0.01	**0.09**	**0.42**	**0.28**	**0.24**	**0.36**	**0.65**	**0.56**	**0.13**	**0.18**	0	**0.04**	**0.06**	**0.08**	**0.06**	**0.07**	**0.05**	**0.10**	**0.05**	**0.08**	**0.08**
12	Owikeno	59	104	**0.20**	**0.05**	**0.38**	0.03	**0.14**	**0.20**	**0.25**	**0.38**	**0.16**	0.02	**0.20**	0	**0.06**	**0.08**	**0.09**	**0.06**	**0.05**	**0.06**	**0.04**	**0.09**	**0.09**
13	Koeye	--	80	--	--	--	--	--	--	--	--	--	--	--	--	0	**0.09**	**0.09**	**0.07**	**0.07**	**0.10**	**0.07**	**0.08**	**0.08**
14	Atnarko River	79	52	**0.26**	**0.09**	**0.44**	**0.06**	**0.19**	**0.25**	**0.22**	**0.33**	**0.21**	**0.04**	**0.26**	0.04	0.00	0	**0.15**	**0.11**	**0.08**	**0.09**	**0.08**	**0.12**	**0.11**
15	Kimsquit	13	62	**0.41**	**0.39**	**0.72**	**0.42**	**0.49**	**0.48**	**0.81**	0.00	**0.43**	**0.31**	**0.39**	**0.27**	**0.24**	--	0	**0.15**	**0.08**	**0.12**	**0.07**	**0.12**	**0.14**
16	Tankeeah	--	78	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	**0.06**	**0.12**	**0.12**	**0.11**	**0.10**
17	Lagoon	--	50	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	**0.09**	**0.07**	**0.08**	**0.09**
18	Canoona	--	79	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	**0.08**	**0.14**	**0.15**
19	Kitlope	15	41	0.02	0.04	**0.36**	**0.18**	**0.15**	**0.27**	**0.59**	**0.45**	**0.13**	**0.10**	-0.02	**0.11**	**0.16**	--	**0.25**	--	--	--	0	**0.10**	**0.11**
20	Mikado	--	62	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0.00
21	Devon	--	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0

Local adaptation accounts for the widespread failure of attempts to transplant sockeye salmon runs from one lake system to another (Withler 1982, Wood 1995) or of restoring wild salmon populations in modified habitat (Williams 1987). Mitochondrial DNA data reported by Murray and Wood (2002, Table 1) provide compelling evidence that all five attempts (each year from 1902-1906) to transplant sockeye fry to Sakinaw Lake from various locations in the lower Fraser River and from Shuswap Lake have failed. Only two mtDNA haplotypes (distinct maternal lineages) were found in adult sockeye spawning in Sakinaw Lake in 1988, 2000, and 2001. These are designated haplotype#5 and haplotype#1. Haplotype#5 was predominant in Sakinaw Lake sockeye at a frequency of 88% (±12% 19 times out of 20). But haplotype#5 was absent in samples from the Fraser River, including samples from all of the original donor lake systems. Except for haplotype#1, none of the haplotypes observed in the donor lake systems (#1, 2, 3, 4 and 6) were observed in Sakinaw Lake. Haplotype#1 is almost ubiquitous throughout the whole Asian and North American range.

To save the hypothesis that transplanted sockeye may have survived in Sakinaw Lake, it would be necessary to assert that the mtDNA samples are not representative, for reasons not yet understood, and that more extensive sampling would change these conclusions; or that haplotype composition has changed such that the Fraser River donor populations once had a very high proportion of fish carrying haplotype#5 and that these have died out; or that only a minority of transplanted fish (those carrying haplotype#1) survived in Sakinaw Lake. Because the haplotypes differ only in a few redundant nucleotides (third base pairs), they are almost certainly not expressed phenotypically and are considered "invisible" (neutral) to natural selection. Thus, such postulated changes in haplotype composition could only occur by chance (genetic drift) and would be extremely unlikely given the sample size of introduced fish (380,000 fry over five years).

In conclusion, Sakinaw sockeye warrant designation as an Evolutionarily Significant Unit or COSEWIC Nationally Significant Population based on the two-part test developed to define salmonid “species” under the US Endangered Species Act. Protein electrophoresis and molecular DNA analyses indicate that Sakinaw sockeye are substantially reproductively isolated from other populations. Their distinctive life history characteristics (early river-entry timing, protracted adult run timing, extended lake residence prior to spawning, small body size, low fecundity and large smolt size) suggest that they are also evolutionarily distinct from other sockeye populations in North America. The evidence for very restricted gene flow between Sakinaw and other populations, and the distance to the nearest extant sockeye population both confirm that there is virtually no possibility of natural rescue from neighbouring sockeye populations. All previous attempts to transplant sockeye to Sakinaw Lake have almost certainly failed. Consequently, we cannot be optimistic about prospects for re-establishing a sockeye run to Sakinaw Lake if the native population were to become extinct.

DISTRIBUTION

Sakinaw sockeye salmon reproduce only in Sakinaw Lake, situated on the Sechelt Peninsula in the Strait of Georgia, British Columbia, and thus, can be considered endemic to Canada. However, they share marine migration corridors and foraging habitat in the north Pacific Ocean with many other sockeye salmon populations. The following summary is included to provide perspective on the distribution and trends in distribution of sockeye salmon at the species level.

Global range

Typically, sockeye salmon are an anadromous species occurring naturally throughout the north Pacific Ocean and in accessible rivers north of 40° N. In North America they occur naturally in the Columbia River (Oregon, Washington, and Idaho), north through British Columbia, the Yukon, southeast and western Alaska as far north as Kotzebue Sound (Figure 3); in Asia they occur from the southern Kuril Islands and Komandorskiy Island to the northwest coast of the Sea of Okhotsk, throughout Kamchatka and north to the Anadyr River (Foerster 1968, Burgner 1991). Both the overall abundance and geographic density of these populations are highest in Kamchatka, western Alaska and British Columbia.

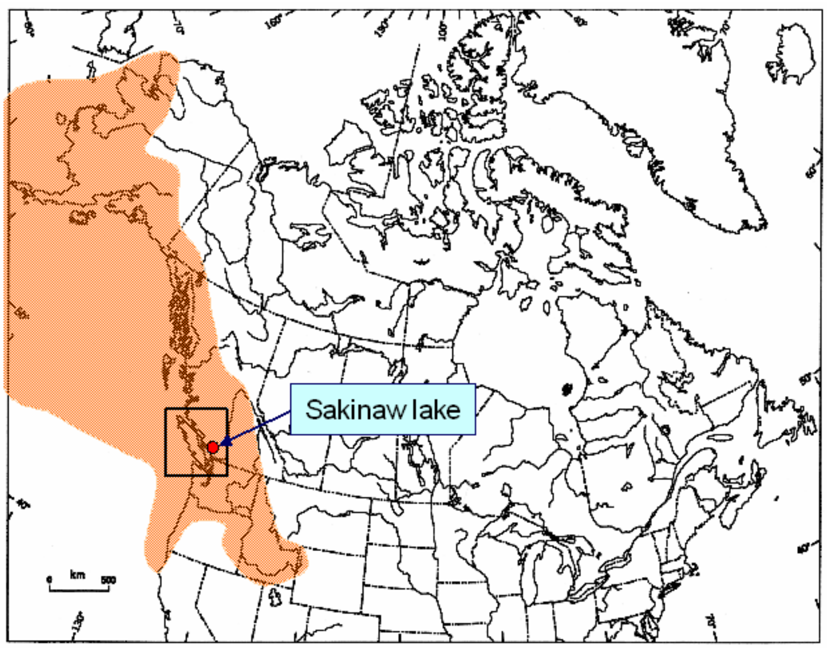

Figure 3. Natural range of sockeye salmon and kokanee within North America (highlighted area, after Wood 1995). The heavy box indicates the area included in Figure 7.

Anadromous sockeye salmon have generally declined in abundance in the southern parts of their range (Ricker 1982, Gresh et al. 2000). They no longer occur naturally in Hokkaido and California, although some populations persist as non-anadromous kokanee. Dams now preclude anadromous runs to large areas of the Columbia River and other smaller drainages in the contiguous United States and British Columbia. Several summary articles (Konkel and McIntyre 1987, Nehlsen et al. 1991, Wilderness Society 1993, Botkin et al. 1995; Slaney et al. 1996) suggest that numerous local populations of sockeye salmon in the Pacific Northwest have become extinct, and that the abundance of many others is depressed.

Canadian range

In Canada, anadromous sockeye salmon occur in many rivers accessible from the Pacific Ocean, from the Fraser River to the Alsek River, and in headwaters of the Columbia River (Okanagan). On occasion, they have also been reported in the Arctic Ocean and MacKenzie River (D. Chiperzak, DFO, unpubl. data). Non-anadromous populations (kokanee) are widespread in Pacific drainages, especially in the Fraser River and coastal lakes that have become inaccessible to anadromous sockeye through isostatic rebound following deglaciation. Kokanee are also known to occur in a few locations in the Arctic drainage adjacent to the Fraser drainage (the Liard and Peace rivers, C.J. Foote, Malaspina University College, pers. comm.).

HABITAT

Habitat requirements

Sakinaw sockeye salmon have the same general habitat requirements as sockeye salmon in other populations (described by Foerster 1968, Burgner 1991). Sakinaw sockeye require suitable spawning and rearing habitat within Sakinaw Lake to reproduce, and foraging habitat in the north Pacific Ocean to attain adult size. Like other anadromous populations, they also require unobstructed passage between these habitats. Seaward migrating “smolts” must pass through the Georgia and Johnstone straits to reach the north Pacific Ocean where they spend two summers before returning to Sakinaw Lake by the same route. In the ocean, sockeye salmon typically inhabit cool (2-7ºC) surface waters (less than 15 m) and those from British Columbia generally remain north of 48ºN and east of 160ºW (French et al. 1976). Their survival is affected by conditions in all these habitats, but maximum population size is probably limited by the availability of suitable spawning and rearing habitat within Sakinaw Lake.

Limnology of Sakinaw Lake

Sakinaw Lake has a surface area of only 6.9 km2 and a perimeter of 35 km (Shortreed et al. 2003). It has two distinct basins (Figure 4). The lower basin is the largest with a maximum depth of 140 m and a mean depth of 43 m. The upper basin is small and shallow with a maximum depth of only 40 m. Both basins are clear with a mean euphotic depth of just over 15 m (Shortreed et al. 2003). The overall drainage basin is only 64 km2 but includes a number of small streams and lakes of which Ruby Lake is the largest with a maximum depth of 112 m.

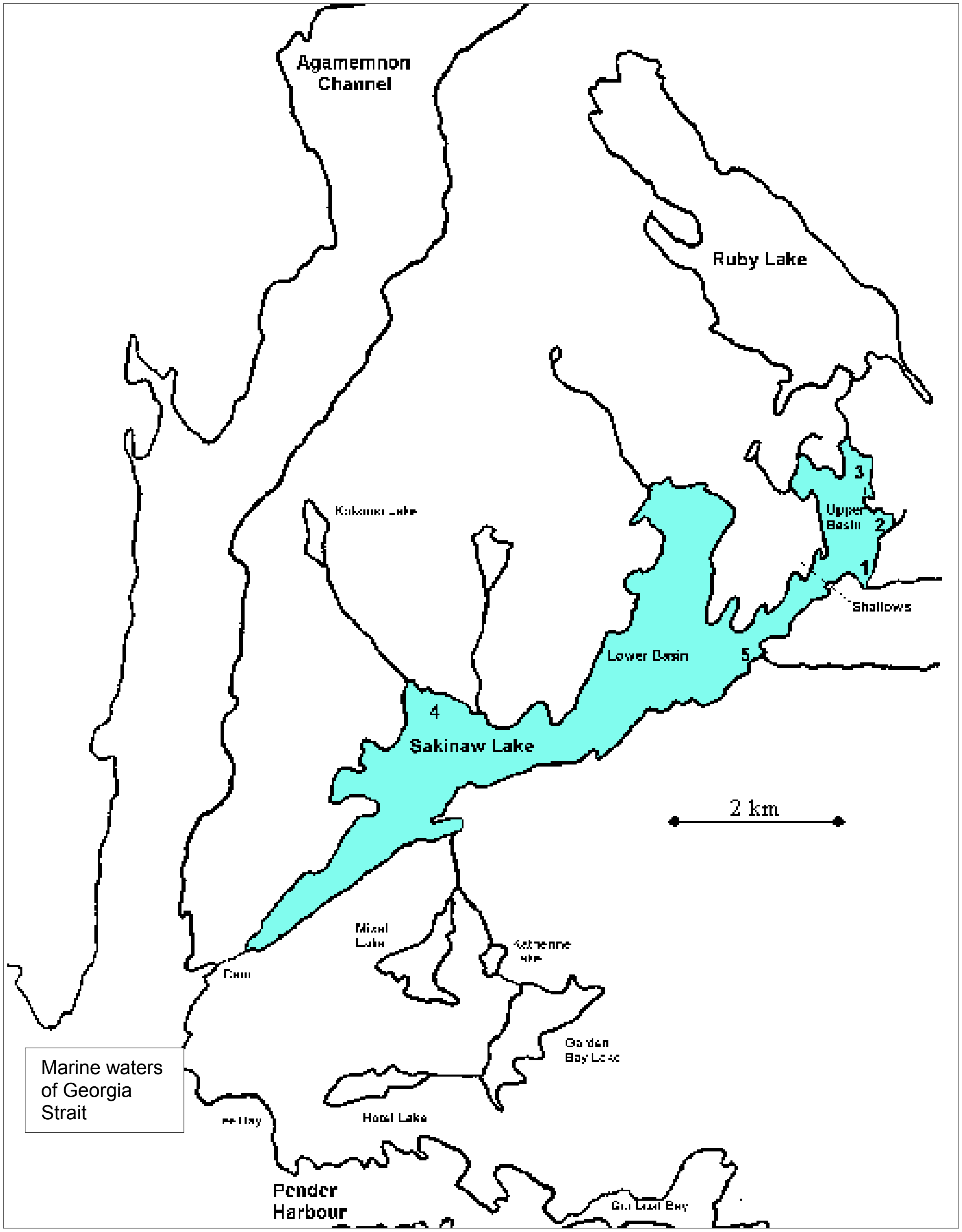

Figure 4. Sakinaw Lake, its tributaries and spawning beaches. Beach 1 (Sharon's Creek); Beach 2 (Haskins Creek); Beach 3 (Ruby Creek Bay); Beach 4 (Kokomo Creek Bay) and Beach 5 (unnamed) (from Murray and Wood 2002).

Chemical, temperature and salinity conditions are rare and unusual because Sakinaw Lake is meromictic with a 30-m freshwater layer overlying warm, anoxic salt water (Northcote and Johnson 1964); this prevents seasonal mixing and results in strong thermal stratification (Hutchinson 1957, Walker and Likens 1975). In summer, the epiliminion extends to 7 m depth and becomes too warm for sockeye, but between 7 m and 30 m there is cool, well-oxygenated habitat that is rich in zooplankton and very suitable for rearing juvenile sockeye (Shortreed et al. 2003). Overall primary productivity in Sakinaw Lake is higher than in other coastal BC lakes but lower than in most lakes of the Fraser River system including Cultus Lake (Shortreed et al. 2003). Total dissolved solid content ranges from 113 to 140‰. Temperature, salinity and conductivity all increase markedly with depth between 30 and 60 m. Temperature increases from 5°C to a maximum of 9°C at 60m. Salinity continues to increase slightly with depth attaining a maximum value slightly over 11‰. A strong smell of hydrogen sulfide is evident in water samples from below 30 m, and samples from below 60 m may froth when brought to the surface. There is no evidence of sea water intrusion into the upper basin.

Spawning habitat in Sakinaw Lake

Unlike most sockeye salmon populations, Sakinaw sockeye spawn almost entirely on beaches within the lake itself, presumably because the water flow in tributary streams is either inadequate (many go dry at their mouths) or especially subject to scouring during heavy rain. Upwelling ground water is probably essential for beach spawning in Sakinaw Lake. Spawning has been observed to a depth of 25 m, apparently only near alluvial fans in places where the gravel is small enough to be readily dislodged by digging (G. McBain, DFO, pers. comm).

A survey of the lakeshore carried out in 1979 revealed that only a small portion of the shoreline was suitable for beach spawning. No large spawning sites were found in the lower (main) basin and subsequent investigation there has focussed on two small spawning areas. Spawning on all beaches was restricted to depths between 0.25 and 25 m with the greatest density of nests (redds) occurring between 3 and 10 m. All major beach-spawning areas occurred near creeks or other obvious sources of ground water. There was considerable evidence of habitat degradation as all spawning beaches were littered with forest debris and supported aquatic plants to a depth of 3 m. Most spawning sockeye were observed in the upper basin of the lake; of these, almost all (95%) were observed within the area that would have been most affected by a foreshore development proposal.

The most serious habitat degradation occurred prior to the diver survey in 1979, but degradation has continued. Dive surveys in 1999 and 2000 indicate that the sockeye are now using only 15% of the area of Beach 1 (900 versus 6,000 m^2). Beach 2 is no longer being used, and the suitable habitat there is only 25% of that available in 1979 (1500 versus 6000 m^2). Old spawning areas not presently used by sockeye are covered with thick mud, organic debris and large logs. Visual surveys of other spawning areas in 2000 and 2001 that examined the bottom looking through the water surface, suggest that similar degradation had occurred to the spawning habitat at Beaches 3, 4 and 5. (G. McBain, DFO, pers. comm.)

BIOLOGY

Life history forms

As a species, sockeye salmon make greater use of lakes for juvenile rearing than do other Pacific salmon. With the exception of river-type and sea-type populations that are widespread but not abundant, the vast majority of sockeye salmon spawn in or near lakes. Sockeye salmon are typically anadromous, but non-anadromous forms of the species also occur, maturing, spawning and dying in fresh water without entering the ocean. These forms are called kokanee when they are genetically distinct from anadromous sockeye, or “residual sockeye” when they are the (mostly male) progeny of anadromous sockeye. A few non-anadromous males have been found in Sakinaw Lake, but it is not yet known whether these are residual sockeye or kokanee. Two specimens provided to the author in April 2002 had the mtDNA haplotype#5 that is predominant among anadromous sockeye. Thus, there is not yet evidence to argue that these non-anadromous individuals can persist without the anadromous form, or could rescue the sockeye population in Sakinaw Lake. Moreover, kokanee are known to be relatively abundant in Ruby Lake that flows into Sakinaw Lake and slippage of juveniles from Ruby into Sakinaw could occur from time to time (G. McBain, DFO, pers. comm.).

Reproduction

Sockeye salmon enter Sakinaw Lake throughout the summer from June to September with peak migration ranging from 20 July to 17 August over 40 years. Spawning does not occur until late fall, peaking in late November, with mean start and end times ranging from 20 October and 11 December over the same years. This behaviour of returning early, foregoing feeding opportunity in the ocean, and holding in the natal lake for three or four months before spawning is atypical of sockeye salmon but it is not uncommon in coastal lakes, apparently as an adaptation to prevailing temperature regimes (Hodgson and Quinn 2002).

Sockeye salmon have a high fecundity (2,000 - 5,200) and small egg size (5.3-6.6 mm in diameter) relative to other salmon of the same size (Burgner 1991). Fecundity in the Sakinaw Lake population is at the low end of the range for sockeye salmon, averaging 2,517 in 69 females collected for broodstock in 1986, 1987, 2000 and 2001; egg size averaged 5.6 mm in diameter and 300 mg in 15 females sampled in 2001 (Murray and Wood 2002).

Sakinaw Lake sockeye salmon rely on incubation habitat within the nursery lake, typically along the shoreline in areas of upwelling water near alluvial fans. Choice of incubation habitat affects the availability of dissolved oxygen and the thermal regime (hence development rate) during incubation, as well as exposure to predation and access to the nursery lake. Experiments have confirmed that both the timing of spawning and fry orientation behaviour (rheotaxis) at emergence exist as genetic adaptations to local conditions in sockeye salmon (Raleigh 1967; Brannon 1967, 1972, 1987).

Peak fry emergence would occur around 6 May (157 days after the peak spawning date of 19 November) based on empirical relationships described by Murray (1980) and the in-gravel temperature regime measured at one spawning beach in 1999-2000. Although similar at fertilization (9°C), in-gravel temperature on the spawning beach was more stable during incubation than in adjacent Mixal Creek, remaining just above 6°C from January to April. In contrast, temperatures in Mixal Creek declined to 3°C by February, then increased to 12°C by April. Lower incubation temperatures will produce larger fry for a specified egg size (Beacham and Murray 1986).

Nutrition and growth

Throughout the species' range, sockeye salmon fry typically emerge free-swimming at 25-32 mm. They feed initially near the lake shoreline, subsequently shifting to the deeper waters of the limnetic zone. Juvenile sockeye are visual predators, feeding primarily on copepods *(Cyclop*s, *Epischur*a, and *Diaptomu*s), cladocerans *(Bosmi*a, *Daphni*a, and *Diaphanosom*a), and insect larvae (Burgner 1991). Growth is influenced by food supply, water temperature, stratification and the length of the growing season, lake turbidity and migratory movements to avoid predation (Goodlad et al. 1974, Burgner 1991). Food availability also depends greatly on the density of juvenile sockeye (Johnson 1961) and other limnetic fish, especially threespine sticklebacks (*Gasterosteus aculeatus*, O'Neill et al. 1987), peamouth chub (*Mylocheilus caurinus*) and sympatric populations of kokanee (Wood et al. 1999). Faster growth rates can increase the survival of sockeye salmon during lake residence and subsequently through increased smolt size (Ricker 1962, Koenings and Burkett 1987, Henderson and Cass 1991)

Sakinaw Lake sockeye smolts are larger (100-150 mm) than those produced in most other nursery lakes. They are similar in size to those produced in Lake Washington, a very productive nursery lake for sockeye salmon (Doble and Eggers 1978, Burgner 1991). Comparison of scales from adult fish reveal that freshwater growth in Sakinaw Lake exceeds that for all other sockeye populations in B.C. (Y. Yole, DFO, pers comm.). Most juvenile sockeye remain in Sakinaw Lake for only one winter (as free-swimming fish) before migrating to sea. Surprisingly, some (about 3%) remain for two winters and become even larger smolts. It is widely believed that smolt age in salmon is influenced primarily by growth rate but that size thresholds for smolting are heritable (e.g., Thorpe et al. 1982) and vary as adaptations among populations, presumably reflecting different tradeoffs in size-specific survival in the freshwater and marine environments. Smolts from coastal populations are typically smaller and younger (implying a lower smolt size threshold) than interior lakes of comparable productivity. From this perspective, the Sakinaw Lake population is atypical of coastal populations.

Most anadromous Sakinaw Lake sockeye salmon mature and return to spawn at age 4 after spending two winters at sea. This life history is denoted age 1.2 reflecting the single freshwater (winter) annulus and two marine annuli on their scales; thus, the age at maturity is the total number of annuli plus one, because no annulus is formed during the first winter of embryonic development. Age composition, by brood year, averages 3% age 3 (1.1), 87% age 4 (1.2 and 2.1), and 10% age 5 (1.3 and 2.2). Despite their large size at smolting, Sakinaw Lake sockeye are small at maturity compared with other sockeye populations in Canada and the Pacific Northwest (Gustafson et al. 1997). The mean postorbital-hypural length of 10 spawners collected in 2001 was 445 mm (468 mm for males, n=5, SD=1.8; and 428 mm for females, n=5, SD=9.6). Mean weights for sockeye salmon passing through the Sakinaw fishway from 1957 to 1972 ranged from 1.81 kg (n=29) to 2.10 kg (n=15). By comparison, sockeye salmon of the corresponding age (2 winters at sea) average 2.73 kg in the Fraser River and 2.56 kg in Bristol Bay (Burgner 1991).

Survival

Juvenile survival has not been investigated in the Sakinaw Lake population but juvenile sockeye in other populations are often exposed to intense predation by a variety of fish and bird species both during lake residence and during early seaward migration (Burgner 1991). In nearshore and open ocean environments, predation by fish, birds, and marine mammals, and competition for food resources with other fish species affects growth and survival of sockeye. Ocean growth and survival of Pacific salmon can be affected by periodic, warm water events (El Niño) in local waters, and by changes in ocean conditions in the North Pacific Ocean (e.g., Francis 1993; Beamish et al. 1997, Mueter et al. 2002a, 2002b).

Potential fish predators of juvenile sockeye in or near Sakinaw Lake include cutthroat trout (*O. clarki*), juvenile coho salmon and chinook salmon (*O. tshawytscha*), prickly sculpin (*Cottus asper*), and lampreys (*Lampetra tridentata* and *L. ayresi*). Round scars apparently inflicted by lampreys were observed on coho salmon smolts during a snorkel survey below the outlet dam on April 26, 2002 (Bates and August 1997). Numerous lamprey scars were also observed on spawning adult sockeye in 2002. These observations lend support to earlier reports (J.D. McPhail, UBC, pers. comm.) that a parasitic, non-anadromous form of *L. tridentata* inhabits Sakinaw Lake. Principal bird predators include the common loon (*Gavia immer)*, red-necked grebe (*Podiceps grisegena)*, common merganser (*Mergus merganser)*, belted kingfisher (*Megaceryle alcyon)*, osprey (*Pandion haliaetus)*, bald eagle (*Haliaeetus leucocephalus*) and various gulls (*Larus* sp.). Mammalian predators of adults likely include river otters (*Londra canadensis*), harbour seals (*Phoca vitulina*), killer whales (*Orca orcensis*), American mink (*Mustela vison*) and black bears (*Ursus americanus*). Seals and river otters are common near the lake outlet and likely eat both smolts and adults within the small Sakinaw estuary and nearby Agamemnon Channel. About 10-15% of adult sockeye passing through the fishway between 1957 and 1987 were scarred. Most scarring is probably due to commercial gillnets or illegal fishing; seals (T.Gjernes DFO, pers comm.) and river otters (G. McBain, DFO , pers. comm.) have been observed chasing or feeding on salmon near the lake outlet and may also contribute to scarring.

Predation on migrating salmon is typically depensatory (e.g., Wood 1987) so its role in limiting smolt-to-adult survival could have increased as the abundance of Sakinaw Lake sockeye salmon declined. However, this would depend on trends in abundance of alternative prey including other salmonids. An aquaculture site established at Daniel Point (just south of Sakinaw) during the early 1990s may also have attracted mammalian predators and increased their abundance in proximity to fish migrating to and from Sakinaw Lake.

Migratory behaviour

Smolt migration out of Sakinaw Lake begins during early April and extends to mid-June, peaking in early May. The migration period was similar during four years of smolt enumeration (1994-1997, Bates and August 1997) with slight shifts in peak migration, which were perhaps affected by changes in lake discharge, temperature and weather.

Adult Sakinaw sockeye are known to arrive in Johnstone Strait as early as 28 June based on a 1975 study of catch composition using scale pattern analysis (Henry 1961, Argue 1975). Tagging experiments by the IPSFC indicate that Fraser River sockeye salmon migrate from the western end of Johnstone Strait to Area 16 in 7 to 14 days at a swimming speed of 40 to 56 km per day (Verhoeven and Davidoff 1962). The only tagging data available for Sakinaw sockeye is for a single fish released on 10 August 1925 in Deepwater Bay (Area 13) and recovered eight days later in Sakinaw (recorded as Sauch-en-auch) Creek (Williamson 1927). These limited data on timing of arrival in Johnstone Strait (late June) and time required for migration through Johnstone and Georgia straits (7-14 days) are consistent with more extensive observations of the timing of arrival at Sakinaw Lake. During 34 years of visual enumeration at the fishway (commencing in late June) the mean date of first arrival was 7 July, ranging from 28 June to 15 July. The mean date of the last recorded arrival was 29 August ranging from 10 August to 28 September. The mean date of peak migration was 30 July ranging from 20 July to 17 August. The mean seasonal duration of the run was 53 days (range 33 to 88 days) with the longest duration and highest abundance occurring in 1975, a year that fishing mortality was minimal because of a general fishing strike in late July and August. Low water flow and high water temperature can delay or disrupt migration into Sakinaw Lake.

POPULATION SIZES AND TRENDS

Indices of spawning abundance

Because all sockeye salmon die after spawning, and always in the same year that they attain maturity, the number of mature fish in the population is usually estimated as the number of fish that survive to spawn. In most populations, this is roughly equivalent to the numbers that survive coastal fisheries and reach their natal spawning habitat (called the “spawning escapement”). Estimates of spawning escapement to Sakinaw Lake are recorded for 1947 to 2002 in DFO’s Salmon Escapement Data System (SEDS). In most years, between 1949 and 1989, the SEDS estimate is based on counts of sockeye entering Sakinaw Lake through the fishway and is considered a reasonably reliable index of both relative and absolute abundance (see discussion in Murray and Wood 2002). Enumeration at the fishway was discontinued between 1990 and 2001, but the number of sockeye spawning on beaches was estimated by various methods of unknown reliability and consistency.

SEDS estimates show no obvious trend between 1947 and 1987, fluctuating between 750 and 16,000, and averaging about 5,000. Although this population has never been "actively managed", the target escapement suggested by DFO is 14,000 sockeye (DFO 1988). Since 1987, escapement estimates have decreased steadily (Figure 5). Summarized by 5-year intervals, reported escapements between 1988 and 1992 averaged just over 1000 (range 500 to 2500); between 1993 and 1996, less than 200 (range none observed to 250); and between 1997 and 2001, less than 50 (range 1 to 122). To some extent, enumeration effort and inconsistent methods will have affected the accuracy of the yearly estimates from 1989 through 1998, but the overall decline is undoubtedly serious. More systematic dive surveys of the spawning grounds conducted in 1999 through 2002 yielded estimates from 14 (23 redds) to 122 spawners (60 redds). In 2002, sockeye were enumerated both at the fishway and by dive survey, allowing a direct comparison; the fence count was 78 whereas the diver count on the spawning beaches was only 44 (G. McBain, DFO, pers. comm). These results suggest that dive surveys may underestimate true abundance, although this seems surprising in view of the excellent viewing conditions, and opportunity for inadvertently counting the same fish again on a subsequent survey. Alternatively, these results may indicate that sockeye experience significant mortality after they enter Sakinaw Lake. The latter explanation seems plausible because sockeye enter the lake several months before spawning, and are vulnerable to predation, especially by a non-anadromous parasitic lamprey (probably *Lampetra tridentata*). All spawning sockeye captured as broodstock in 2002 bore lamprey scars although none had fresh wounds (G. McBain, DFO, pers. comm.)

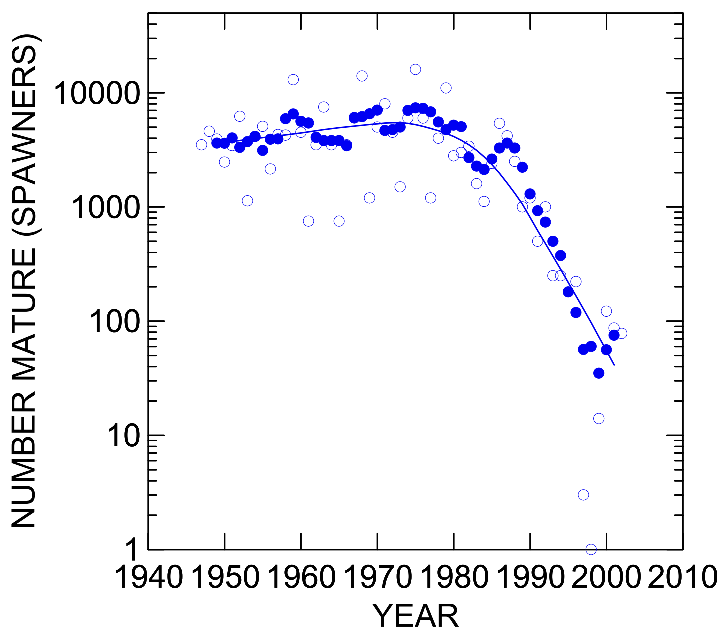

Figure 5. Trends in number of mature individuals in the Sakinaw Lake sockeye salmon population. Open circles are annual estimates of spawning escapement; filled circles are the corresponding estimates smoothed over one-generation (4 yr); line is fitted to smoothed data by LOWESS.

Annual counts of spawning fish should represent all mature fish in the population in each year, but they often fluctuate widely because of year-to-year variations in brood year (parental) abundance and survival. To remove annual "noise" unrelated to any underlying trend in population status, spawner counts should be smoothed, for example by computing a running average over one-generation. The (negative) slope of a straight line fitted to a smoothed time series plotted on a logarithmic abundance scale will provide the best estimate for a constant rate of decline caused by an underlying threatening process. This procedure also facilitates comparison with threshold rates of decline that trigger designation under the IUCN Criteria. Annual escapement data for Sakinaw Lake sockeye from 1988 to 2002 were smoothed with a 4- year running average to generate a 3-generation, 12-year time series of smoothed values, corresponding with years 1990 to 2001 in Figure 6. No spawners were reported in 1995, but this was treated as a case of missing data rather than an absence of spawners. The smoothed data were log-transformed and regressed on year (p<0.001) to estimate the rate of decline at 33% per year, or 99% decline over 3-generations. The alternative procedure suggested in the COSEWIC guidelines based on the reduction in abundance from the first to last year of the time series will be affected by annual fluctuations in individual year class strength, and thus, sensitive to the particular two years chosen for comparison. However, in this case, it yields similar estimates ranging from 93% (1990 visual estimate to 2001 dive survey) to 87% (1991 visual estimate to 2002 fence count) reduction over three generations.

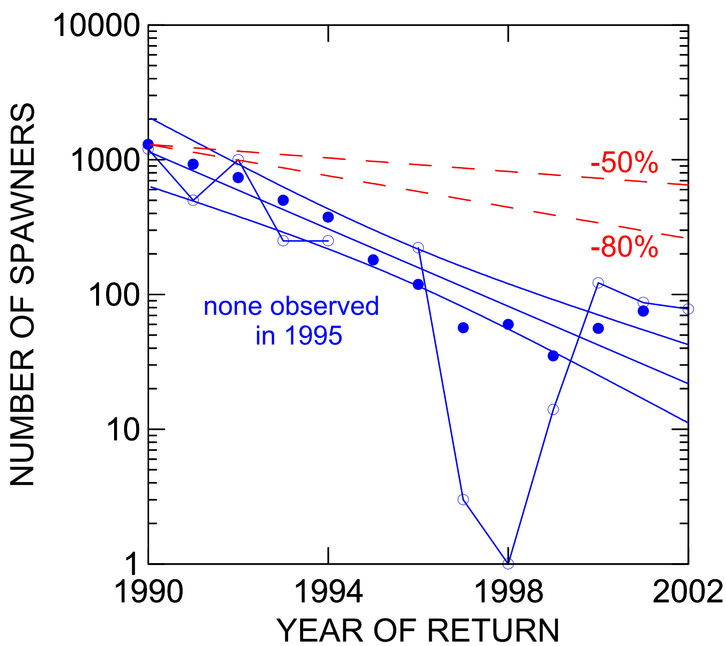

Figure 6. Average rate of decline in number of mature individuals in the Sakinaw Lake sockeye salmon population estimated by regression of 1-generation smoothed escapement data (filled circles) is 33% per year or 99% over three generations (12 yr). Open circles are annual estimates of spawning escapement; curved lines are 90% confidence intervals for regression line; dashed lines indicate IUCN thresholds of 50% and 80% decline over 12 years. Data for 1995 are treated as missing.

Indices of juvenile abundance

Smolts were enumerated by mark-recapture experiments at the outlet of Sakinaw Lake from 1994 to 1997. The total smolt outmigration in those years was estimated at 15,880, 12,760, 2,500 and 5,200, respectively, based on a trap efficiency of 3 to 5% (Bates and August 1997). If smolt-to-adult survival rate was 4.5%, an average value for other sockeye populations with large smolts (Forester 1968), the corresponding total adult returns before fishing mortality would have been 715, 574, 113, and 232 adults in 1996, 1997, 1998 and 1999, respectively. Of course, reported escapements in these years were considerably lower (1 to 222), probably because of underestimation by visual survey, and real losses to fishing mortality and in-lake predation. However, even if we disregard the visual estimates of spawning escapement and assume that marine survival has been favourable and fishing mortality negligible, the smolt abundance estimates indicate that total adult abundance must have declined by an order of magnitude since the more reliable counts in the 1980s.

LIMITING FACTORS AND THREATS

There are a variety of limiting factors and threats to the survival of Sakinaw Lake sockeye, including those in the freshwater and marine environments from both natural and anthropogenic factors.

Freshwater habitat

Beach spawning habitat in Sakinaw Lake is susceptible to landslides caused by rapid increases in stream flow and flooding, especially in winter when rain falls on snow. Mean annual precipitation ranges from 850 mm at lower elevations to 2,500 mm at higher elevations. Maximum precipitation occurs in winter as rain with less than 10% of total precipitation falling as snow at sea level, although this proportion increases significantly with elevation (see Murray and Wood 2002 and Shortreed et al. 2003 for detailed descriptions of climate and limnology).

Human activities or natural events that reduce upwelling or reduce substrate permeability by adding silt or wood debris near spawning sites could cause mortality during incubation by interfering with the delivery of oxygenated water and the removal of metabolic wastes. Beach spawning habitat has been degraded by the construction of recreational boating facilities and the cumulative effects of log storage. The most serious habitat degradation occurred prior to the diver survey in 1979, but degradation has continued. Dive surveys in 1999 and 2000 indicate that the sockeye are now using only 15% of the area of Beach 1, and that none are using Beach 2 where only 25% of the formerly suitable habitat now appears suitable. Old spawning areas not presently used by sockeye are covered with thick mud, organic debris and large logs.

Although Sakinaw Lake lies at an elevation of only 5 m, access to and from the lake can be difficult for sockeye salmon during periods of low water flow. The lake outlet has been partially or completely blocked since the early 1900s by dams built for log and water storage. A permanent dam and fishway were constructed by DFO on the outlet in 1952. Since then, lake levels have been regulated to store water for both the developing recreational and cottage community, and the sockeye migration. Low water flow and high water temperature can delay or disrupt migration into Sakinaw Lake, and sockeye enter the fishway only on the high tide at night. The presence of predators, most notably river otters, in or near the fishway can disrupt the spawning migration. When migration is disrupted, fish that return to the ocean cannot gain access until the following night because the fishway gate is closed during the daylight high tide. Passage to the fishway was improved in 1995 by the installation of two large rock weirs in the creek below the fence to create large pools. These pools act as steps and offer some protection for the migrating sockeye from illegal fishing and predation. In addition, effort has been made to restructure the outflow so that it remains concentrated in a narrow channel.

Natural marine factors

It is generally believed that most natural marine mortality is caused by predation, and that physical factors (temperature, salinity, currents) and intrinsic biotic factors (genetic adaptation, nutrition, parasites and disease) affect vulnerability to predators. Marine predators include a wide range of species from diving birds, piscivorous fish, to pinnipeds and killer whales. There is some evidence from scarring and trawl catches to suggest that Sakinaw sockeye may be especially vulnerable to marine predation by lampreys (*Lampetra ayresii*) that are relatively abundant in Georgia Strait near Sakinaw Lake (R. Beamish, DFO, pers. comm.). In addition, ocean growth and survival of all species of Pacific salmon can be affected by periodic warm water events (El Niño) in local waters, and by changes in ocean conditions in the North Pacific Ocean (e.g., Francis 1993; Mueter et al. 2002a, 2002b).

Fisheries

Sakinaw sockeye are killed both as directed catch in terminal fisheries and more importantly, as incidental catch in mixed-stock fisheries targeting larger populations of sockeye and pink salmon. Significant terminal fishing has probably occurred in most years but reliable estimates of terminal catch are available for only three years: 1947, 1952 and 1972. The terminal harvest rate in 1947 was only 1.4% based on a terminal catch of 50 sockeye and an estimated escapement of 3500 sockeye. In 1952, the terminal harvest rate was considerably higher at 14% based on a reported gillnet catch of 1000 sockeye by three or four row boats fishing in Lee Bay and an escapement of 6000 sockeye. The 1952 fishery was open six days per week, but both commercial and sport fishing were prohibited in a small sanctuary off the mouth of Sakinaw Lake that was patrolled to deter illegal fishing (A. Skipper, DFO, pers. comm.). Illegal fishing and poaching of sockeye from the Sakinaw fishway has been a concern to enforcement staff since their earliest records on Sakinaw Lake sockeye, but the magnitude of the illegal harvest has never been estimated. In 1972, the terminal harvest rate was higher still at 23 to 29% based on an estimated catch of 1350 to 1800 sockeye taken by 2 or 3 gillnetters, primarily in Lee Bay (followed by Middlepoint, Bargain Harbour and Sabine Channel, R.P. Kraft, DFO, pers. comm.). The escapement in 1972 was 4500 sockeye, about average over the previous 20 years.

Sockeye salmon return to Sakinaw Lake through Johnstone Strait (Figure 7). They share this migration corridor with other sockeye populations including those returning to lakes in the vicinity of Johnstone Strait (Nimpkish, Heydon, Phillips and Village Bay lakes) and the “northern diversion” component of sockeye returning to the Fraser River. “Diversion rate” refers to the proportion of the total catch of Fraser sockeye that is taken along the northern approach route (i.e., through Johnstone Strait rather than Juan de Fuca Strait). A higher diversion rate implies a higher fishing effort in fisheries that kill Sakinaw sockeye including:

- *Statistical Area 11* – historically a minor troll and gillnet fishery off the north end of Vancouver Island.
- *Johnstone Strait* – the major fishery on the northern diversion component of Fraser River stocks. Although typically a seine fishery, troll and gillnet gear is also used. Smaller catches from native and test fishing are included in the commercial catch statistics. Johnstone Strait is sub-divided into upper (Area 12) and lower (Area 13) reaches.
- *Georgia Strait* – troll fishing has occurred throughout Georgia Strait but a small net fishery located in Statistical Area 16 (much of it concentrated in Sabine Channel) is most important with respect to Sakinaw sockeye.

The overall intensity of mixed-stock fishing in Johnstone and Georgia straits generally increased until the late 1990s in response to high abundance and high diversion rates of Fraser River sockeye. Fishing effort by seine boats appears to have declined in both areas since the late 1970s when measured in cumulative boat days (Figure 8), but this measure of effort does not take into account how technology has increased fishing efficiency allowing seine vessels to set their nets more often and more effectively. Moreover, gillnet effort in Johnstone Strait was consistently higher between 1989 and 1994 (average 7563 boat days, range 6003 to 9479) than in any earlier period (average 4358 boat days, range 1333 to 6104). Gillnet fishing effort in Georgia Strait (mostly in Sabine Channel near Sakinaw Lake) was also higher between 1991 and 1994 (average 1095 boat days, range 205 to 2438) than in previous years (average 212 boat days, range 5 to 529). This increased fishing effort by gillnet boats in Johnstone and Georgia straits coincided with the period of rapid decline in Sakinaw escapements. Reduced fishing rates after 1997 reflect fishing restrictions in response to conservation concerns, an overall reduction in the fishing fleet, and area-based licensing requirements. Additional closures (seaward of Lewis Point) since 1980 have succeeded in reducing harvest rate on Nimpkish sockeye in Area 11 and upper Area 12 (Starr et al. 1984). However, early fisheries in lower Area 12 (sub-areas 1 to 4) would still kill sockeye from Sakinaw Lake and other “non-Fraser” stocks (those from Fulmore, Phillips Heydon, and perhaps Village Bay lakes).

It should be noted that increased fishing effort in mixed-stock fisheries does not necessarily imply increased fishing mortality on small populations like Sakinaw sockeye. Detailed information on run timing and migration routes past fisheries are required to reliably estimate population-specific harvest rates in mixed-stock fisheries, and these data are seldom available for minor stocks. “In-season” regulation of fishing effort typically depends on test-fishing indices of the aggregate abundance, and thus, the abundance of

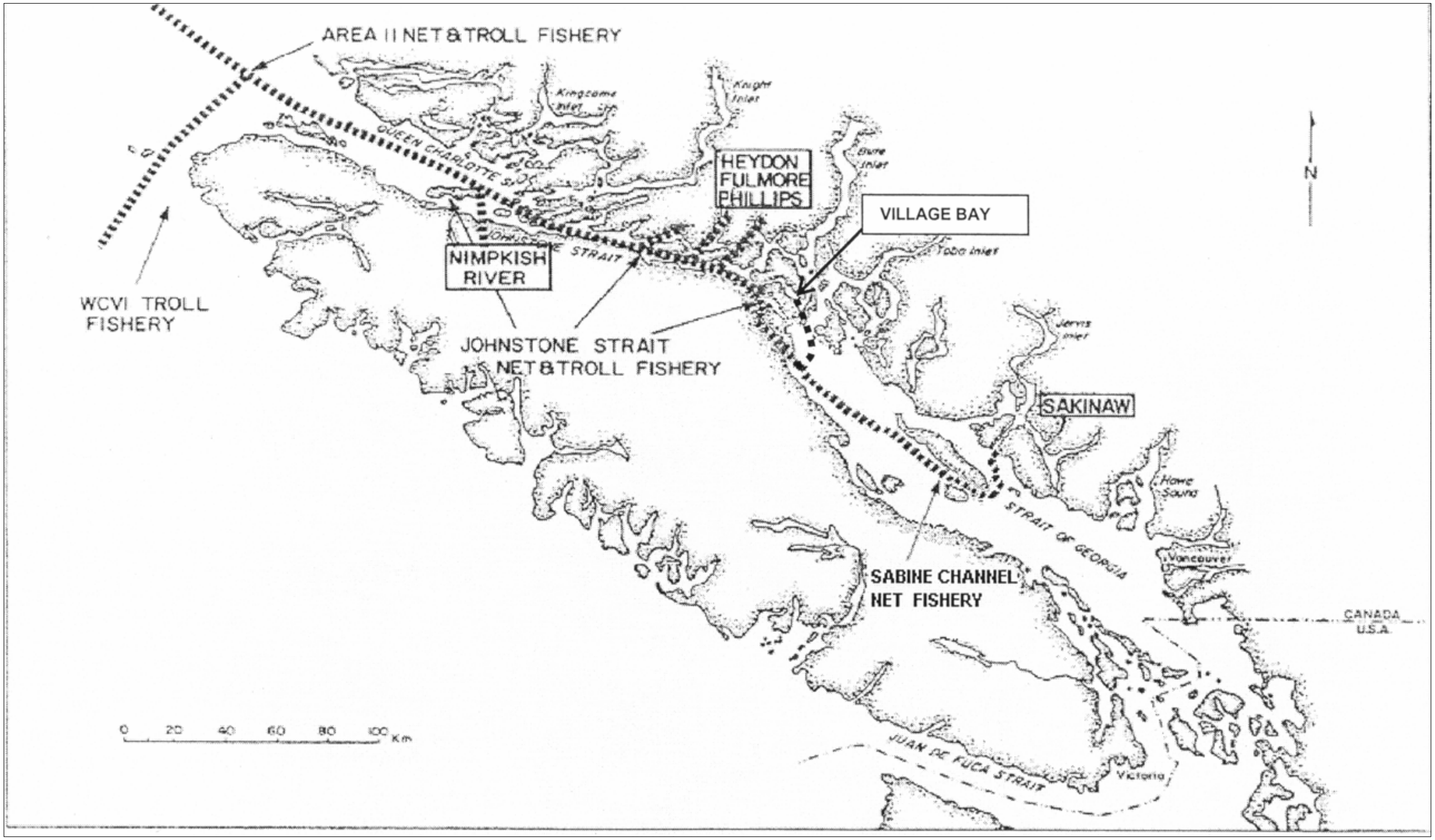

Figure 7. Primary route for adult migration (dotted lines) and location of fisheries for non-Fraser sockeye populations (Nimpkish, Heydon, Fulmore, Phillips, Village Bay and Sakinaw). Sakinaw sockeye are harvested primarily in the Johnstone Strait and Sabine Channel net fisheries. (from Murray and Wood 2002).

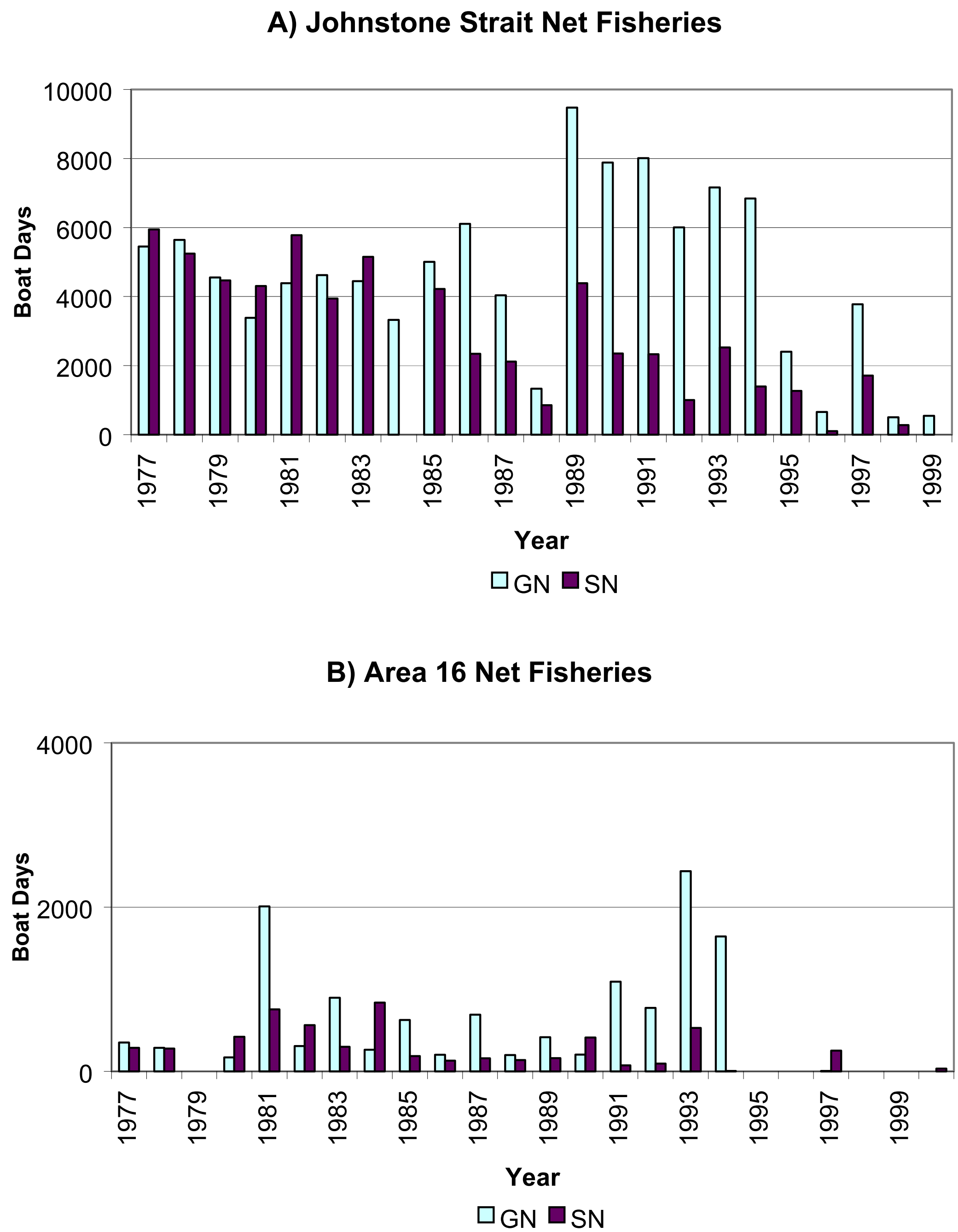

Figure 8. Annual fishing effort by gillnet (GN) and seine (SN) vessels during July to mid-September while Sakinaw sockeye are migrating through mixed-stock fishing areas in Johnstone Strait (Areas 12 and 13) and Georgia Strait (Area 16) (from Murray and Wood 2002).

large Fraser River sockeye populations. Sakinaw Lake sockeye are said to be managed "passively", meaning that fishing effort is not regulated based on in-season estimates of abundance, although the spawning escapement is monitored to allow post-season evaluation of the fishing plan.

The Pacific Salmon Commission (PSC) used scale analysis to estimate the contribution of Sakinaw Lake sockeye to net fisheries in Johnstone and Georgia straits in the 1975 fishing season. These estimates of catch composition imply that the total catch and exploitation rate of Sakinaw Lake sockeye in Areas 12, 13 and 16 in that year were 14,300 fish and 47%, respectively (Argue 1975). Most (92%) of this fishing mortality occurred in Johnstone Strait prior to a general fishing strike that began in the last week of July and continued through most of August; the resulting escapement to Sakinaw Lake that year was the largest (16,000) and latest (until 30 September) on record. Comparable stock composition data for Sakinaw Lake sockeye are not available for other years. However, Starr et al. (1984) concluded from run reconstruction analyses that total exploitation rates on Sakinaw Lake sockeye varied from 20 to 67%, averaging 41% between 1970 and 1982. They estimated that harvest rates in the Johnstone Strait (Areas 11, 12, and 13) and Area 16 fisheries averaged 37% and 4%, respectively.

Murray and Wood (2002) inferred the minimum total exploitation rate on Sakinaw Lake sockeye for the periods 1986-89 and 1992-94 using weekly estimates of proportions of non-Fraser and Early Stuart sockeye in the Round Island test fishery catches (Area 12) that had been determined by scale racial analysis (Gable and Cox-Rogers 1993; PSC unpublished data). In their first method, Murray and Wood (2002) assumed that Sakinaw Lake sockeye were harvested at the same rate as co-migrating Fraser River sockeye populations (mainly early Stuart sockeye) in the northern approach fisheries. Stock composition in the Area 12 test fishery was assumed to represent stock composition in the total catch from Areas 11, 12 and 13. A fishery-specific harvest rate was estimated by dividing the estimated weekly catch of Fraser River sockeye by the weekly abundance of Fraser sockeye available to the fishery. The latter quantity was inferred from estimates of weekly abundance in the lower Fraser River, lagged to account for migration time, and multiplied by the estimated diversion rate to include only fish that had returned through Johnstone Strait. Using this method, estimates of total harvest rate on early Stuart sockeye in northern approach fisheries (and by extension, Sakinaw Lake sockeye) ranged from 1 to 56% (average 21%) assuming a 7-d migration, and 1 to 97% (average 57%) assuming a 14-d migration.

In their second method, Murray and Wood (2002) reconstructed the probable catch of Sakinaw Lake sockeye from PSC estimates of the aggregate non-Fraser sockeye catch each week. Of the non-Fraser populations, Nimpkish River sockeye are present only in Areas 11 and 12; Heydon, Fulmore and Phillips lake sockeye are present only in Areas 11, 12, and 13, whereas Sakinaw Lake sockeye are present in all four areas. Murray and Wood (2002) assumed that Sakinaw Lake sockeye accounted for 8%, 20%, and 43% of the aggregate non-Fraser catch in Areas 11 and 12, Area 13, and Area 16, respectively, reasoning that they must account for a higher proportion of the aggregate as other populations stop contributing. These rough estimates of Sakinaw catch, together with SEDS escapement data, suggest that exploitation rates on Sakinaw Lake sockeye in Johnstone and Georgia strait net fisheries averaged 49 to 57% (depending on assumption about migration time) between 1986 and 1989, and 89 to 99% between 1993 and 1994. Estimates of exploitation rates would be biased high if escapements were underestimated as seems likely for 1993 and 1994 given that enumeration at the fishway was discontinued in 1990 (until 2002).

Introduction of exotic species

Sockeye salmon fry were transplanted into Sakinaw Lake each year from 1902 to 1906. The sockeye fry were reared at the Fraser River Hatchery near New Westminster, which operated from 1884 to 1915. The donor stocks were the Harrison (Big Silver, Weaver Creek, Trout Lake, Harrison River Rapids sites), Pitt River (Upper and Lower) and Birkenhead rivers and Shuswap Lake (Scotch and Tappin creeks, Adams River). Approximately 380,000 fry were transplanted into Sakinaw Lake from the various donor stocks (Aro 1979). Genetic evidence indicates that these transplants were unsuccessful (see previous section on Nationally Significant Populations and Figure 2).

The British Columbia Fish and Wildlife Branch attempted to augment the natural population of sea-run cutthroat trout in Sakinaw Lake by stocking 297,931 juvenile cutthroat trout (most over 10 g in weight) between 1965 and 1989 (http://www.bcfisheries.gov.bc.ca/fishinv/db/default.asp). Lacustrine predators can limit sockeye smolt production and cutthroat trout are known to be predators on young sockeye at all times of the year (Foerster 1968). Thus, stocking Sakinaw Lake with cutthroat trout may have decreased the survival of juvenile sockeye in Sakinaw Lake.

SUPPLEMENTATION AND RESTORATION

Supplementation by artificial propagation

Recent “enhancement” projects for Sakinaw Lake sockeye started in 1986 when 28,000 eggs from Haskins Beach were reared at the Ruby Creek hatchery with the eggs from each female occupying a single tray in the hatchery. Since 1986, all parental fish (brood stock) have been sampled for disease, namely infectious hematopoietic necrosis virus (IHN) and bacterial kidney disease (BKD). All fish were found to be free of either disease, except for one female in 1986, whose eggs were infected with IHN. The 2,200 infected eggs were planted back on the spawning beach for natural incubation. The remaining eggs were incubated in the hatchery resulting in 23,000 unfed fry being released into Sakinaw Lake in mid-April 1987. In November 1987, 18 spawning female sockeye were captured (50% from each of Beaches 1 and 2) and their eggs were incubated at the Thornborough Channel Salmon Enhancement Society hatchery on Ouellette Creek. In mid-April 1988, 57,000 unfed fry were released at Beach 1. In 1988, eggs from 18 females were incubated at the Ouellette hatchery producing 33,000 fry that were again released into the lake at Beach 1. Artificial propagation was discontinued until 2000 when 16,000 eggs from 10 females were incubated and the fry reared to 1 g in weight at the Ouellette hatchery; 14,981 “fed fry” were released into the middle of the lake on 8 June 2001. In

2001, eggs were collected from 15 females and the resulting fry were reared to 1 g; over 30,000 fed fry were released in early June 2002. In 2002, only six spawning females, most already partially spawned, could be obtained as broodstock, resulting in less than 5,000 uveniles alive in captivity at the time of writing.

The Saga Seafarms Ltd aquaculture site, located 500 m from the Sakinaw Lake outlet, reared a single generation of sockeye from the Pitt River population as an experiment that began in 1991. There were no reports of any sockeye escaping from the pen and the aquaculture site is no longer active. The site manager reported that seals and river otters were a nuisance at the site.

Habitat restoration activities

Logging debris has been removed sporadically from the outlet and spawning beaches of Sakinaw Lake. A log jam and other debris were removed from the outlet creek in 1972. Beach 2 was cleared of logging debris to a depth of 5 - 10 m in 1974. Lakeshore residents have continued to clear debris on a small scale by pulling wood off the bottom using snorkels and ropes. Log removal is presently underway at Beach 1 in areas where ground water moves into the lake. Drain rock was added at Beach 2 to restore spawning habitat in a 25-m by 5-m area where colder water temperature indicated upwelling ground water; unfortunately, only a single female sockeye has been observed (in 2002) at Beach 2 since the addition of gravel (G. McBain, DFO, pers. comm.).

SPECIAL SIGNIFICANCE OF THE SPECIES

Sockeye salmon are economically the most important species of Pacific salmon, contributing to commercial, recreational and aboriginal catches along the Pacific coast of North America. The number of extant populations has declined in the southern parts of the species' range (e.g., Nehlsen et al. 1991, Slaney et al. 1996). As of January 2003, sockeye salmon are considered threatened by extinction in four ESUs, two in southern Canada, (Sakinaw Lake and Cultus Lake, based on October 2002 Emergency Assessments by COSEWIC) and two in the US Pacific Northwest (Snake River and Ozette Lake, listed under the US Endangered Species Act).

Sakinaw Lake is the largest lake on the Sechelt Peninsula and supports the last remaining anadromous sockeye salmon population in southern Georgia Strait (excluding those that migrate through Georgia Strait to the Fraser River). Conservation of Sakinaw sockeye is a high priority for the Sechelt Indian Band because Sakinaw Lake lies within their traditional territory and historically provided the Sechelt people with abundant returns of sockeye salmon. Sockeye salmon import marine-derived nutrients to Sakinaw Lake and may play a significant role in maintaining the productivity of the Sakinaw Lake ecosystem, including a variety of animal and plant life. The juveniles contribute to the complexity of the lake's food web, consuming invertebrates and serving as prey for native fish, birds and mammals. Returning adults are consumed by river otters, bears and lampreys, and the carcasses provide food for bald eagles and other species. Thus, Sakinaw sockeye play a significant role in the ecology of the Sakinaw Lake ecosystem.

EXISTING PROTECTION OR OTHER STATUS

Sakinaw sockeye are not protected within any park or marine protected area. Existing protections for Sakinaw sockeye are similar to those for Interior Fraser coho salmon, summarized previously by Irvine (2002) and restated here as follows: Canada is a signatory to the international Convention on Biological Diversity that requires governments to develop legislation and policies to protect ecosystems and habitats and maintain viable species populations. The Canada Oceans Act directs DFO to manage Canada's marine resources to conserve biological diversity and natural habitats. The federal Fisheries Act has long required that proposed alterations to habitat be authorized by DFO. However, in BC, provincial and municipal governments also regulate many land and water use activities that can affect fish populations. For example, the provincial Water Act governs the allocation of water, water licenses, and the regulation of works in streams.

In 1998 DFO released its New Directions Policy for the Pacific region (DFO 1998). The first two principles in this policy state that conservation of Pacific salmon stocks is DFO's primary objective, to take precedence over other objectives in managing the resource, and that a precautionary approach to fisheries management will continue to be adopted. The New Directions Policy stimulated development of a (draft) Wild Salmon Policy (DFO 2000) to promote the long-term viability of Pacific salmon populations and their natural habitat. This policy document is still being revised to incorporate public consultation and is scheduled for completion in 2003. Reduced mixed-stock fishing effort in Johnstone Strait since 1997 is one consequence of DFO's recent emphasis on conservation, consistent with the New Directions Policy. DFO is also committed to developing a recovery plan to co-ordinate restoration activities in consultation with stakeholders and the Pacific Salmon Endowment Fund.

NatureServe (http://www.natureserve.org/explorer/servlet/natureserve?int=Species) lists sockeye salmon as *Secure* (G5) as a species, but *Critically Imperiled* in Idaho (S1), *Imperiled* in Washington State (S2), *Apparently Secure* (S4) in Oregon, *Secure* in Alaska (S5) and *Under Review* in California and British Columbia.

SUMMARY OF STATUS REPORT

Sakinaw Lake sockeye salmon (Sakinaw sockeye) warrant designation as an Evolutionarily Significant Unit (or COSEWIC Nationally Significant Population) based on the two-part test developed to define salmonid "species" under the US Endangered Species Act. Protein electrophoresis and molecular DNA analyses indicate that Sakinaw sockeye are substantially reproductively isolated from other populations. Their distinctive life history characteristics (early and protracted river-entry timing, extended lake residence prior to spawning, small body size, low fecundity and large smolt size) suggest that they are also evolutionarily distinct from other sockeye populations in the Pacific Northwest and Alaska. The evidence for very restricted gene flow between Sakinaw and other populations and the distance to the nearest extant sockeye population both confirm that there is virtually no possibility of natural rescue from neighbouring sockeye populations. All previous attempts to transplant sockeye to Sakinaw Lake have almost certainly failed. Consequently, we cannot be optimistic about prospects for re-establishing a sockeye run to Sakinaw Lake should the native population be lost.

The persistence of Sakinaw sockeye is threatened by two primary factors: mortality from fisheries, and degradation of freshwater habitat. At present, fishing mortality is probably the single greatest threat. Overfishing can be considered the proximate cause of decline in the sense that fishing effort was not reduced significantly until 1998, and Sakinaw sockeye continue to be killed in fisheries despite the observed decline in spawning escapements to Sakinaw Lake that began in 1987. Sakinaw sockeye are captured together with sockeye and pink salmon from more productive populations in mixed-stock fisheries during their return migration through Johnstone and Georgia straits. It is evident that “passive management” and (limited) artificial supplementation have been inadequate to restore Sakinaw sockeye in the face of this fishing mortality. Further changes to fisheries will be necessary to promote recovery.

Sakinaw sockeye likely became increasingly vulnerable to overfishing in mixed-stock fisheries as their natural productivity was eroded by habitat degradation within Sakinaw Lake. The spawning beaches have been degraded by historic logging, milling and booming. The lake was dammed at the outlet to transport logs to the ocean, and log storage near the outlet has sometimes blocked adult salmon migration. Development of residential lots and recreational boating along the shore of Sakinaw Lake has more recently degraded spawning beaches further as stream flows have been diverted to prevent flooding and a boat ramp was constructed through the middle of one of the major spawning beaches. Domestic water use throughout the drainage contributes to reduced summer flows that can adversely affect adult migration into the lake; low water levels remain a serious concern. However recent attempts to restore spawning beaches and to improve fish passage at the dam appear to have set the stage for recovery.

If present trends continue, the Sakinaw sockeye will likely go extinct in the near future. The trend in smoothed escapement data from 1988 to 2002 indicates a reduction of 99% over 3 generations (12 years). The total number of mature individuals (all of which die after spawning) has averaged less than 80 (range 14 to 122) over the last full generation (4 years; 1999-2002). Adult numbers averaged 5,000 individuals historically. Thus, the reduction to less than 80 adults is drastic, and there is no margin for further decline.

TECHNICAL SUMMARY

Oncorhynchus nerka
Common name: Sockeye salmon (English) Saumon rouge (French)
Population name: Sakinaw Lake sockeye salmon (Sakinaw sockeye)
Range of Occurrence in Canada: BC (Sakinaw Lake, Sechelt Peninsula, and coastal Pacific Ocean)

Extent and Area information	
• *Extent of occurrence (EO)(km²) (freshwater phase)*	6.9 km^2 (Sakinaw Lake)
• *specify trend (decline, stable, increasing, unknown)*	Probably Stable
• *are there extreme fluctuations in EO (> 1 order of magnitude)?*	Unlikely
• *area of occupancy (AO) (km²)(freshwater phase)*	6.9 km^2, but all spawning occurs within an area <0.01 km^2
• *specify trend (decline, stable, increasing, unknown)*	Decline in suitable spawning area
• *are there extreme fluctuations in AO (> 1 order magnitude)?*	No
• *number of extant locations*	One (Sakinaw Lake)
• *specify trend in # locations (decline, stable, increasing, unknown)*	Stable (but number of spawning sites has declined)
• *are there extreme fluctuations in # locations (>1 order of magnitude)?*	No
• *habitat trend: specify declining, stable, increasing or unknown trend in area, extent or quality of habitat*	Probably declining
Population information	
• *generation time (average age of parents in the population) (indicate years, months, days, etc.)*	Four years
• *number of mature individuals (capable of reproduction) in the Canadian population (or, specify a range of plausible values)*	Average is ~80 spawners over last full generation (range 14 to 122 between 1999 and 2002)
• *total population trend: specify declining, stable, increasing or unknown trend in number of mature individuals*	Declining since late 1980s
• *if decline, % decline over the last/next 10 years or 3 generations, whichever is greater (or specify if for shorter time period)*	- 99% in 3 generations (last 12 years; regression analysis). - 93% (1990 vs 2001) or 87% (1991 vs 2002) in 3 generations (using endpoints)
• *are there extreme fluctuations in number of mature individuals (> 1 order of magnitude)?*	Not in recent years, but annual fluctuations can be large
• *is the total population severely fragmented (most individuals found within small and relatively isolated (geographically or otherwise) populations between which there is little exchange, i.e., ≤ 1 successful migrant / year)?*	One population - Sakinaw is genetically and demographically isolated from all other sockeye populations
• *list each population and the number of mature individuals in each*	NA
• *specify trend in number of populations (decline, stable, increasing, unknown)*	NA
• *are there extreme fluctuations in number of populations (>1 order of magnitude)?*	NA

Threats	
– overfishing, mainly in mixed stock fisheries, is probably the primary threat and proximate cause of the collapse in population size – loss of spawning habitat – low summer water levels and high temperatures periodically hinder migration – cumulative impacts from past logging operations – residential development around lake and domestic water use – depensatory predation from river otters, seals, lamprey and cutthroat trout	
Rescue Effect	
• *does species exist elsewhere (in Canada or outside)?*	Yes (but this ESU reproduces only in Sakinaw Lake; other ESUs of sockeye salmon occur elsewhere in Canada and outside)
• *status of the outside population(s)?*	Variable
• *is immigration known or possible?*	No – Sakinaw is a distinct population.
• *would immigrants be adapted to survive here?*	No
• *is there sufficient habitat for immigrants here?*	NA
Quantitative Analysis	Genetic analyses, population modeling.

ACKNOWLEDGEMENTS

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Dr. Wood received a B.Sc (Honours) in Biology from Simon Fraser University (1977) and a Ph.D in Zoology from the University of British Columbia (1984). He has been a research scientist with Fisheries and Oceans Canada since 1984 and has over 20 years experience in research on population and evolutionary biology of marine and anadromous fish. He was head of the North Coast Salmon Section (1994-1997), chaired the DFO Science Branch team that prepared the Wild Salmon Policy Discussion Paper, and is currently head of the Conservation Biology Section at the Pacific Biological Station in Nanaimo. He holds adjunct faculty positions in the Department of Biology at the University of Victoria and in the School of Resource and Environmental Management at Simon Fraser University. He has been a member of the Marine Fishes Species Specialist Subcommittee of COSEWIC since 2000. Dr. Wood has authored 44 primary publications and 37 secondary publications, and co-edited two books.