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Status of Sakinaw Lake Sockeye Salmon (*Oncorhynchus nerka*)

État du stock de saumon rouge (*Oncorhynchus nerka*) du lac Sakinaw

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Abstract

This report summarizes our current knowledge of Sakinaw Lake sockeye salmon (*Oncorhynchus nerka*). Sakinaw Lake is located on the Sechelt Peninsula in Fisheries and Oceans Canada (DFO) management Area 16. Data were collected between 1939-2001. Quantity of data available for each year varied, ranging from intensive total fishway counts in some years to one-time escapement surveys in others. Catch information, smolt production estimates, and basic biological characteristics for Sakinaw sockeye are very limited. Sakinaw Lake sockeye salmon have shown recent dramatic declines in total abundance. All available data indicate that the critically low sockeye returns to Sakinaw Lake in 1999, 2000, and 2001 are correlated with the compounding effect of poor marine survival and low brood year escapements. If marine survival continues to be poor and escapement levels continue to decrease for Sakinaw sockeye, drastic measures are required to prevent the downward spiral to extirpation.

Major concerns that have lead to the conclusion that if present conditions continue, Sakinaw Lake sockeye salmon are likely to become extirpated in the foreseeable future, include: loss of spawning habitat in the lake; low summer water levels and high temperatures that periodically block migration into the lake; past logging effects and present effects of residential development around the lake; and fishing effort in Johnstone and Georgia Straits. All these factors have contributed to the overall downward trend in abundance.

Opportunities exist for enhancement and restoration of the lake's sockeye stock, which include increasing escapements, fry outplants, improvement of spawning grounds, and control of competitors or predators. However, a comprehensive recovery plan should be developed for Sakinaw sockeye salmon to explore all the options, to ensure that the proposed measures address the recovery of Sakinaw sockeye, address local and regional concerns, and do not contribute to further harm.

Résumé

Dans ce rapport, nous résumons nos connaissances actuelles sur le saumon rouge (*Oncorhynchus nerka*) du lac Sakinaw. Le lac Sakinaw est situé sur la péninsule Sechelt, dans la zone de gestion 16 de Pêches et Océans Canada (MPO). Nous disposons de données recueillies de 1939 à 2001. D'une année à l'autre, la quantité de données variait, allant de dénombrements exhaustifs des saumons à une passe migratoire certaines années à des relevés uniques de l'échappée d'autres années. Les données sur les caractéristiques biologiques fondamentales et les prises ainsi que les estimations de la production de smolts du saumon rouge du lac Sakinaw sont très limitées. L'abondance totaledu saumon rouge du lac Sakinaw a fortement baissé ces derniers temps. Toutes les données disponibles indiquent que les très faibles remontes de saumons rouges au lac en 1999, en 2000 et en 2001 sont corrélées à l'effet combiné d'une faible survie en mer et des faibles échappées. Si la survie en mer continue d'être faible et que les échappées continuent de baisser, des mesures radicales devront être prises pour éviter la disparition du saumon rouge du lac Sakinaw.

Voici les principaux problèmes qui ont permis de conclure que, si les conditions actuelles se maintiennent, le saumon rouge disparaîtrait sans doute dans un avenir prévisible : la disparition de frayères dans le lac; les faibles niveaux d'eau estivaux et les températures élevées qui empêchent périodiquement le saumon de migrer dans le lac; les effets de l'exploitation forestière passée et les impacts actuels de l'expansion domiciliaire autour du lac; l'effort de pêche dans les détroits de Johnstone et de Georgia. Tous ces facteurs ont contribué au déclin général de l'abondance du saumon rouge du lac Sakinaw.

Il existe des possibilités de rétablir le stock, notamment en accroissant les échappées, en ensemençant des alevins, en améliorant les frayères et en luttant contre les compétiteurs ou les prédateurs. Il faudrait cependant élaborer un plan de rétablissement exhaustif qui aborde toutes les options et assure que les mesures proposées permettent au saumon rouge du lac Sakinaw de se rétablir, donnent suite aux préoccupations locales et régionales et ne nuisent pas davantage au stock.

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Introduction

Sockeye salmon, *Oncorhynchus nerka* (Walbaum, 1792) occur in North America around the Pacific Rim from the Columbia River in the south to the Nome River in Alaska. In Asia, this species ranges from Hokkaido, Japan, the Kuril and Komandorskiy Islands, and the northwest coast of the Sea of Okhotsk in the south to the Anadyr River in the north (Foerster 1968, Burgner 1991).

Sakinaw Lake or "Sauchenauch" Lake is located on the Sechelt Peninsula in the Department of Fisheries of Canada (DFO) management Area 16 (Figure 1). It is the largest lake on the Sechelt Peninsula (Figure 2) and lies within the Sechelt Indian Band's traditional territory. Historically, Sakinaw Lake and the surrounding watershed provided the Sechelt people with abundant returns of both sockeye and coho *(O. kisutch*). Sockeye salmon in Sakinaw Lake have declined dramatically in total abundance. The fate of the sockeye salmon in Sakinaw Lake is a high priority within the Sechelt Indian Band.

Anadromous salmon returning to spawn in lakes and streams from Alaska to California have declined dramatically since the early 1900's (Ricker 1982; Gresh et al. 2000). Causes of reduced escapements vary, but excessive historical harvests, predation, loss of tributary populations, decline in quality of beach spawning habitat, industrial and residential development, and watershed habitat degradation have all had substantial impacts. In addition, in the late 1990's ocean productivity declined and its impact on marine survival of salmon caused rapid declines in the numbers of returning adult salmon coast wide (Welch et al. 2000). Recent publications (Konkel and McIntyre 1987, Nehlsen et al. 1991, Wilderness Society 1993, Botkin et al. 1995, Slaney et al. 1996) reported that a number of local populations of sockeye salmon in the Pacific Northwest have become extinct, and the abundance of many others is depressed. This PSARC document has been prepared in response to a request to provide an update on the status of Sakinaw Lake sockeye salmon in Statistical Area 16 and to review our current understanding of the reasons for their decline.

Sakinaw Sockeye

Climate

The Sechelt Peninsula climate is marked by warm, dry summers and wet, very mild winters. The mean annual temperature is approximately 9°C with a summer mean of 15°C and a winter mean of 3.5°C. Mean annual precipitation ranges from 850 mm at lower elevations to 2,500 mm at higher elevations. Frosts are common in winter, but snow cover at sea level is ephemeral. Maximum precipitation occurs in winter as rain; less than 10% falls as snow at sea level but this proportion increases significantly with elevation. Rain on snow events can occur resulting in rapid increases in stream flows and occasional flooding. The annual total precipitation for Sakinaw Lake is 150 cm, annual snow fall is 64 cm with 296 frost free days (Environment Canada 2001).

Lake Characteristics

Sakinaw Lake has an elevation of 5 m and is over 8 km in length. It has a surface area of about 8 km^2 (816 ha), a perimeter of 31,100 m. Sakinaw Lake has two distinct basins. The lower basin is the largest and has 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 40 m. Its drainage basin (64 km^2) includes a number of small streams and lakes as well as Ruby Lake with a maximum depth of 112 m (Figure 3). The lake outlet has been partially or completely blocked by dams built for logging purposes and water storage since the early 1900's. A permanent dam and fishway were constructed on the outlet late in 1952 by DFO and lake levels have been regulated since then to store water for the sockeye migration (Figure 4).

Lakes in the Pacific Northwest typically develop a summer thermocline resulting from solar heating, with water below the thermocline remaining colder and denser than the warmer and lighter water above it. Surface water in a thermally stratified lake is termed the epilimnion, whereas water below the thermocline is termed the hypolimnion. The hypolimnion may become depleted in oxygen as a result of natural decomposition of plant and animal matter on the lake bottom, if mixing is inhibited by thermocline formation. Lakes in the Pacific Northwest also undergo a single mixing event of the epi- and hypolimnion in the fall or winter in a process called turnover and are generally referred to as monomictic (e.g., Gustafson et al. 1997).

Unlike most other lakes in the Pacific Northwest, Sakinaw Lake is an example of a lake with fresh water over salt water or a meromictic lake that does not undergo a seasonal mixing event (Hutchinson, 1957; Walker and Likens 1975). Temperature, salinity and chemical conditions in Sakinaw Lake are rare and unusual (Northcote and Johnson 1964). Total dissolved solid content ranges from 113 – 140 ppm. There is a marked increase in temperature and salinity below a depth of 30 m. A rapid temperature increase occurs between 30 and 60 m (5 to 9 C^o). Similarly, a marked increase in salinity and conductivity also occurs in this layer. Below 60 m the salinity increase slightly, attaining a maximum value slightly over 11‰. Dissolved oxygen falls sharply at depths below 20 m and drops to near zero below 30 m. A strong H_2S smell is evident in all water samples from below 30 m and those below 60 m exhibited strong frothing when brought to the surface.

Although the separate depression at the northeast end of the lake extends well below 30 m, there is no evidence of sea water intrusion into this basin from its thermal, salinity, or conductivity characteristics. Ruby Lake, lying at an elevation of about 18 m above Sakinaw Lake, does not contain any sea water in its basin and has a total dissolved solid content of 40 ppm, well below that for Sakinaw Lake.

There is no estimate for the age of the sea water in the main basin. As opposed to nearby Powell Lake (Williams et al. 1961), it appears to be of rather recent origin. There may have been periodic intrusions of sea water prior to the existence of the dam at the outlet, or possibly, more recently from the combination of strong winds and high tides. The higher total dissolved solid content of the surface waters of Sakinaw Lake (113 ppm), as compared with Ruby Lake (40 ppm), may be the result of migration of dissolved solids from the saline layer to the surface layer through limited mixing (Northcote and Johnson 1964).

Stockner and Shortreed (1978) conducted a limnological survey of 35 salmon nursery lakes in British Columbia and the Yukon. They found that Sakinaw Lake ranked the most productive of the 5 South Coast lakes surveyed (Nimpkish, Folmore, Heydon, Phillips) based on chlorophyll *a* concentrations greater than 1.5 mg * m^{-3} and higher algae volumes of *Cyanophytes*, *Chrysophyceans* and diatoms. However, the lake had low nitrogen levels with a nitrogen to phosphorus ratio of 3.4 to 1. Zooplankton biomass was high in Sakinaw Lake where it exceeded 1000 mg * m^{-3}. There were high concentrations of *Cyclops* spp and a greater diversity of zooplankton *Bosmina* spp., *Daphnia* spp., *Epischura* spp., *Diatotomus* spp., and *Sida* spp relative to the other 4 lakes surveyed in the South Coast.

Life History

Comprehensive reviews of sockeye salmon life history and habitat requirements can be found in Foerster (1968), Burgner (1991), Gustafson et al. (1997), and others. This section is meant to serve as a general description of sockeye salmon life history with emphasis on Sakinaw sockeye.

Sockeye salmon exhibit a wide variety of life history patterns that reflect varying dependency on the fresh water environment. They characteristically make more use of lake rearing habitat in juvenile stages than other Pacific salmon. With the exception of river-type and sea-type populations that are widespread but not abundant, the vast majority of sockeye spawn in or near lakes. Although sockeye are anadromous, non-anadromous forms of the species also occur, maturing, spawning and dying in fresh water without entering the ocean; these forms are called "kokanee" where they are genetically distinct from anadromous sockeye, or "residual sockeye" where they are the (mostly male) progeny of anadromous sockeye. Sakinaw Lake supports both anadromous and non-anadromous forms, but it is not yet known whether the non-anadromous fish are kokanee or residual sockeye; the non-anadromous form is known from two specimens collected by gillnets and provided to the authors in April 2002.

Freshwater

Sockeye generally spawn in streams that are tributaries to large lakes. These streams can vary in type, ranging from small tributaries to large mainstem rivers and side-channels. Additionally, some sockeye stocks, like Sakinaw sockeye, spawn along the shorelines of lakes. The sockeye of Sakinaw Lake normally spawn in the lake itself, because most of the tributary streams tend to dry out near their mouths except during times of moderate to heavy rains. Sakinaw sockeye spawning from November to January need adequate ground water flows to provide proper spawner distribution on the spawning grounds. Successful egg and alevin survivals are dependent on clean spawning gravel and low to moderate winter stream flows. Sockeye eggs and fry can be negatively impacted by high flows during the fall and winter incubation period. Erosion and downstream movement of spawning gravel is a major cause of egg and alevin losses, and severe flooding can cause mortalities exceeding 90%. Land use practices and natural events that introduce substantial amounts of silt into spawning streams affect sockeye inter-gravel survivals by reducing the permeability of the gravel. Reduced permeability can affect the survival of incubating eggs and alevins by interfering with the delivery of oxygenated water and the removal of metabolic wastes.

The composition of spawning substrate utilized by sockeye varies widely from coarse sand to the crevices between large rocks (Foerster 1968). Sakinaw sockeye spawn on beaches in places where the gravel is small enough to be readily dislodged by digging, and the digging process tends to remove the silt and clean the gravel where the eggs are deposited. The gravel-cleaning process would be more efficient in streams where the current carries the dislodged fine materials downstream than in still waters of the lake shore.

Water depth does not seem to be a critical factor to the female Sakinaw sockeye in selecting a spawning site. Spawning on beaches can extend to considerable depths. However, spawning along beaches and fluvial fans is usually at depths of less than 3-4 m. The presence of upwelling ground water is most likely the essential and determining factor for successful sockeye beach spawning in Sakinaw Lake.

At a size of approximately 25 to 32 mm, from January through June, sockeye fry emerge and initially feed near the lake shoreline in the littoral zone, subsequently shifting to the deeper waters of the limnetic zone. At this small size, sockeye fry are vulnerable to predation by other fishes and birds, and survivals can be lowered substantially by aggregations of natural or artificially produced predators. Juvenile sockeye rear in Sakinaw Lake for 1 to 2 years. Growth influences the duration of stay in the nursery lake and is influenced by intra- and interspecific competition, food supply, water temperature, thermal stratification, migratory movements to avoid predation, lake turbidity, and length of the growing season (Burgner 1991). Production of food organisms is particularly important at this life stage because faster growth rates can increase the survival of the young sockeye. While in the lacustrine environment, fry and juveniles feed as visual predators, primarily on copepods *(Cyclop*s, *Epischur*a, and *Diaptomu*s), cladocerans *(Bosmi*a, *Daphni*a, and *Diaphanosom*a), and insect larvae (Burgner 1991). Juveniles face competition for available food resources with other fish.

Estuarine and Ocean

Sakinaw sockeye smolts emigrate to sea in the spring at a length of approximately 100 to 150 mm and are subjected to intense predation by a variety of fish and bird species. Trout have been identified as especially significant predators during this out-migration life phase, and gulls and grebes are significant avian predators of sockeye smolts.

The freshwater/saltwater transition zone provided by estuary habitat can be important to the success of sockeye smolts. A natural, productive estuary provides food resources necessary for the smolts to transit the area, and can offer refuges from numerous fish and bird predator species. In near shore 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 all species of Pacific salmon can be affected by periodic warm water events (El Niño) in local waters, and by cyclic changes in ocean conditions in the North Pacific Ocean. Returning Sakinaw sockeye will have spent 2-3 years at sea upon returning to their natal spawning grounds, with the majority returning as 4 year old fish.

Lake Community

Sakinaw Lake has anadromous and non-anadromous sockeye salmon; chum salmon *O. keta,* chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*, coastal cutthroat trout *O. clarkii,* peamouth *Mylocheilus caurinus*, prickly sculpin *Cottus asper*, and threespined stickleback *Gasterosteus aculeatus*. Notably missing are rainbow trout *O. mykiss* and Dolly Varden *Salvelinus malma.* The Pacific lamprey *Entosphenus tridentatus* has been taken from Sakinaw Lake outlet and the rare parasitic freshwater Vancouver lamprey *Lampetra macrostoma* is present in Sakinaw and Ruby Lakes. Bosminids and daphnids are the planktonic cladocerans, while *Diaptomus oregonensis* and *Cyclops thomasi* are present in the planktonic copepods. The mysid *Acanthomysis awatchensis* occurs in the lake (Northcote and Johnson 1964).

Stocks Groups

Fraser Sockeye

Sockeye production from the Fraser River dominates the catch of all fisheries in the South Coast Region. The Pacific Salmon Commission (PSC) recognizes 8 to 10 major stocks (or races) and 30 to 40 minor stocks (or races) in the watershed. Fraser sockeye stocks have been divided into two major stocks based on early and late run timing. Generally the Early stock is characterized by little delay off the mouth of the Fraser and enters the river between July and late August (or early September). The Late stock typically delays 3 to 6 weeks off the mouth of the Fraser and then enters the river between early September and mid-October.

Non-Fraser Sockeye

The major Non-Fraser sockeye producer in the South Coast Region is the Nimpkish River, located at the northern end of Vancouver Island. The timing of the Nimpkish River sockeye stocks is early, peaking at Malcolm Island in Johnstone Strait in early to mid July. There is an earlier component to the Nimpkish stock aggregate that is present in Johnstone Strait from mid-May onward.

Four minor sockeye stocks are also located in Johnstone (Fulmore, Phillips, Heydon) or Georgia Straits (Sakinaw). Heydon, Fulmore and Phillips sockeye stocks have been aggregated based on their similar timing, and stock size and low productivity. All three are small coastal systems that are low in productivity. Sockeye spawning in rivers draining into each of these unproductive lakes are characteristically 4 and 5-year-olds; the largest component spends 2 years in fresh water. They migrate through upper Johnstone Strait from mid-June to late July, returning to the mainland inlets of Area 12 (Fulmore) and Area 13 (Phillips and Heydon). These fish are passively managed due to their concurrent migration with Nimpkish stocks and the overlap of their run with early Fraser River stocks.

The only Georgia Strait sockeye stock is found in Sakinaw Lake. Sakinaw is the most productive of the 5 non-Fraser sockeye lakes in the South Coast region (Stockner and Shortreed 1978). Sakinaw sockeye can be distinguished from early Fraser and other minor sockeye stocks in the South Coast by their small size, age composition, freshwater growth scale patterns or genetic markers.

The Sakinaw stock is composed primarily of 4-year-old lake-spawning sockeye. They migrate through Johnstone Strait, peaking during the last two weeks of July and are considered to be an early stock. There are no fisheries specifically for Sakinaw sockeye, although they are intercepted by Johnstone and Georgia Strait fisheries for Fraser River sockeye (Early Stuart, Nadina, Gates and Raft stocks).

The non-Fraser stocks tend to return earlier than the Fraser stocks (except for the Early Stuart), beginning their terminal migration in early to mid-June, peaking by late July and finishing before mid August in Johnstone Strait. Depending on the year, Fraser stocks begin in late June and will then continue to the end of October. In general, the early Fraser stocks are more abundant than the late stocks in three years out of four. The late stocks, primarily due to Adams River sockeye, are most abundant in the 1997/2001 cycle, which is the most abundant of all four cycles.

Diversion Rate

Stocks returning to the Fraser River reach the river mouth either by traversing Johnstone and Georgia Straits or by passing through Juan de Fuca Strait (Figure 5). Because the dominant route of travel has historically been through Juan de Fuca Strait, the proportion of fish utilizing the northern approach has been generally called the "diversion rate". This rate changes from year to year and is routinely estimated by the PSC (Hamilton 1985). Also, it is assumed that non-Fraser stocks approach exclusively from the north (Figure 6).

Fisheries

Northern approach sockeye are taken in fisheries which include:

> Statistical Area 11 (troll and gillnet). This is a minor fishery off the north end of Vancouver Island.

Johnstone Strait (seine, troll, and gillnet). This is the major fishery harvesting north approach stocks and is largely a seine fishery. This fishery has been divided into upper (Area 12) and lower (Area 13) Johnstone Strait.

Georgia Strait (seine, troll and gillnet). The net fishery is a small (mostly seine) fishery located in central Georgia Strait (Statistical Area 16).

Native and test fishing catches in Johnstone Strait are included with the commercial catches.

Locations of these fisheries have not changed a great deal over the years; however, their intensity has increased. In general, there has been an increase in the effective harvest rate of the fisheries. This has been particularly true of the Johnstone Strait seine fishery.

Historically, commercial harvests of sockeye were almost exclusively with gillnets in terminal escapement areas. However, in recent times both seines and trollers have competed with gillnetting operations for the same fish. During the period 1953 to 1962, approximately two thirds of the total sockeye catch was taken by gillnet and one third by seine net. Trollers accounted for less than one percent of the total catch. Since that time the distribution of sockeye catch by gear has changed considerably. Between 1973 and 1982 the annual gillnet catch of sockeye decreased to approximately 50% of the total catch while the seine and troll catch increased to 40 and 10% respectively. Changes in allocation of catch among gear types has created several management problems, one of the most serious being the increased difficulty in estimating harvest rates by stock. Trollers, and to a lesser extent seines, often operate far from terminal escapement areas and consequently may catch sockeye from several different stocks. Without detailed information on run timing and routing through various fisheries it is very difficult to generate reliable harvest rate estimates on a stock-by-stock basis.

Methods

Data Sources

Data used in this document are estimates of annual catch from test, commercial and Native fisheries, and escapement estimates from lake counts, fishway counts and dive surveys. The following is a summary of the sources and methodology for the collection of these data. Inconsistencies or possible sources of error are noted where appropriate.

Catch

Estimates of Sakinaw Lake sockeye catch are made for Canadian and U.S. commercial fisheries as well as Native fisheries. The catch of sport caught Sakinaw sockeye is considered insignificant in recent years but the unreported sport catch may have been substantial during the 1960’s and 70’s.

Canadian commercial and test fishery catches are from sales slip records. All Canadian commercial catches were obtained from the Commercial Salmon Catch Database maintained at the Pacific Biological Station in Nanaimo, B.C.   U.S. commercial catches are from the Washington Department of Fisheries/Tribal Catch Database. Estimates of Canadian Native food and commercial catches are from British Columbia Catch Statistics, (Bijsterveld and James 1986 and MacDonald 1987).

Commercial catch data for Sakinaw sockeye are not available. Sakinaw sockeye are caught in mixed stock fisheries in Johnstone Strait and Georgia Strait. The PSC uses racial analysis (Gable and Cox-Rogers 1993) to determine the proportion of Fraser and non-Fraser sockeye caught in the Johnstone Strait test fisheries. Fraser sockeye are identified to specific stock groups whereas the non-Fraser proportion is not identified as to specific stocks (Nimpkish, Fulmore, Heydon, Phillips, Sakinaw). The proportions of the various Fraser sockeye stock groups in the test fisheries are used to allocate Johnstone Strait catch and to determine the diversion rate through Johnstone Strait for the various Fraser sockeye stocks.

For the purposes of this report total commercial catch reported for Statistical Areas 11, 12, 13 and 16 were used. Catch data for years 1952 to 1999 was obtained from the commercial salmon catch database. Terminal First Nation fisheries and sport fisheries have occurred in the past on Sakinaw Lake sockeye but they are poorly documented and have not been considered in this report.

Escapement

Official escapement estimates of spawning counts (BC16's) for Sakinaw sockeye have been recorded since 1953 and are available in the Salmon Escapement Database System (SEDS), Serbic 1991. There are numerous exceptions, especially in recent years, where an alternative data source has been used, as there is no BC16 report. Additional data was obtained from local fisheries offices, Sechelt First Nation, and dive surveys of the spawning grounds. Source documentation (e.g. paper "B.C.16's" forms, DFO - Stream Inspection Log forms, British Columbia Department of Fisheries Annual Reports and other unpublished reports) has been retrieved and examined in several instances to facilitate interpretation of poorly qualified summary estimates contained in the SEDS database. Estimates of spawning escapements are also available for 1957 to 1989 from the fisheries guardian's diary of nightly counts over the dam, through the fishway or into a counting trap. Escapements for 1957 to 1989 were counted through a fishway and are considered reliable. From 1990 to 1998 visual estimates were made on the spawning beaches. These estimates are fraught with all the reliability issues associated with undocumented effort and methodology.

Fishway Counts

In 1951 the sockeye run was counted with the aid of a counting fence. A concrete dam was installed in November 1952. Reasons for the dam construction included increased water storage in Sakinaw Lake as well as a means to collect and enumerate returning adult salmonids. The current dam structure is located approximately 200 m from the low tide line and effectively prevents upstream migration. On the north side of the structure a fishway was built into the dam. Stop logs in the dam permit the storage of water and control of lake discharge during the period of sockeye migration and spawning. From 1953 to 1986 the Sakinaw Lake fishway was normally operational from the end of June through to the first week of September for the enumeration of sockeye. All fish counted through the fence during this period were assumed to be sockeye.

Enumeration was conducted at night from 21:00 to 05:30 depending on run strength, tide level and lake water temperature. The sockeye were locked out between counts. Information collected each night included weather, tide, lake level, air and water temperature, duration of count, sockeye counted, average weight, and comments (this is a valuable source of information on commercial fisheries, predators, poaching and local resident's concerns about lake levels). In 1987 a fish trap was installed in the fishway to collect migrating sockeye for enumeration. Sockeye were counted and released on a daily basis.

Dive Surveys

Dive surveys were conducted in 1979 and re-established for the years 1999 to 2001. The dive surveys were conducted on the known spawning beaches in Sakinaw Lake.

Unknown methodology was used in 1979 to conduct the dive surveys of Sakinaw sockeye spawning areas. There is however a video tape record of some of the dives that provides a record of the spawning areas and habitats surveyed in 1979 (T. Shardlow, DFO Nanaimo, pers comm). This first dive survey of Sakinaw Lake's spawning beaches gave a reliable escapement estimate (10,222) relative to the fishway count (9720) in the same year. It is assumed that the procedures used in 1979 are similar to those employed in the recent dive surveys. The recent dive surveys are the only estimates of spawner abundance for Sakinaw Lake.

A crew of three divers, as per Worker's Compensation Board (WCB) regulations, conducted the surveys in 1999-2001. On the first dive, two divers swam the site by descending to a maximum depth of 12 m. This was deemed the maximum spawning depth from 1999 observations. The divers proceeded along that depth contour to the end of the site, which was judged by an estimate of distance while on the surface, whether there was suitable spawning gravel and slope of the underwater terrain. They then ascended 3 – 5 m, depending on visibility, and returned in the opposite direction, providing some overlap with observed area below to ensure no redds or carcasses were missed. This was continued until they reaching the surface. Divers subjectively assessed the available habitat and looked for redds. Redds were counted but not marked in 1999 as sinking gillnets were being used at the same locations to obtain sockeye brood stock. Spawned carcasses and live fish were counted and noted. In 2000-2002, redds were counted and marked on the first dive, new redds on subsequent dives were marked.

Biological Traits

Sampling for biological traits in catches and escapements of Sakinaw sockeye has not been routinely completed each year. The absence of annual age-at-return information from both catch and escapement samples precludes assessment of brood year specific production variations or stock and recruit analyses for Sakinaw sockeye at present. Tissue samples were collected in 1988, 2000 and 2001 to determine the genetic relationship of Sakinaw sockeye to other sockeye populations (Wood et al. 1994; Nelson et al. *in press*).

Length, Weight and Sex

Average weight of sockeye passing through the fishway was collected from 1957 to 1972. Limited length, sex and fecundity information from the brood stock collections has only been collected during the last three years.

Age

Fish scales used to determine age structure were derived from escapement samples. The European method of age designation was used, in which a decimal point separates the number of winters spent in freshwater (minus the incubation period) from the number of winters spent in saltwater (Burgner 1991). Total age is calculated by adding 1 year to the total of freshwater and saltwater age. For example, an age 1.2 sockeye would have spent one winter in fresh water and 2 winters in the sea for a total age of 4 years. Historic scale notation for the same fish would be age 4_2.

Smolt Migration

Downstream smolt traps were built and installed in the Sakinaw Lake outlet creek (Bates and August 1997). In 1994 and 1995 the traps were built in the outlet of the adult trap where the majority of flows from the lake were focused. The trap consisted of a trough from the lower sill in the fishway leading into a live box. In 1996 and 1997, traps were constructed downstream of the dam and the fishway. This later trap design was a simple winged structure with fence panels fishing a portion of the creek. The water and fish were subsequently directed into a trough and then into a live box.

Trap efficiency (0.03 to 0.05) was calculated in all years that the traps were fished. The effective areas that the traps were fishing were calculated as a percentage of the cross sectional area that the trap was capturing. This was calculated by determining the trap cross sectional area and dividing by the creek cross section.

All smolts were identified to species, counted, weighed, measured, sampled for scales and released downstream.

Fishery

Effort

Effort information (boat days) was calculated as the product of the number of days the fishery by gear type was open and the number of vessels participating in the fishery. Vessel counts were obtained visually via over flights during the commercial fishery.

Harvest Rates

Harvest rate estimates for Sakinaw sockeye caught in Area 11, Johnston Strait (Areas 12 & 13) and Georgia Strait (Area 16) were calculated for commercial gillnet and seine fisheries for the periods 1986-89 and 1992-94. Data was analysed by statistical week (month/week). Estimated proportions of non-Fraser and Early Stuart sockeye in the Round Island test fishery catches (Area 12) were determined by scale racial analysis (Gable and Cox-Rogers 1993; PSC unpublished data). Proportions of non-Fraser and Early Stuart sockeye in the catch were assumed to be constant for each area and 7 or 14 days was used as the migration timing through the areas. Of the non-Fraser sockeye, Nimpkish sockeye are only present in Areas 11 & 12; Heydon, Fulmore and Phillips present in Areas 11, 12, & 13 and Sakinaw present in all four areas. The proportion non-Fraser Sakinaw sockeye in each area is assumed to increase as they migrate through each area (Areas 11 & 12 - 8%; Area 13 - 20%: Area 16 - 40%). The proportions used are from an unpublished analysis conducted by the PSC in 1975 (J. Woodey, PSC, Vancouver, pers comm.). Harvest rates for Sakinaw sockeye were calculated using the escapement estimates from BC16 reports and fishway counts. PSC escapement data were used to calculate the Early Stuart harvest rates. Harvest rate was calculated as catch divided by catch plus escapement.

Data Analysis

Escapement

The escapement estimates for Sakinaw Lake sockeye were plotted for each year and by brood year. To reduce the effect of changes in observers over time and their unknown level of thoroughness in enumerating spawners and because escapement estimates are obtained by different procedures during some years (i.e. fence counts, mark-recapture visual observations during stream walk and over flights), all escapement data were standardized by $Z_I = (X_I - X)/SD$. Where Z_I = the standard score for year I (such that the mean of $Z_I = 0$); X_I= log of the original escapement value; X= the mean of the log of all recorded escapements for Sakinaw Lake sockeye; SD = standard deviation of the log of all the escapements.

The standardized escapement time series data were smoothed using a procedure introduced by Cleveland (1985). LOWESS (locally weighted regression) data smoothing with tension parameter = 0.5 was applied to the escapement time series. A "locally weighted” linear regression is used to obtain smoothed values for each value of y, given the values for x. That is, for each x_i, a linear regression is computed in which nearby values are weighted more heavily than values further away. Then the estimated regression coefficients are used to predict a smoothed value for y_i, given x_i. The procedure is particularly suitable for assessing trends in escapement because it takes into account unequal spacing between years (i.e. missing escapement records) and produces a smoothed function which is not sensitive to outliers. Escapement data typically contains numerous missing values and unexplained outliers. The LOWESS-smoothed curves were used to clarify the relationships between the escapement estimates and years.

Run Reconstruction

The examination of historic information from fisheries on migrating salmon typically involves run-reconstruction methods. "Backwards run reconstruction" is a procedure by which a salmon run is reconstructed backwards in time and space using catch-by-area-stock-and-date and escapement-by-stock-and-date information, to estimate the abundance-by-area-and-date that was present prior to any fishing. The purpose of the technique is to estimate timing-abundance curves by stock and to estimate area and stock specific harvest rates.

Starr et al (1984) reconstructed coastwise estimates of harvest rate and catch by stock for British Columbia sockeye from 1970 to 1980. Data inputs used include escapement (number and timing) by stock, catch by area, and known migratory routes for each stock. Separation of catch into component stocks is made proportionate to the escapement of each stock following a procedure known as run reconstruction Starr and Hilborn (1988).

Harvest Rate Indicators

The use of Early Stuart sockeye to represent the harvest history of the Sakinaw Lake sockeye population assumes that these populations have the same harvest patterns. The harvest assumption cannot be tested directly but two lines of evidence suggest that the pairing of Early Stuart with Sakinaw sockeye is reasonable. First, scale analysis of sockeye taken in the Johnstone Strait fisheries identify the presence of non-Fraser and Fraser sockeye at the same time (Henry 1961; Gable and Cox-Rogers 1993; Figure 7). Second, tagging information supports the presence of non-Fraser and Early Stuart sockeye in the Johnstone Strait fisheries at the same time (Verhoeven and Davidoff 1962). Scale analysis and tagging infer that the run timing of Early Stuart sockeye in commercial fisheries of Johnstone Strait is very similar to the mid-June to late July run timing of Nimpkish, Heydon, Fulmore and Phillips and Sakinaw lakes (DFO 1988; Annual Reports of the Pacific Salmon Commission).

Non-Fraser sockeye are vulnerable to harvest in Johnstone Strait (Areas 11, 12 and 13 and in Georgia Strait (Area 16 - Sabine Channel) net fisheries. While these mixed stock fisheries are directed towards migrating Fraser River sockeye, non-Fraser sockeye, including Sakinaw are caught. In most years the fishing effort on Fraser sockeye occurs in late summer during August in order to control the harvest rate on more vulnerable early migrating stocks, such as the non-Fraser and Early Stuart sockeye. However, in years of high Early Stuart abundance fisheries have been conducted as early May in Area 11 or mid-June in Area 12. Both DFO, PSC and its predecessor the International Pacific Salmon Fisheries Commission (IPSFC) intensively monitor the fishery. Estimates of diversion rate (proportion of Fraser sockeye migrating through Johnstone Strait as opposed to through Juan de Fuca Strait), catch statistics, effort and stock composition are available (Hamilton 1985, IPSFC and PSC Annual Reports). The diversion rates are for all Fraser River stocks combined not just for Early Stuart sockeye.

Although the specific goal of the Johnstone Strait sampling programs is to monitor harvest rates of Fraser sockeye stocks, the data also provide insight on the harvest of non-Fraser stocks. The migration timing of Sakinaw sockeye is similar to the timing of the Early Stuart, i.e. peak migration in Area 12 occurs in mid-July. However, the run timing for Sakinaw sockeye is more protracted than that of other non-Fraser or Early Stuart sockeye, as indicated by the timing through the Sakinaw Lake fishway. During the period of the Early Stuart migration, the PSC estimates the stock composition of sockeye catch in Johnstone Strait fisheries occurring in Area 12. Racial analysis distinguishes the proportion of Fraser (by stock group) and non-Fraser sockeye catch by statistical week. There are likely at least five stocks, Sakinaw, Nimpkish, Heydon, Fulmore, Philips that contribute to the non-Fraser catch. The relative contribution of these stocks to non-Fraser catch depends on several factors including timing and location of the fishery. For example, Sakinaw sockeye likely contribute relatively more to the catch in Area 16 fisheries than in Johnstone Strait fisheries.

Using the catch and stock composition data, two approaches were applied to determine a rough estimate of the exploitation rate of net fisheries on Sakinaw sockeye. First, the harvest rate of Johnstone and Georgia Strait fisheries on Early Stuart sockeye were assumed to be similar to the exploitation rate experienced by Sakinaw sockeye in these fisheries. To calculate the harvest rate, the assumptions were: 1) that stock composition of Early Stuart sockeye from test fishing catch sampled in Area 12 applies to catch in Areas 11 and 12 during the same week and to the catch in Areas13 and 16 in the same or subsequent weeks; 2) the diversion rate for Early Stuart sockeye is similar to the diversion rate for all Fraser River stocks (i.e. a specific diversion rate for Early Stuart sockeye is not available); and 3) that the abundance of Early Stuart sockeye migrating through Johnstone and Georgia Straits was equal to the diversion rate multiplied by the total return of Early Stuart sockeye (catch for all areas plus escapement). The corresponding harvest rate was then calculated by dividing the estimated catch of Early Stuart sockeye in all areas and weeks by the number of Early Stuart sockeye estimated to have migrated through Johnstone and Georgia Straits. Data, of varying quality, were available to attempt this analysis from 1986-1988 and 1992-1994. If these harvest rates are assumed to represent the exploitation rate on Sakinaw sockeye, they are most likely minimum estimates because Sakinaw are potentially exploited in other fisheries, including Johnstone and Georgia Strait fisheries occurring after Early Stuart sockeye have left the area. The later fisheries exert considerably more effort than July fisheries.

The second approach used was to attempt to reconstruct the potential catch of Sakinaw sockeye in the Johnstone and Georgia Strait fisheries by making some assumptions about the proportion of non-Fraser catch to attribute to Sakinaw. The assumptions were similar to the first approach: 1) that stock composition from catch sampled in Area 12 applies to catch in Areas 11 and 13 during the same week and Area 16 in the subsequent week; and 2) that 8% of the non-Fraser catch in Areas 11 and 12, 20% in Area 13 and 43% in Area 16 were of Sakinaw origin. These numbers are based on scale racial analysis of the relative abundance of Sakinaw sockeye in the area contributing to the catch (J. Woodey, PSC, Vancouver, pers comm.). In addition, for Area 16 only, the non-Fraser proportions from the last sampled week (usually statistical week 7/4) were extended to the second week in August (8/2) to account for the more protracted run timing of Sakinaw sockeye. It is likely Sakinaw are present in Area 16 for a longer time period and vulnerable to fisheries in August. In some years, when there has been considerable effort directed toward sockeye in Area 16 in early August, the resulting exploitation rate on Sakinaw sockeye could be high during this period despite a relatively low proportion of Sakinaw origin sockeye in the catch. Two estimates of escapement are available for Sakinaw, a BC16 number and the original estimates from the fishway.

Assessment of Threat

The International Union for the Conservation of Nature (IUCN) has developed threatened species criteria (IUCN 2001), which are rules for assigning species or closed populations with negligible opportunity for rescue (<1 migrant per year) from other populations into categories representing different levels of threat. The IUCN rules are based on information about such characteristics as number and distribution of individuals, fluctuations and decline in abundance and distribution, and risk of extinction.

Assessment of threat for Sakinaw sockeye was analysed using RAMAS Red List software from Applied Biomathematics (Akçakaya et al. 2001) that implements IUCN threatened species criteria. The IUCN characteristics are used as input data; the output is a classification into one of the categories, such as Critically Endangered, Endangered, Vulnerable, or Least Concern.

For example, a taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by Criteria A:

Population reduction is in the form of either of the following:

1) An observed, estimated, inferred or suspected reduction of at least 80% over the last 10 years or three generations, whichever is the longer, based on (and specifying) any of the following:
    a) direct observation;
    b) an index of abundance appropriate for the taxon;
    c) a decline in area of occupancy, extent of occurrence and/or quality of habitat;
    d) actual or potential levels of exploitation;

e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.

2) A reduction of at least 80%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer, based on (and specifying) any of (b), (c), (d) or (e) above.

The IUCN Critical Endangered category equates to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) categories "Threatened" or "Endangered".

Genetics

To determine whether sockeye in Sakinaw Lake are reproductively isolated from sockeye in other lakes of the central and south coast of British Columbia, we examined data from previous surveys of genetic variation in 33 allozyme loci (Wood et al. 1994), 10 microsatellite loci (µsatDNA; Nelson et al. *in press*) and mitochondrial cytochrome b and ND1 genes (mtDNA; Wood et al. *in prep*). The mitochondrial DNA results are not yet published but are based on the method described by Bickham et al. (1995) for detecting RFLP haplotypes after amplification of the cytochrome *b* gene; this approach was subsequently extended to include the *ND1* gene. A total of 21 composite haplotypes were detected using DNA amplified from both genes in samples collected throughout the natural range of sockeye salmon (Wood et al. *in prep*). Of these, we observed only 2 in Sakinaw Lake, 3 in Heydon Lake, 3 in the upper Fraser-Thompson River drainage above Hell's Gate, 5 in the lower Fraser River, compared with 7 and 11 in the Nimpkish and Owikeno drainages, respectively (Table 1). These haplotypes are passed from one generation to the next within eggs (not sperm) and thus represent separate female lineages detected within each sample.

F_{ST} statistics are reported to indicate the proportion of total genetic variation that can be attributed to differentiation among populations. Where the effect of mutation can be ignored, pairwise-F_{ST} statistics can be used to infer gene flow between pairs of populations at equilibrium using the relationship $F_{ST} = 1/(4N_em+1)$ where N_e is the genetically effective population size and m is the proportion of migrants each generation (Wright 1969). Thus, N_em is the gene flow in absolute number of migrants from one population to another each generation. As these populations have arisen within the last 10-15,000 years (since the last glaciation), it seems reasonable to ignore mutation. However, the assumption of equilibrium is more tenuous so the absolute estimate of gene flow may be biased. Even so, the pairwise-F_{ST} statistics provide a useful, objective criterion for assessing relative degrees of reproductive isolation. The pairwise-F_{ST} statistics for microsatellite DNA data were taken directly from Table 2 in Nelson et al. (*in press*); for brevity, we included only data for the largest sample from each lake where statistics for replicate samples were reported. Pairwise-F_{ST} statistics for mitochondrial DNA data were computed with ARLEQUIN version 2 (Schneider et al. 1999).

Results and Discussion

Escapement Estimates

Early comments on sockeye escapements to Sakinaw Lake are presented in Table 2 and escapement estimates by decade from 1953 to 2001 for Sakinaw sockeye are presented in Table 3. Escapement estimates from the BC 16 reports are consistently higher than those from the fishway (Figure 8). A management escapement level of 14,000 sockeye has been proposed for Sakinaw sockeye (DFO 1988). However, the methodology used to develop the management escapement level for Sakinaw sockeye is unknown. Escapement estimates into Sakinaw Lake have varied in the last 40 years since the trap and dam structure was built. Populations appeared somewhat stable from 1955 to 1985 with a peak escapement of 16,000 in 1975 but have decreased rapidly in the last 12 years (Figure 9). The 5 year average annual escapement for 1996 to 2001 is about 80 sockeye. Figure 10 shows a pattern of cyclic dominance for the 1947 brood year, repeating every four years beginning in 1959 until 1983. The other brood years show no clear trend for a subdominant year.

Sakinaw coho and chum salmon show similar declining trends in escapement during the same period as sockeye (Figure 11). This is not surprizing given the poor stock status of chum and coho salmon in Georgia Strait (Ryall et al. 1999, Simpson et al. 2001).

There is concern regarding the inconsistencies in methodologies and the lack of effort directed to escapement enumeration in recent years. The methodology used in Sakinaw Lake for the majority of years was accomplished by counting the sockeye through the dam of fishway at night or counting chum and coho on the spawning grounds. In some years the enumeration program was very thorough and in other years it was very limited and sporadic. In some areas there are no observations at all. The methods for deriving the reported escapement estimates are not standardized but usually involve counting the salmon by species and relating these counts to timing of observations, and possibly other factors, to get a total population estimate. The salmon counts into Sakinaw Lake are affected markedly by tide levels, water levels and weather conditions as well as the timing of the surveys. Lack of standardized approaches sometimes results in estimates being affected by staff changes, although staff that remained at Sakinaw Lake for a number of years generally maintain consistency. For this reason the reported estimates are not considered to be absolute estimates of spawning numbers but are treated as indices of trends in escapement (Shardlow et al. 1987). However, the estimates are the only consistent historical measure of stock status available. The consistency of escapement estimates among years is uncertain but trends in escapement do reflect trends in catch or test fishing data when these data have been compared. Therefore, escapement trends for Sakinaw Lake sockeye are considered a relative measure of abundance and are likely to be both relatively reliable and informative in determining patterns of relative abundance summed over decades of time.

Adult Size

Average length of spawners collected in 2001 for brood stock were 445 mm (10 fish) and 468 mm for 5 males, and 428 mm for 5 females respectively. Sakinaw sockeye passing through the fishway from 1957 to 1972 ranged in weight from 1.14 to 2.95 kg. Adult migration weight varies by year with the highest average weight of 2.1 kg in 1971 and the lowest weight of 1.81 kg in 1964 (Table 4). Sakinaw sockeye have small body size compared to other sockeye populations in the Pacific Northwest (Gustafson et al. 1997).

Age Composition

Age composition of Sakinaw sockeye is variable but normally dominated by age 1.2 sockeye based on calendar year returns (Table 5). Sakinaw sockeye age composition, by brood year, averages 2.65% age 3 (1.1), 87.12% age 4 (1.2 and 2.1), and 10.22% age 5 (1.3 and 2.2). The majority of Sakinaw sockeye smolts (97.5%) emigrate as yearlings (age 1.*); the remaining smolts (2.5%) emigrate after 2 years (age 2.*) of lake residence.

Based on scales, age 1.3 Sakinaw sockeye return earliest followed by age 1.2 and then age 2.2. (Table 6). This observation has been recorded for other sockeye stocks (Foerster 1968, Gustafson et al. 1997).

Fecundity and Egg Size

For a given fish size, female sockeye have the highest fecundity and smallest egg size among Pacific salmon. Average fecundity across the range of sockeye is from 2,000 to 5,200 (Burgner 1991). Available information that provides these measurements for Sakinaw sockeye was insufficient to adequately evaluate patterns of fecundity among females. However, data on average fecundity were available from brood stock collection. The 17 females used for brood stock in 1986 had an average fecundity of 1,665 eggs. In 1987 fecundity for the first egg take (18 females) averaged 3,172 eggs and for the second egg take (14 females) it was 2,865 eggs. The 20 females collected for brood stock in 2000 and 2001 had an average fecundity of 2,410 eggs with a range from 1,545 to 3,036 eggs. Egg diameter for 15 females was 5.6 mm and an average weight of 300 mg. Sakinaw sockeye fecundity is at the lower range for most sockeye populations, while egg size and weight are within the range of other sockeye populations (Gustafson et al. 1997). Sakinaw sockeye fecundity seems to be variable from year to year. However, since the fecundities were collected from wild females off the spawning beaches some of the egg counts may be partial fecundities.

Spawning

Timing

There are only limited records on the spawning time for Sakinaw sockeye. As with run timing, spawning is variable from year to year. Spawning has been reported to start as early as September 10th and to finish on December 20th. Mean start and end times are October 20th and December 11th respectively, with the peak on November 19th. The early spawning time may be in error because there seems to be some confusion in the reports as to the definition of spawning. Some of the records report lake entry as the start of spawning. These records were ignored.

The recent dive surveys confirm the earlier reported spawning times and duration, starting in late October, peaking in mid November and finishing in early December (Table 7).

Dive Surveys

1979

A survey of the lake shore carried out in 1979 (R. Elvidge, DFO, Vancouver, pers comm.) in response to a land development proposal revealed that only a small percent of the shoreline offered potential for beach spawning. Most of the identified spawning areas were located in the upper basin of the lake near the inlet of Ruby Creek (Figure 3). After a preliminary survey determined that there were no large spawning sites in the lower basin, studies were only carried out on the two small spawning areas in the lower basin.

Some general physical parameters for sockeye spawning beaches observed throughout the lake were as follows:

1. Spawning occurs at depths ranging from a maximum of 25 m to within 25 cm of the existing lake surface. The greatest density of redds were found in the 3 to 10 meter depth range.
2. All major beach spawning areas occurred in the vicinity of creek mouths or observable ground water sources.
3. All spawning beaches were littered with forest debris and supported a population of aquatic plants at depths of less than 3 m.

The five observed spawning beaches were numbered according to size of spawning population, with Beach 1 having the largest area (Figure 3). The following is a brief description of each beach. Timing, distribution and abundance of sockeye spawners on each beach are presented in Table 7. All shoreline measures are approximate.

Beach 1 (Sharon's)

This beach occupies 300 m of shoreline, extending from 100 m north, to 200 m south of the southerly boundary of Lot L3255 (Figure 12). Both ends of this beach are terminated by steep rock faces extending below observed spawning depths. The densest spawning concentration occurred at the southern end of the beach in the vicinity of the creek outflow, although an equal peak concentration occurred in the vicinity of southern boundary of Lot L3255. This occurred at a later date and for a shorter duration. The redds in this area were deeper than average with the deepest being observed at a depth of 23 m.

Beach 2 (Haskin)

This beach includes the remainder of the bay surrounding the development site plus a further 75 m extending along the adjoining peninsula (Figure 12). The total length of the beach is 400 m and is divided into three areas of differing topographic nature. The southerly 85 m, bounded by the two stream outflows is the most productive, with the densest spawning concentration occurring at the outflow of the most southerly stream. This area includes the lowest 75 m of the stream in which the only stream spawning sockeye in the system were observed. Heavy spawning occurred in the stream with competition from spawning coho during the latter stages of sockeye spawning. The northerly 175 m were lightly spawned in patches of marginal quality spawning material. Redds here were found only between depths of 3 to 10 m. The central 150 m of beach 2, during most observations, revealed aggregates of fish in pre-spawning stages of activity, and although the spawning material appeared better than that of the northerly area of Beach 2, no spawning occurred here. It should be noted that a public boat launching ramp is located on this beach.

Beach 3

Sockeye spawned within the bay into which Ruby Creek flows (Figure 13). This area has a shoreline distance of 200 m and a width of 100 m. The major spawning area is located in close proximity to the Ruby Creek outflow with a second minor spawning area occurring in the south arm of the bay. The redds in these areas are located at a greater distance from the shore, yet within a shallower range of depths in comparison to those of the other spawning areas in the upper basin. The spawning depth range in this area was from 2 to 7 m.

Beach 4

This area has a shoreline distance of 650 m and supports the largest spawning aggregate observed within the main basin (Figure 14). Both the east and west boundaries of this beach are defined by creeks entering the lake at the point where potential spawning beach terminates and solid or heavy rock shoreline continues. The densest spawning occurred along the most westerly 150 m with a few redds scattered sparsely along the central length of the beach. A slightly heavier concentration occurred for 150 m near the easterly boundary but not within 100 m of the easterly creek. A shallow bay surrounding the outflow area of the easterly creek was heavily covered with logging debris. The majority of redds on Beach 4 occurred between the depths of 3 to 7 m with a maximum depth of only 10 m. Observations on this beach, although not continued to completion of spawning, revealed that spawning here commenced and peaked at a later date and possibly extended to a later date than any other observed beach in the lake.

Beach 5

This was a small but concentrated spawning area (75 x 20 m) located in a bay at the outer end of the narrows between the lake basins (Figure 15). A creek enters the bay immediately to the west of the spawning area and both sides are bounded by shallow, marshy shoreline. This area was not discovered until November 8th, at which time the highest spawning aggregation was recorded. Subsequent observations indicated that the timing of spawning on this site would be similar to those areas in the upper basin but that a considerable part of early spawning was not observed.

Some percentages and spawning population distributions in relation to the land development proposal were as follows:

- Of the total number of spawning sockeye observed in the upper basin of the lake, 94.9% was observed within the area that would be most affected by the foreshore development proposal;
- The sockeye observed spawning on the beach within the lot lines of Lot L3255 represented 47.4% of the upper basin spawning population;
- Peak sockeye spawning within the upper basin occurred on November 16th. Of the sockeye spawning in the upper basin, 91.8% was observed within the area that would be most affected by the foreshore development proposal and 54.0% was observed on the beach within the lot lines of Lot L3255.

1999

Dive surveys of sockeye spawners and redds took place once a week at two locations on Sakinaw Lake from November 15th to December 6th, 1999. The purpose of the survey was to provide an estimate of the number of spawning sockeye and redds. The dive surveys were conducted in an effort to get escapement estimates for Sakinaw sockeye because the fishway counts were no longer being conducted. Beaches 3, 4 and 5 were not surveyed because funds were limited and no evidence of sockeye spawning had been reported for these beaches for many years (G. McBain, DFO Madera Park, pers comm.). A total of 14 sockeye and 23 redds were observed and marked in 1999 (Table 7).

Beach 1

The area surveyed was approximately 10-15 m of shoreline from the right bank of the creek, 35-45 m from the left bank, and out 15-20 m to a maximum of 15 m in depth. The total area surveyed was 450-800 m^2. There was a significant amount of good, clean spawning gravel with some leaf litter in front of this creek due to a high water event in

1992. It drops steeply to 15 m of depth. There were some submerged logs at the edges of the site but little else. The perimeter of the site was obvious as the gravel ends and the bottom becomes thick mud and organic debris.

On the first dive (November 15th) one spawned out female sockeye carcass was found and 4 redds were marked. Each redd was approximately 0.75 m wide and 1.25 m long (0.94 m^2). One female sockeye occupies, on average 1.0 to 1.6 m^2 depending on female size and spawning location. Including the space between redds, the area required for sockeye spawning has been calculated at 3.0 m^2 (Foerster 1968). Four new redds were located and marked at 7-12 m on November 22nd. Six sockeye were seen on November 29th and 4 new redds were marked at the same depth as the ones on November 22nd. On the last dive (December 6th) 3 redds were located at 10 m and 1 at 5 m. Three of the markers used to mark previous redds had been displaced by a large amount of gravel that had slid and or been deposited by high creek flows during the previous week.

Beach 2

This beach is located in front of Haskins Creek at the bottom of Sakinaw Lake Road. Access was from the road and the dive was conducted from the beach. The boat launch marked the beginning of the site, which continued for approximately 100 m northeast to the other side of the creek mouth. The total area surveyed was estimated to be 1,000-1,500 m^2 and was surveyed initially to 20 m in depth. The bottom in the deeper portions of this site consist mostly of thick mud and organic debris, likely unsuitable for salmonid spawning. Gravel and sand suitable for spawning occurred entirely along the beach to a depth of 2-3 m, the beach then drops off quickly. Spotty sand/gravel patches were seen down to 7-10 m directly in front of Haskins Creek. There were many large, submerged logs in front of the creek as well.

No fish or redds were observed on the first dive on this beach (November 15th). It was noted that future dives did not need to go as deep as 20 m because there was no suitable spawning gravel below 10 m. On November 22nd, 7 sockeye were seen at the mouth of Haskins Creek and 2 redds were marked at 7 m. One of the redds had a peamouth chub in it. Another redd was marked at 2 m and it had a large cutthroat trout in it. During the November 29th dive, 3 new redds were marked at 7 m in the same area as the previous dive. Three sockeye were seen and one trout. A new redd was marked at 8 m during the fourth dive on December 6th. Two spawned and unspawned coho carcasses were also observed during this dive. These carcasses had most likely washed out of Haskins Creek since coho had been actively spawning in the creek since November 22nd.

2000

From November 13th to December 3rd, 2000 a dive survey of sockeye spawners and redds took place at the same sites as those surveyed in 1999. Habitat and substrate had changed little, with the exception of the new spawning gravel which had been placed on Beach 2 at the mouth of Haskins Creek during the summer of 2000 (see Enhancement and Restoration). A total of 129 sockeye and 60 redds were observed in 2000 (Table 7).

Beach 1

Positive identification and observation of spawning sockeye was seen on each of the four dives on Beach 1. A maximum of 25 to 35 sockeye were seen during each dive in 2000, only one sockeye on the last dive appeared to be fresh. Redds were more numerous (53) than in 1999. Only 3 carcasses were seen. The only active sockeye spawning observed in 2000 occurred on this beach.

Beach 2

Only seven sockeye were observed at Beach 2 on the November 13th, the first day of the survey. No redds were observed on the spawning gravel placed at the mouth of the creek in the summer of 1999. On the following dives, only coho were seen milling at the mouth of Haskins Creek (Table 7).

2001

The survey of sockeye spawners and redds took place in Sakinaw Lake between October 29th and November 19th 2001. Sockeye were seen on October 29 on Beach 1 where 20 redds and 35 sockeye were observed. Also, an additional 12 sockeye and 6 redds were seen amongst the sunken logging debris on Beach 1. On November 12th the divers counted 30 sockeye and 12 redds along Beach 1. The primary spawning area on Beach 1 continues to be associated with the existing creek outflow and in remnant channels along the beach. About 50% of the spawning on the second dive occurred in fairly heavily covered areas of sunken old large wood. Twenty sockeye and 6 new redds were seen on Beach 1 and 6 redds were observed in the area of the sunken logging debris. The last dive was conducted on November 19th and the divers observed 22 sockeye and 3 new redds. The total number of sockeye and redds observed on Beach 1 in 2001 was 87 and 41 respectively (Table 7). No sockeye or redds were observed on Beach 2 during the dives in 2001.

Spawning Habitat

The amount and quality of spawning habitat used by sockeye in Sakinaw Lake has declined since 1979. Beaches 1 and 2 each had an area of 6,000 m^2 in 1979. The information from the recent dive surveys indicates that the areas used by sockeye on Beach 1 has been reduced by 85% to 900 m^2. Although sockeye have not been seen using Beach 2 in recent years the divers estimate that the potential spawning habitat for sockeye on Beach 2 has been reduced by 75% to 1,500 m^2. The areas not presently used by sockeye are covered with thick mud, organic debris and large logs. Recent surface surveys of Beaches 3, 4 and 5 indicate that similar degradation of spawning habitat has occurred on these beaches. Sockeye no longer spawn in Ruby Creek.

Logging and related forest practices are an important, but not the sole, cause of declining salmon populations. Other activities including agricultural, urban development, fishing, and dams are also important. Past timber production practices on the lands around Sakinaw Lake has degraded the habitat that salmon need to survive by increasing sedimentation in streams, stream temperatures, and the incidence of landslides. It also has destroyed spawning sites and created impediments to the movement of spawners upstream and juveniles downstream.

There are three cottages located on Beach 1 (Figure 12). The unnamed creek (locally known as Sharon's Creek) near the cottages has run on the other side of the valley in the past and that it has tried on at least two occasions to cut a path back towards the old channel only to be placed back in the existing channel. As recently as 1992, the last big spawn (1,000+; Figure 8) was buried under tons of material after a spring rain on snow flood event. Logs have been regularly boomed in front of the beach. Logs were also stored in front of Beach 2 (Haskins Creek) and there was a sawmill there until the 1970's that used to discharge its sawdust into the creek, using it as a natural conveyor. The main log booms for the mill were stored at the outlet of Ruby Creek (Beach 3) until the mid 1960's. A local resident states that the gravel and beach were much cleaner in her youth and there was less aquatic vegetation than there is now (S. Bushell, Sakinaw Lake, pers. comm.). Years of log storage and debris build-up on Sakinaw sockeye spawning beaches has done serious damage by covering potential spawning gravel or by increasing incubation losses because of siltation and poor gravel porosity.

Changes in ground water hydrology may also have occurred resulting in reduced ground water percolation. Changes in ground water hydrology may have occurred because of increased upland logging, creek diversions, floods (rain on snow events) and water extraction.

Emergence Timing

Figure 16 shows the in-gravel water temperatures for Mixal Creek and the sockeye spawning area on Beach 1. The mean temperature (SD) for Mixal Creek throughout the year was 9.9°C (4.23) and for spawning Beach 1 was 8.0°C (1.91). Temperatures in the spawning gravel were much more constant than temperatures in the creek. Given a spawning date of November 19, 1999 and winter temperature regimes for both habitats types, emergence timing can be calculated using $\ln(E) = 5.77 - 0.113T$, where E is the emergence time in days and T is the temperature °C (Murray 1980). Sakinaw sockeye fry would emerge after 141 days (April 18, 2000) at a mean creek temperature of 7.4°C (3.06) and after 157 days (May 6, 2000) at a mean in-gravel temperature of 6.3° C (3.06). Lower incubation temperature produce larger fry for a given egg size (Beacham and Murray 1986). It is also critical that emergence timing coincide with increased plankton productivity in the spring. Larger size and a delay in emergence timing may confer an advantage in foraging for food (Foerster 1968)

Smolt Size and Abundance

Estimate of juvenile abundance are required to identify whether changes in survival originate in freshwater or at sea. In Sakinaw Lake very few estimates have been made for juvenile abundance. The following data for 1994 to 1997 is from a report by the Sechelt Indian Band (Bates and August 1997).

Length and Weight

The mean smolt length in 1994 was 122.4 mm compared with 139.2, 133.0 and 129.0 mm in 1995, 1996 and 1997 respectively. Smolt weight data also showed a similar trend with the smallest smolts in 1994 at 20.91 g compared with 28.3, 24.1 and 21.0 g in 1995, 1996 and 1997, respectively. Differences in smolt size occurred during migration with larger smolts leaving the lake at the beginning and smaller ones at the end of the migration. For example, in Cultus Lake smolt length and weight also varies among years and ranges from 62 to 94 mm and 2.4 to 10.2 g (Foerster 1968). Sakinaw sockeye smolts are very large relative to those produced in most other sockeye lakes and similar in size to those produced in Lake Washington. Like Sakinaw Lake, Lake Washington is known as a productive sockeye lake that produces unusually large smolts, with 10% typically exceeding 125 mm in fork length (Doble and Eggers 1978, Burgner 1991). Sakinaw sockeye show the greatest freshwater growth on scale patterns of all sockeye populations in B.C. (Y. Yole, DFO, Vancouver, pers comm.). Freshwater circuli counts for age 1.* smolts (predominately returning as age 1.2 or 4_2) ranged from 13 to 27 with a mean (SD) of 19.6 (2.91) circuli (Figure 7). Age 2.* smolts ranged from 25 to 40, with a mean of 30.9 (4.58) freshwater circuli. Good freshwater growth is consistent with the limnological findings of Stockner and Shortreed (1978).

Abundance

The total smolt out migration for Sakinaw sockeye in 1994, 1995, 1996 and 1997 was calculated at 15,880, 2,760, 2,500, 5,200, respectively, based on a trap efficiency of 3 to 5%. Based on an average 4.5 % smolt to adult survival rate (Forester 1968), predicted adult production in 1996, 1997, 1998 and 1999 was estimated at 715, 574, 113, and 232 adults, respectively. Given the escapement estimates for 1996 and 1999 the average smolt to adult survival rate was 0.83% (Table 8). Forester (1968) cites the smolt to adult survival rate for Cultus Lake at 9.2%. The 0.84% survival rate would be a very low given the large size of the sockeye smolts leaving Sakinaw Lake. Ricker (1962) demonstrated that large smolts have a lower mortality rate than small smolts.

Migration

Smolt migration began during the first week of April and extended into the middle of June. On average peak smolt out-migration occurred in the first week of May. The migration period was the same between years with slight shifts in migration presumably dictated by changes in lake discharge and temperature.

During a snorkel survey on April 26, 2002, no smolts were observed in the lake outlet channel but a school of 100 smolts was observed below the dam in the first plunge pool. The ratio appeared to be 70% coho and 30% sockeye. The sockeye appear to be 15 – 20 grams and some of the coho up to 30 grams. There was evidence of wounds on some of the sockeye and coho smolts. The wounds were round in shape and were consistent with wounds inflicted by lampreys. The wounds were also infected with the common freshwater fungus *Saprolegnia*.

Run Timing

Based on co-migrating with Early Stuart sockeye and racial scale analysis, Sakinaw sockeye arrive in upper Johnstone Strait in mid June (Henry 1961; Figure 17). The estimated time for sockeye to migrate from the west end of Johnstone Strait to Area 16 is between 7 to 14 days at a swimming speed of 40 to 56 km per day, according to tagging experiments conducted by the IPSFC (Verhoeven and Davidoff 1962). The first sockeye have been observed entering Sakinaw Lake as early as May (G. McBain DFO Madera Park pers comm.). Year-to-year migration of sockeye into Sakinaw Lake is very variable as indicated by the fishway counts in Table 9. Visual enumeration at the fishway normally commenced in late June and indicate that Sakinaw sockeye first arrive from June 28th to July 15th, with a mean arrival date of July 7th (Figure 18). The last sockeye arrive from August 10th to September 28th with a mean end date of August 29th. Peak migration occurs on July 30th with a range from July 20th to Aug 17th (Figure 19). The mean duration of the run is 53 days with a range from 33 to 88 days. Various factors appear to cause a delay or disruption of migration timing for Sakinaw sockeye. The most common comments have been that the outlet flow from the lake was too low or the water temperature was too high. Tide levels also affect migration into the lake. Sakinaw sockeye normally only enter the fishway on a high tide at night. The presence of predators, most notably river otters, in or near the fishway disrupt the spawning migration. If the sockeye return to the ocean they have to wait until the next night to migrate into the lake because the fishway gate was 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.

Peaks and valleys are present in the yearly run timing curves. The peaks and valleys may have resulted from fishing effort on specific parts of the run or the presence of distinct spawning populations entering the lake at different times. For example, in 1987 the fishway counts were complete because of the installation of a trap that retained all the fish migrating each day. The run timing graph show numerous peaks and valleys (Figure 20). Johnstone Strait and Area 16 net fisheries started in 8/1 and 8/2, respectively, and continued for 2 to 3 days per week until the end of week 9/2. There were no net fisheries in Johnstone Strait prior to 8/1, yet peaks and valleys are present in the migration. The spawning ground survey in 1979 reports that spawning on Beach 4 commenced and peaked at a later date and possibly extended to a later date than any other observed beach in the lake. Variation in spawning time has been associated with variation in migration timing (Foerster 1968).

Harvest Rates

Sakinaw sockeye are passively managed. Harvest rates for Sakinaw sockeye depend on early Fraser sockeye abundance.

In 1952, approximately 6,000 sockeye migrated through the fishway into the lake. The gillnet fishery (3 or 4 row boats) in Lee Bay landed about 1,000 (4,728 lbs @ 4.5 lbs/fish) sockeye at the local fish camp in Pender Harbour during July and early August. The harvest rate for this terminal fishery was estimated at 14%. This harvest was considerably higher than the 50 sockeye landed by this fishery in 1947 (escapement estimated at 3,500). The 1952 fishery was regulated by a closed day, a small sanctuary off the mouth of Sakinaw Lake closed to commercial and sport fishing, and patrols to deter illegal fishing (A.C. Skipper, DFO Madera Park, pers. comm.).

It should be noted that illegal fishing and poaching of sockeye from the fishway has been of concern for as long as records have been keep on Sakinaw sockeye. However, there are no estimates given as to the magnitude of the harvest.

In 1972 approximately 4500 sockeye migrated into the lake which represented the previous 20 year average. The catch was estimated from 1,350 to 1,800 sockeye taken by gillnets (2 or 3 boats), primarily in Lee Bay, followed by Middlepoint, Bargain Harbour and lastly in Sabine Channel. The harvest rate for this terminal fishery was from 23 to 29% (R.P. Kraft, DFO, Madera Park pers. comm.).

The PSC provided estimates for the contribution of Sakinaw sockeye to the 1975 net fisheries in Areas 12, 13 and 16, based on scale analysis of fishery samples (Table 10). The preliminary total catches and escapement estimates in the memo were updated using DFO data. Based on the information in Table 9 and an escapement of 16,000 (Table 2), 14,300 Sakinaw sockeye from a total stock of 20,300 (70.4%) were taken in the Johnstone and Georgia Straits net fisheries. Johnstone Strait accounted for 92% of the catch or 13,200 Sakinaw sockeye. The harvest rate for the four day per week Johnstone Strait fishery was 65 % (13,200/ 23,000) and 5.4% in the Sabine Channel net fishery (A.W. Argue, DFO, Nanaimo, pers. comm.).

The run reconstruction analysis by Starr et al. (1984) showed a pattern of cyclic dominance for Sakinaw sockeye, repeating every four years beginning in 1971 and a sub-dominant year which cycles every four years from 1970 (Table 11). They concluded that there was no overall stock trend evident from 1970 to 1982. Exploitation rates on Sakinaw sockeye varied from 20 to 67%, averaging 41%. The average harvest rates for Johnstone Strait (Areas 11, 12, and 13) was 37%, and 4% in Area 16.

Using the data in Table 12 for the years 1986-1988 and 1992-1994, the estimated harvest rate on Early Stuart sockeye ranged between 1 to 3% for the 7 day migration and 2 to 5% for the 14 day migration, averaging 1% and 2%, respectively for each migration time

Table 13. The results of the analysis for the various scenarios are presented in Appendices 1 – 2. The PSC reports exploitation rates on Early Stuart sockeye ranging from 1-22% (Fraser River Panel 1987 -1999) based on ocean and river catches (i.e. excluding in-river First Nation and recreational catches above Mission). If these harvest rates are assumed to represent the exploitation rate on Sakinaw sockeye, they are most likely minimum estimates because Sakinaw are potentially exploited in other fisheries, including Johnstone and Georgia strait fisheries occurring after Early Stuart sockeye have left the area. These later August fisheries have the potential to exert considerably more effort on Sakinaw sockeye than the July fisheries.

The second approach used was to attempt to reconstruct the potential catch of Sakinaw sockeye in the Johnstone and Georgia Strait fisheries by making some assumptions about the proportion of non-Fraser catch to attribute to Sakinaw sockeye (Appendices 3 – 4) from the scale analysis of test catches in Johnstone Strait. For the years (1986-1989), the average estimated exploitation rate in Johnstone and Georgia Strait net fisheries was 49% and 56% for the BC16 data, respectively for each migration time (Table 12). Using the fishway escapement estimates produced low exploitation rates because of the lower escapement counts. However, during this period, the fishway estimates averaged 33% and 46% depending on migration timing used. For 1993 and 1994, there are only BC16 escapement estimates, which yield exploitation rate estimates of 98% and 82%, respectively (Table 13).

Estimates of harvest or exploitation rates for Sakinaw sockeye are affected by the following: 1) scale racial analysis only provides information on the aggregate non-Fraser stocks; 2) proportion of non-Fraser catch derived from scale racial analysis may under estimate the Sakinaw sockeye contribution to the non-Fraser catch because Sakinaw sockeye age structure (predominately 4-year olds) and freshwater scale circuli counts are more similar to Fraser River sockeye than to the other non-Fraser stocks (Figure 7); 3) duration of the Round Island test fishery varies from year to year depending on overall sockeye abundance or the abundance and timing of early Fraser sockeye entering Johnstone Strait; 4) the diversion rate through Johnstone Strait for Early Stuart sockeye was not available, only the overall diversion rate for all Fraser River sockeye stocks was obtained from the literature; and 5) escapement estimates for Sakinaw sockeye, especially in recent years are fraught with reliability issues associated with undocumented effort and methodology. These factors contribute to the uncertainty of the estimates. However, the data presented here are the best available with harvest rates ranging from 37 to 65% for Johnstone Strait (Areas 11, 12 and 13) and 4 to 29% for Area 16 and exploitation rates for Sakinaw sockeye ranging from 1 to 67%.

Fishing Effort

Sockeye stocks in this region are the largest in British Columbia and probably the second largest in the world (after Bristol Bay in Alaska). The total runs in this region varied from 3.6 million to 14.2 million in the period covered (1970 to 1999). However, trends are masked by the cyclic dominance phenomenon in Fraser River stocks. In general, the 1982/1986 cycle has increased over this period, while the other three cycles have shown little or no change, particularly the 1980/1984 cycle. The proportional allocation of catch between the targeting fisheries varies from year to year and is a function of the "diversion rate" through Johnstone Strait. The higher the diversion rate the greater the proportion caught in the Area 12 and Area 13 fisheries.

Days fished and boat days open are presented for Johnstone Strait (Areas 11, 12 and 13) and Georgia Strait (Area 16) in Table 14. The number of fishing days in Johnstone Strait has declined from highs of 66 and 86 days for seines and gillnets, respectively, in 1977 to lows of 0 and 4 days, respectively, in 1999 (Figure 21A). Peaks in fishing effort occurred in response to high abundance and high diversion rates of Fraser sockeye through Johnstone Strait. Low fishing rates after 1997 are in response to conservation concerns, reduction in the fishing fleets and area licensing. A similar pattern of effort occurs in Georgia Strait Area 16 (Figure 21B). Increased effort in Johnstone and Georgia Straits for the years 1977 to 1997 coincide with the general decline in Sakinaw escapements (Figure 8).

Early Nimpkish closures (seaward of Lewis Point) since 1980 have reduced the harvest of Nimpkish sockeye in Area 11 and upper Area 12 (sub-areas 5 to 18) (Starr et al. 1984). However, early fisheries in lower Area 12 (sub-areas 1 to 4) would still impact non-Fraser stocks (Fulmore, Phillips, Heydon and Sakinaw) and effort in lower Area 12 probably increased because the Area 12 net fleet was concentrated in a smaller area.

Enhancement

Sockeye

Transplants of sockeye fry into Sakinaw Lake occurred 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 Harrison (Big Silver and Weaver Creeks, Trout Lake, Harrison River Rapids), Pitt River (Upper and Lower), Birkenhead River 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).

Recent enhancement projects for Sakinaw 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. All brood stock fish since 1986 have been sampled for disease and found to be free of infectious hematopoietic necrosis virus (IHN) and bacterial kidney disease (BKD), except in 1986 when the eggs from one female were found to be infected with IHN. The 2,200 eggs from this female were planted back on the spawning beach to continue incubation. The remaining eggs were incubated in the hatchery and 23,000 unfed fry were released into Sakinaw Lake in mid April. In November 1987, 18 female sockeye were spawned (50% from each of Beaches 1 and 2) and the eggs were incubated at the Thornborough Channel Salmon Enhancement Society hatchery on Ouellette Creek. The outfall from the hatchery flows directly to ground to prevent introducing diseases into salmon bearing waters. In mid April, 57,000 unfed fry were released at Beach 1 (Haskins). The 1988 eggs from 18 females were incubated at the Ouellette hatchery and 33,000 fry were released into the lake at Beach 1. Sockeye enhancement stopped for Sakinaw sockeye until 2000 when 16,000 eggs from 10 females were incubated at the Ouellette hatchery. The resulting 14,981 fed fry at 1 g in size were released into the middle of the lake on June 8th. The 2001egg take from 15 females was 32,242 eggs with a mean fecundity of 2,567 eggs for 13 females. Two females were partials, yielding only 380 and 782 eggs. The resulting fry will be reared to 1 g and released in early June 2002.

Cutthroat Trout

Predators play an important role in sockeye smolt production and cutthroat trout are important predators of young sockeye at all times of the year (Foerster 1968). From 1965 to 1987 the British Columbia Fish and Wildlife Branch stocked Sakinaw Lake with 277,726 juvenile cutthroat trout weighing from 0.6 to 30.3 g. Increased cutthroat trout populations in Sakinaw Lake would have increased the mortality rate on Sakinaw sockeye fry and smolts.

Restoration Projects

Logging debris removal from the outlet of Sakinaw Lake and its spawning beaches has been conducted sporadically since 1972 when a log jam and other debris were removed from the outlet creek. In 1974, Beach 2 was cleared of logging debris to a depth of 5-10 m. Lake shore residents have continued to do some small scale cleaning by pulling wood off the bottom using snorkels and ropes. A log removal program on a small scale is presently needed on Beach 1 in areas where ground water moves into the lake.

An example of a sockeye habitat restoration project with a long record of assessment is a groundwater channel located along the shores of Kitsumkalum Lake, adjacent to sockeye beach-spawning habitat. As a result of logging developments, a nearby stream deposited large volumes of silt on the lakeshore spawning beds. A 180-metre long and 6-metre wide groundwater spawning channel was constructed in 1984 along the lakeshore adjacent to the spawning beds to provide stable incubation habitat for this lake-spawning population. Through the 1980s, the spawner population ranged from 100 to 500 fish. In contrast, the population after channel construction through the 1990s ranged between 1,500 and 5,000 spawners (DFO 2000).

A small beach spawning restoration project on the Haskins Beach was built in the summer of 2000. Stilling pipes were placed along the shoreline and monitored to determine water temperatures. Constant low water temperatures relative to lake temperature were used to determine ground water presence. After defining the ground water areas a small spawning beach (25 m x 5 m) was built using drain rock in an area of upwelling ground water on Beach 2. The upwelling ground water was visible as the new gravel settled and the ground water cleared the silt from the new gravel. Unfortunately all the spawners have been using Beach 1 since the addition of the new gravel on Beach 2.

Captive Brood

The Saga Seafarms Ltd. aquaculture site located 500 m from the Sakinaw Lake outlet reared sockeye in 1991. One generation was reared at the site and it was, at best, a difficult experiment and learning experience. DFO was investigating different sockeye stocks that might be suitable for captive rearing. The major selection factor for the sockeye stock used was that the stock must be IHN free. At the time, the Pitt River sockeye stock was IHN free. Eggs were provided to the United Hatchery, on Vancouver Island near the Rosewall Creek hatchery in 1989. The fish were reared in the quarantine facility and all water was from ground and the effluent was discharged to ground. The sockeye performed very well in freshwater, outgrowing both chinook and coho. However, rearing of around 20,000 sockeye in saltwater at the site was another story. Diets used seemed inadequate, BKD was rampant and the fish pigmented poorly. However, the feed conversion rates were very high. Otters preferred the sockeye to any other fish on site. There were no reports of any incidents of sockeye escaping from the pen. The aquaculture site is no longer active. Seals and river otters were a major problem at this site according to the site manger. If captive brood stock techniques are going to be used for Sakinaw Lake sockeye, then the Saga Seafarms experiment would suggest that the entire program would have to be conducted in freshwater, as proposed for Cultus Lake sockeye.

Competitors and Predators

Potential competitors for common food of juvenile Sakinaw sockeye during lake residence may include the threespine stickleback, peamouth chub, and kokanee (Foerster 1968, Burgner 1991).

Potential predators on juvenile Sakinaw sockeye include: cutthroat trout, juvenile coho and chinook, prickly sculpin, and Vancouver lamprey. Principle bird predators include: terns, gulls, mergansers, loons, cormorants, grebes, kingfishers, osprey and bald eagles and mammalian predators include river otters, mink, seals and bears (Foerster 1968, Burgner 1991).

Bird and/or seal predation could reduce the survival of outgoing smolts and/or incoming adults in the limited estuary and Agamemnon Channel. Predation by seals and birds may have been depensatory, thereby reducing smolt-to-adult survival – as the abundance of Sakinaw sockeye continued to decline.

Between 1957 and 1987, about 10-15% of the sockeye passing through the fishway were scarred. Although the cause of the scarring was attributed to commercial gillnets or illegal fishing, seal predation may have caused some of the scarring. Seals have been observed feeding on salmon off the mouth of Sakinaw Lake and before the permanent dam was installed, seals were observed in the lake (T.Gjernes DFO, Nanaimo pers comm.). Increased numbers of seals or other predators (river otters and mink) may have been attracted by an aquaculture site located just south of Sakinaw at Daniel Point during the early 1990s. There is most likely mortality at sea due to seal predation and illegal fishing, although the magnitude is unknown and difficult to quantify. Note that the scars on the sockeye passing through the fishway cannot be accurately attributed to seal predation separately from nets.

Assessment of Threat

The 4-year (one generation) smoothed trend for Sakinaw sockeye escapements indicates a decline of 98% over 3 generations ($p<0.001$, $b=-0.325$) (Figure 22). This greatly exceeds the World Conservation Union (IUCN) thresholds under Criterion A for both the "Endangered" (50%) and "Critically Endangered" (80%) categories (http://www.iucn.org/themes/ssc/redlists/redlistcatsenglish.pdf). An Endangered status is also indicated by other IUCN criteria based on current abundance and area of occupancy. Status designations under the new Canadian Species At Risk Act (SARA) will be determined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC has adopted the IUCN criteria although they do not use the Critically Endangered category. Thus there is little doubt that Sakinaw sockeye will be listed as "Endangered" by COSEWIC provided the population warrant consideration as a "wildlife species" under SARA.

A wildlife species is defined in SARA as "a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and (a) native to Canada; or (b) has extended its range into Canada without human intervention and has been present in Canada for at least 50 years." Genetically distinct populations of threespine stickleback, whitefish, and marine mammals are already listed under SARA. Moreover, individual populations of sockeye salmon inhabiting small lakes (e.g., Ozette Lake, Quinault Lake) have been deemed Evolutionarily Significant Units (ESUs) that warrant full protection under the US Endangered Species Act (Gustafson et al. 1997). 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). We apply this two-part test to Sakinaw Lake sockeye following Gustafson et al. (1997).

Evidence for reproductive isolation

Several surveys of neutral genetic variation in allozymes (Wood et al. 1994), microsatellite DNA (µsatDNA; Nelson et al. *in press*) and mitochondrial DNA (mtDNA; Wood et al. *in prep*) demonstrate that Sakinaw sockeye are reproductively isolated from other anadromous sockeye populations in the region (Figure 23). Pairwise-F_{ST} statistics based on comparisons of allele frequencies at 10 µsatDNA loci between sockeye in Sakinaw Lake and the nearest 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 15, above diagonal). These values would be expected at equilibrium for pairs of populations constant size exchanging fewer than 4 and 2 effective spawners per generation, respectively. Pairwise-F_{ST} statistics based on comparisons of mtDNA haplotype frequencies 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). The Kimsquit Lake sample was indistinguishable in this mtDNA survey. However, a very large allele frequency difference (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 14 (F_{ST} =0.09) confirm that this is a coincidental result of random genetic drift rather than continuing gene flow between Kimsquit and Sakinaw.

The mtDNA data also indicate that attempts to transplant sockeye to Sakinaw Lake from various locations in the lower Fraser River and from Shuswap Lake failed. Each mtDNA haplotype (representing a different female lineage) is denoted by a separate colour and its frequency by the area in the ring diagrams in Figure 23. Haplotype 5 (red) is predominant in Sakinaw Lake but absent from all locations sampled in the Fraser River (288 sockeye specimens from 11 lakes, Wood et al. *in prep*, and 199 kokanee specimens from 3 lakes (C. Wood unpubl. data).

Evidence for local adaptation

This report and the information presented in Gustafson et al. (1997) demonstrate that Sakinaw sockeye are distinct from other sockeye stocks in the Pacific Northwest (including Johnstone and Georgia Strait and Fraser River stocks) in terms of their genetic structure, physical, chemical, and biological characteristics of their nursery lake, early river-entry timing, protracted adult run timing, extended lake residence prior to spawning, small body size, low fecundity and large smolts.

Summary of threats and potential for mitigation

We conclude that if present conditions continue, sockeye will be likely to become extirpated from Sakinaw Lake in the foreseeable future. The following factors have contributed to this trend: loss of spawning habitat in the lake, low summer water levels and high temperatures that periodically block migration into the lake, past logging effects and present effects of residential development around the lake, and high fishing effort in Johnstone and Georgia Straits. All these factors have contributed to the overall downward trend in abundance. Holtby and Scrivener (1989) suggest that overall variability in salmon abundance will tend to increase in the wake of land-use activities, particularly when accompanied by high levels of exploitation and adverse environmental conditions. Current Sakinaw sockeye escapements average below 80 adults per year, with no room for further declines. Historical escapement estimates range from a few thousand sockeye in the mid-1950s to a peak recorded escapement of about 16,000 in the 1975. Abundance increased by about 1% per year from 1950-1979 and decreased by about 1.6% per year between 1980-1999.

Sakinaw sockeye migrate through Johnstone and Georgia Straits where they continue to be harvested during sockeye and pink salmon fisheries. Passive management and limited enhancement efforts have been inadequate to restore the Sakinaw sockeye run. Further changes to the Johnstone Strait sockeye and pink fisheries will be necessary to promote recovery.

Although overfishing is most certainly the proximate cause of the decline of Sakinaw sockeye, other factors probably contribute by eroding the population's productivity. Sakinaw Lake is subject to wide fluctuations in flow because of the long hot summers with little precipitation, winter floods that result from rain and snowmelt at lower elevations. Forestry and urbanization have been the major development activities in the Sakinaw drainage. Logging can alter hydrologic and sediment transport systems in watersheds. Such alterations can reduce fish habitat productivity by affecting the amount and quality of flowing water, gravel substrates, cover, and food required by fish for survival (Chamberlin et al. 1991). Past logging practices exaggerated the natural fluctuations in river flow, changed temperature regimes, and contributed to the instability in the Sakinaw system (DFO 1988). Erosion of stream banks and transport of fine sediment and logging debris caused a decline in the quality and stability of spawning gravel, a decline in egg to fry survival, and a reduction in fry size. Poor logging practices contributed to the degradation of the spawning beaches where lake and spawning beaches used as a dump, mill pond, or booming ground. Early logging dammed the lake at the outlet to provide a means of transporting logs to the ocean. Log storage off the outlet of Sakinaw Lake has blocked the adult salmon migration.

The development of residential lots along the shore of Sakinaw Lake impacted the spawning beaches by diverting stream flows to prevent flooding. Increasing population levels required increased access to the lake for recreation and domestic water use. The need for lake access resulted in the construction of a boat ramp through the middle of one of the major spawning beaches in the lake. Lake shore residents often complain about storage of water for sockeye migration because high lake levels affect the use of their docks and beaches. Water use in the whole drainage contributes to reduced summer flows and low flows impact sockeye migration. Delayed migration out of the ocean exposes Sakinaw sockeye to increased predation.

Sockeye stock size can be constrained by a variety of factors. These limiting factors can be classified as reducing fry recruitment or reducing fry-to-adult survival. Fry recruitment may be limited by spawner abundance and the quality or quantity of incubation habitat that determines overall egg-to-fry survival. Thus, poor recruitment can be mitigated in several ways, depending on the limiting factor. Decreasing harvest rate should be effective wherever the quantity of incubation habitat is not limiting. Restoring or expanding natural spawning habitat (e.g., by removal of beaver dams or construction of spawning channels) should also be effective unless the number of spawners is severely limiting. In this case, short-term supplementation with artificially-propagated fry may also be required, but this can only be effective in restoring a naturally-spawning population if concurrent efforts are taken to "set the stage" for recovery by decreasing fishing (and other known sources of) mortality and restoring degraded habitat.

Sakinaw sockeye survival at sea is dependent on ocean conditions. It is hoped that the return of favourable ocean conditions will improve marine survival in the near future. However, incidental fishing mortality must still be reduced to increase escapement as rapidly as possible above current critically low levels. Concurrent activities to restore natural spawning habitat and to bolster fry recruitment by artificial production in the short–term are recommended to promote recovery.

It should be noted that Sakinaw Lake escapement estimates were historically dependent on counting sockeye through the fishway at the outlet dam. This counting activity was discontinued when duties were reassigned despite lack of funding for alternate means of enumeration. Limited funding for the lake dive surveys in recent years continues to compromise DFO's ability to provide reliable estimates of escapement. A major upgrade is required to the fishway (installation of automated counter) to ensure continuous unimpeded migration and reliable total counts of salmon to Sakinaw Lake. The addition of a smolt counting program (trawl survey, smolt trap or electronic counter) would improve our ability to estimate smolt abundance at time of migration as required to partition survival and growth between the freshwater and marine phases and to reveal factors limiting production.

It is highly probable that Sakinaw sockeye will be listed as "Endangered" under SARA. Protein electrophoresis and mitochondrial DNA analysis indicate that Sakinaw sockeye are substantially reproductively isolated from other sockeye populations. Their distinctive life history characteristic (early river-entry timing, protracted adult run timing, extended lake residence prior to spawning, small body size, low fecundity and large smolts) suggest that they are also evolutionarily distinct from other sockeye populations in the Pacific Northwest and Alaska. The evidence for 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. Moreover, the failure of previous attempts to transplant sockeye to Sakinaw (and other lakes - Withler 1982, Wood 1995) demonstrate that Sakinaw sockeye are for all practical purposes, irreplaceable.

Opportunities still exist for enhancement and restoration of the Sakinaw population. These involve reducing fishing and other terminal mortality to increase escapements, continuing to supplement fry recruitment by artificial propagation, improving natural spawning habitat, and control of competitors or predators. However, a comprehensive recovery plan should be developed for Sakinaw sockeye to explore all options, to ensure that the proposed measures address the recovery of Sakinaw sockeye, address local and regional concerns, and do not contribute to further harm.

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Tables

Table 1. Mitochondrial DNA haplotype frequencies used in pairwise-Fst analysis. All data except those for Sakinaw and Heydon samples are from Wood et al. (in prep.).

Lake/River	Sample size	Haplotype 1	2	3	4	5	6	8	9	13	15	16	17	19	20	21
Upper Fraser River	158	89	52	17												
Shuswap	19	7	5	7												
Birkenhead River	25		22	3												
Weaver Creek	23	3	3	12	3		2									
Harrison Rapids	25	2	13	10												
Cultus	25		5	6	14											
Widgeon Slough	13			13												
Sakinaw	27	3				24										
Heydon	24	15		4	5											
Nimpkish	24	7		8		1	1		3	3				1		
Long	25	14	9			2										
Owikeno	59	10	2	20		5	4			2	3	1	10		1	1
Atnarko	79	13		35		20		7		4						
Kimsquit	13	3				10										
Kitlope	15	6	5	1		3										

Table 2. Comments on relative escapements for Sakinaw sockeye from 1933 to 1946. British Columbia Fisheries Department Annual Reports.

Year	Comments
1933	Heavy escapement
1934	Equal to brood year
1935	Better than brood year – highest on record
1936	Normal supply
1937	Not as good as usual
1938	Better than recent years
1939	Not up to expectations
1940	
1941	Greater than brood year (1937)
1942	Better than brood year but highest on record
1943	Light but comparable to brood year
1944	Light notwithstanding the fact that the commercial fishery was not intensive
1945	Comparable to brood year
1946	Light – improvement over brood year

Table 3. Escapement estimates and migration and spawning times for Sakinaw Lake sockeye. BC 16 escapement estimates from the SEDS database and fishway counts from the fisheries guardian's nightly logs. BC 16 data for 1947-48 from British Columbia Fisheries Department Annual Reports. N is the numbers of nights sockeye counted through the fishway. Duration is the number of days from the start to the end of migration or spawning. Coverage is the proportion of the run counted (N/duration).

Year	Escapement			Migration					Spawning			
	BC 16	Fishway	N	Start	Peak	End	Duration	Coverage	Start	Peak	End	Duration
1947	3500											
1948	4600											
1949	3931	3931		Jun-28	Jul-24	Aug-28	61					
1950	2473	2473		Jun-30	Jul-20	Sep-01	63					
1951	3450	3451		Jun-15	Jul-21	Aug-30	76					
1952	6222	6222	39	Jun-20	Jul-23	Aug-17	58	0.67				
1953	1131	1131		Jul-15	Jul-27	Aug-22	38					
1954	4143	4143		Jul-12	Jul-30	Aug-22	41					
1955	5079	5079		Jul-13	Aug-17	Aug-28	46					
1956	2150	2047		Jul-15	Jul-23	Aug-24	40					
1957	4300	4028	34	Jul-06	Jul-20	Aug-31	56	0.61				
1958	4250	2251	31	Jul-07	Aug-04	Sep-08	63	0.49				
1959	13000	12573	46	Jul-10	Jul-29	Aug-31	52	0.88				
1960	4500	4025	49	Jul-05	Jul-23	Aug-26	52	0.94				
1961	750	354	25	Jul-09	Jul-31	Aug-28	50	0.50				
1962	3500	1806	25	Jul-15	Aug-06	Aug-28	44	0.57				
1963	7500	4653	33	Jul-11	Jul-30	Aug-25	45	0.73				
1964	3500	1826	29	Jul-21	Aug-07	Aug-25	35	0.83				
1965	750	192	16	Jul-11	Aug-05	Aug-22	42	0.38				
1966	3500	2634	48	Jul-11	Aug-14	Sep-09	60	0.80				
1967	6000	3703	38	Jul-04	Jul-30	Aug-20	47	0.81	Sep-10	Sep-25	Oct-09	29
1968	14000	11226	45	Jul-13	Aug-01	Aug-28	46	0.98	Sep-20	Oct-25	Nov-16	57
1969	1200	352	42	Jul-01	Aug-12	Sep-01	62	0.68	Sep-20	Oct-27	Nov-09	50
1970	5000	3374	55	Jul-12	Aug-06	Sep-03	53	1.04	29-Oct	6-Nov	27-Nov	29
1971	8000	7766	63	Jul-06	Aug-05	Sep-10	66	0.95	29-Oct	15-Dec	3-Jan	66
1972	4500	3424	33	Jul-03	Jul-23	Sep-09	68	0.49	15-Nov	15-Dec	3-Jan	49
1973	1500	598	27	Jul-10	Jul-25	Aug-31	52	0.52	29-Oct	30-Nov	20-Dec	52

Table 3. Continued

Year	Escapement			Migration					Spawning			
	BC 16	Fishway	N	Start	Peak	End	Duration	Coverage	Start	Peak	End	Duration
1974	6000	2116	22	Jul-07	Jul-29	Sep-04	59	0.37	3-Nov	30-Nov	20-Dec	47
1975	16000	4176	20	Jul-02	Aug-11	Sep-28	88	0.23	30-Oct	28-Nov	4-Jan	66
1976	6000	4181	12	Jul-01	Jul-31	Aug-20	50	0.24	4-Nov	30-Nov	2-Jan	59
1977	1200	696	27	Jul-04	Jul-20	Aug-22	49	0.55	15-Oct	23-Nov	15-Dec	61
1978	4000	2411	26	Jul-03	Jul-26	Aug-30	58	0.45	1-Nov	10-Dec	5-Jan	65
1979	11000	9885	36	Jul-01	Jul-30	Aug-29	59	0.61	28-Oct	26-Nov	19-Dec	52
1980	2800	2310	39	Jul-06	Aug-05	Aug-28	53	0.74				
1981	3000	553	14	Jul-10	Aug-04	Aug-20	41	0.34	27-Oct	28-Nov	20-Dec	54
1982	3400	1710	21	Jul-01	Jul-20	Aug-23	53	0.40	30-Sep	12-Nov	15-Dec	76
1983	1600	798	13	Jul-08	Jul-24	Aug-10	33	0.39	31-Oct	10-Nov	7-Dec	37
1984	1115	427	16	Jul-05	Jul-24	Aug-21	47	0.34				
1985	2400	1380	24	Jul-14	Aug-01	Aug-23	40	0.60	Oct-10	Nov-10	Nov-21	42
1986	5400	2414	22	Jul-06	Jul-23	Sep-09	65	0.34				
1987	4200	4339	67	Jul-02	Aug-06	Sep-15	75	0.89				
1988	2500	1912	41	Jul-07	Aug-01	Aug-30	54	0.76				
1989	1000	707	22	Jul-08	Jul-25	Aug-28	51	0.43				
1990	1200	45	3									
1991	500											
1992	1000											
1993	250											
1994	250											
1995	N/O											
1996	222											
1997	3											
1998	1											
1999	14											
2000	122											
2001	87											
Mean	3661	3174	31	Jul-07	Jul-30	Aug-29	53	0.59	20-Oct	19-Nov	11-Dec	52

Table 4. Mean weight (kg), standard deviation (SD) and 95% confidence level for Sakinaw Lake sockeye passing through the fishway from 1957 to 1972.

		Weight				
Year	N	Mean	SD	95%	Minimum	Maximum
1957	34	1.85	0.223	0.078	1.36	2.27
1958	29	1.89	0.183	0.070	1.36	2.27
1959	46	2.05	0.200	0.060	1.82	2.73
1960	46	1.95	0.168	0.050	1.59	2.27
1961	32	1.95	0.209	0.075	1.14	2.27
1962	20	1.97	0.133	0.062	1.59	2.05
1963	25	2.02	0.167	0.069	1.70	2.27
1964	29	1.81	0.155	0.059	1.59	2.05
1965	14	1.83	0.108	0.062	1.59	2.05
1966	41	2.05	0.108	0.034	1.82	2.27
1967	9	1.96	0.211	0.162	1.70	2.27
1968	44	2.08	0.093	0.028	1.82	2.27
1969	11	2.09	0.330	0.222	1.59	2.95
1970	24	2.01	0.170	0.072	1.82	2.27
1971	15	2.10	0.138	0.077	1.82	2.27
1972	5	1.95	0.124	0.155	1.82	2.05

Table 5. Age composition of Sakinaw sockeye salmon sampled from the fishway and off the spawning grounds.

Year	Age 1.1		Age 1.2		Age 1.3		Age 2.1		Age 2.2		Total	
	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent
1972	0	0.00	121	82.88	19	13.01	0	0.00	6	4.11	146	27.65
1974	14	13.46	84	80.77	6	5.77	0	0.00	0	0.00	104	19.70
1975	0	0.00	110	99.10	0	0.00	1	0.90	0	0.00	111	21.02
1976	0	0.00	131	90.97	7	4.86	0	0.00	6	4.17	144	27.27
1980	0	0.00	10	83.33	2	16.67	0	0.00	0	0.00	12	2.27
2001	0	0.00	3	25.00	8	66.67	0	0.00	0	0.00	11	2.08
Overall	14	2.65	459	86.93	42	7.95	1	0.19	12	2.27	528	

Table 6. Age distribution for Sakinaw sockeye passing through the fishway in 1972. N = 146.

	Age		
Date	1.2	1.3	2.2
Jul-13	4		
Jul-15	6	2	
Jul-17	1		
Jul-19	8	1	
Jul-20	11	2	
Jul-24	4	2	
Jul-25	8	5	
Jul-26	18	4	2
Aug-03	28	3	
Aug-16	10		1
Aug-21	11		1
Aug-24	7		
Sep-02	6		1
Total	122	19	5
Percent	0.84	0.13	0.03

Table 7. Sakinaw Lake sockeye salmon spawning ground dive survey observations in 1979, 1999, 2000 and 2001. Codes: N/O none observed; N/C no count; * Poor visibility, surface observations only, no divers.

1979					
		Beach 1 ($6000m^2$)		Beach 2 ($6000m^2$)	
Date		North 100 m	South 200 m	North 200 m	South 200 m
02-Oct		N/C	N/O	N/C	N/O
12-Oct		N/C	N/O	N/O	N/O
26-Oct		N/C	1500	N/O	800
03-Nov		N/C	900	N/C	500
16-Nov		1,000	900	80	400
27-Nov		800	750	50	400
11-Dec		600	500	30	200
20-Dec	*	N/O	8	N/O	N/O
Total		2,400	4,558	160	2,300

		Beach 3 ($2000m^2$)		Beach 4	Beach 5
		Ruby Creek Inlet	South Area	($3250m^2$)	($1500m^2$)
02-Oct		1	N/C	N/C	N/C
12-Oct		16	N/C	N/O	N/C
26-Oct		40	N/C	N/O	N/C
03-Nov		125	N/C	2 redds	N/C
16-Nov		200	13	90	30
27-Nov		24	30	150	28
11-Dec		50	8	N/C	N/C
20-Dec	*	N/O	N/O	N/C	N/O
Total		455	51	240	58
Grand Total		10,222			

Table 7. Continued

	1999			
	Beach1		Beach 2	
Date	45 Metres		100 Metres	
	Sockeye	Redds	Sockeye	Redds
15-Nov	1	4	N/O	
22-Nov	N/O	4	4	3
29-Nov	6	4	3	3
06-Dec	N/O	4	N/O	1
Total	7	16	7	7
Grand Total	14	23		

	2000			
	Beach 1		Beach 2	
Date	45 Metres		100 Metres	
	Sockeye	Redds	Sockeye	Redds
13-Nov	30	24	7	N/O
22-Nov	35	16	N/O	N/O
27-Nov	32	3	N/O	N/O
03-Dec	25	10	N/O	N/O
Total	122	53	7	
Grand Total	129	60		

	2001			
	Beach 1		Beach 2	
Date	45 Metres		100 Metres	
	Sockeye	Redds	Sockeye	Redds
29-Oct	35	20	N/O	N/O
12-Nov	30	12	N/O	N/O
19-Nov	22	3	N/O	N/O
Total	87	41	0	0
Grand Total	87	41		

Table 8. Summary of the smolt numbers collected leaving Sakinaw Lake from 1994 to 1997. The trap efficiency is the calculated correction for the smolt trap used to estimate the total smolt out migration from Sakinaw Lake. The predicted adult return is based on a 4.5% smolt to adult survival rate. Smolt to adult survival base on escapement estimates in Table 2 and 4 year old fish.

Brood Year	Smolt No.	Trap Efficiency	Total Smolt	Predicted Adult Return	Escapement Estimates	Survival
1992	794	0.05	15880	715	222	1.398%
1993	638	0.05	12760	574		
1994	75	0.03	2500	113		
1995	155	0.03	5200	234	14	0.269%
Average						0.834%

Table 9. **Annual adult sockeye counts through the Sakinaw Lake fishway. N is the number of counts made each year. Counts usually made between 22:00 to 01:00 during a high tide; fish locked out between counts. Gate to fishway intermittently left open in some years; event not necessarily recorded, therefore counts are not always complete. A fish trap was installed in 1987 and the sockeye were counted and released each morning. Fishway and trap counts discontinued after 1990.**

	Year														
Date	1952	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
09-Aug	372	13		168	12		143		61		34	80	200	23	64
10-Aug	19		21	145	9				26		37	62	165	11	21
11-Aug	5			172	78		120		84		67	100	227	73	87
12-Aug	0			188	30		84	218	7	22		118	218	10	43
13-Aug	7		62	219	76	5	63		38	5	89	12	92	27	33
14-Aug	2		4	288	13	33	45		73		123		40	1	35
15-Aug	0			302	19	14	10	225	118	24	85		78	1	0
16-Aug	0			254	33	11		112	53	31	55		45	29	68
17-Aug	0			96	20			125	111	12	26		107	37	62
18-Aug			12	266	22	34		70	36		65		125	18	60
19-Aug				152	20	8		12	10		50		94	20	40
20-Aug			5	65	6	3	18		78		14	8	87	16	79
21-Aug				34		4	22		28		107		74	15	75
22-Aug			22	25			37		3		102		50	6	73
23-Aug				37	7	5	10		7		83		56	0	98
24-Aug			45	22			7		2		90	5	48	0	40
25-Aug											63		30	0	12
26-Aug			103		10										50
27-Aug			105					0			78	10			127
28-Aug											51		4		60
29-Aug			120								110			4	43
30-Aug			154								63			0	28
31-Aug			46								83			0	84
01-Sep														1	116
02-Sep														0	31
03-Sep			122					0							30
04-Sep											50				
05-Sep			39								28				
06-Sep											30				
07-Sep															
08-Sep			29												
09-Sep											2				
10-Sep															
11-Sep															
12-Sep															
13-Sep															
14-Sep															25
15-Sep															
16-Sep															
17-Sep															
Total	8174	5985	4209	14532	5985	2315	3768	6616	3790	2157	4600	5670	13194	2321	5344
N	40	35	32	47	50	26	26	34	30	17	49	39	46	43	56

Table 9. Continued.

Date	Year									
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
09-Aug	0	110							400	100
10-Aug	50								100	200
11-Aug	50	120			1000	200			10	125
12-Aug	2				1200			150		300
13-Aug	175									150
14-Aug	152		20	300						20
15-Aug	150									30
16-Aug	30	50			250					50
17-Aug	50	200		30						20
18-Aug	50						50	200		30
19-Aug	160		50	2						
20-Aug	200					5	5	250		
21-Aug	240	60			100					
22-Aug	150		35		100		5			
23-Aug	250			60						
24-Aug	200	20								
25-Aug	160		20							
26-Aug	100	10						100		
27-Aug	60									
28-Aug	120							36	100	
29-Aug	120									
30-Aug	80							20		
31-Aug	80		10							
01-Sep	50	21								
02-Sep	120									
03-Sep	120									
04-Sep	180			30						
05-Sep	350									
06-Sep										
07-Sep					200					
08-Sep		0								
09-Sep		30								
10-Sep	220									
11-Sep										
12-Sep										
13-Sep										
14-Sep										
15-Sep										
16-Sep			3							
17-Sep										
Total	9737	5396	2571	4090	6151	6157	2673	4389	11864	4290
N	64	34	28	23	21	13	28	27	37	40

Table 9. Continued

	Year									
Date	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
09-Aug		25		1	69	50	81			
10-Aug					101		86			
11-Aug		50					163			
12-Aug					12		80			
13-Aug		60					254			
14-Aug				15	47		160			
15-Aug	27	75					105	6	1	
16-Aug	32			15			91	13	19	
17-Aug		50				135	85	37	15	
18-Aug	14				64		66	35	6	12
19-Aug		15					44	39	35	14
20-Aug	6						36	118	26	
21-Aug		10		5	24	100	20	74		
22-Aug							103	34		
23-Aug					9		20	25		
24-Aug							96	14		
25-Aug							72	18	11	
26-Aug							55	11	16	
27-Aug							37	16	22	
28-Aug							55		27	
29-Aug							36			
30-Aug							43	27		
31-Aug							39			
01-Sep							43			
02-Sep							6			
03-Sep							0			
04-Sep							1			
05-Sep							6			
06-Sep							32			
07-Sep						20				
08-Sep										
09-Sep						50				
10-Sep							45			
11-Sep							12			
12-Sep							10			
13-Sep							5			
14-Sep							13			
15-Sep										
16-Sep										
17-Sep										
Total	2534	3692	2781	2411	3365	4400	6326	3900	2696	2035
N	15	22	14	17	25	23	68	42	23	4

Table 10. Sakinaw adult sockeye migration timing and estimates of total Sakinaw sockeye catch in Area 12, 13 and 16 net fisheries for 1975.

	Migration				Catch		
Area	Start	Finish	Duration	Peak	Sakinaw	Total	Percent
12	Jun-28	Jul-26	28	Jul-12	9700	119238	8%
13	Jul-05	Aug-02	28	Jul-23	3500	17719	20%
16	Jul-05	Aug-09	35	Jul-29	1100	2543	43%
Total Catch					14,300	139500	10%

Table 11. Sakinaw sockeye catch, exploitation and harvest rates for Johnstone Strait (Areas 11, 12 and 13) and Georgia Strait (Area 16) from 1970 to 1982. Data from Starr et al. (1984).

	Sakinaw				CATCH				Harvest Rate			
YEAR	Run	Catch	Escapement	Exploitation	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16
1970	9355	4355	5000	0.466	17	3827	237	274	0.002	0.409	0.025	0.029
1971	16118	8118	8000	0.504	1	4820	1085	2211	0.000	0.299	0.067	0.137
1972	7465	2965	4500	0.397	20	1955	592	397	0.003	0.262	0.079	0.053
1973	2102	602	1500	0.286	9	420	77	96	0.004	0.200	0.037	0.046
1974	11608	5608	6000	0.483	74	3378	762	1394	0.006	0.291	0.066	0.120
1975	24801	8801	16000	0.355	33	6573	1771	424	0.001	0.265	0.071	0.017
1976	8925	2925	6000	0.328	36	2451	394	44	0.004	0.275	0.044	0.005
1977	3596	2396	1200	0.666	36	1840	448	71	0.010	0.512	0.125	0.020
1978	9239	5239	4000	0.567	85	4155	956	43	0.009	0.450	0.103	0.005
1979	13775	2775	11000	0.201	59	1993	565	158	0.004	0.145	0.041	0.012
1980	3710	910	2800	0.245	17	777	109	7	0.005	0.210	0.029	0.002
1981	4269	1269	3000	0.297	11	680	564	13	0.003	0.159	0.132	0.003
1982	7987	4587	3400	0.574	35	2916	1524	111	0.004	0.365	0.191	0.014
Total	122950	50550	72400	0.411	435	35787	9084	5245	0.004	0.291	0.074	0.043

Table 12. Annual escapement, total return (all ages combined: predominately 4-year olds) from that escapement, and return per spawner for Early Stuart sockeye 1960 to 1993. Total brood return is catch plus escapement. R/S is recruits per spawner. Early Stuart catch is the total catch for the stock (all fisheries). Inside catch is the sockeye catch for Areas 11, 12, 13 and 16 in statistical weeks 6/3 to 7/4 . Diversion rate is the proportion of the total Fraser River sockeye catch migrating through Johnstone Strait as estimated by the PSC. ES is the estimated catch of Early Stuart sockeye in Johnstone Strait given the diversion rate for that year. Data from DFO 1995 and PSC Annual Reports 1990 to 1999.

Year	No. Spawners	Total Brood Return	R/S	Early Stuart Catch	Inside Catch	JS Diversion Rate	ES caught in JS
1956	25020				62187		
1957	234850				155530		
1958	38807				173527		
1959	2670				76501		
1960	14447	110394	4.41	95947	47292	0.19	18230
1961	198921	1222936	5.21	1024015	354135	0.16	163842
1962	26716	103107	2.66	76391	60434	0.12	9167
1963	4607	20835	7.80	16228	94168	0.11	1785
1964	2390	74149	5.13	71759	109166	0.10	7176
1965	23045	255842	1.29	232797	102261	0.10	23280
1966	10830	75785	2.84	64955	100074	0.25	16239
1967	21044	92554	20.09	71510	326856	0.25	17878
1968	1522	42887	17.94	41365	214962	0.18	7446
1969	109655	417211	18.10	307556	347763	0.15	46133
1970	32578	84786	7.83	52208	94847	0.24	12530
1971	95940	339693	16.14	243753	171449	0.12	29250
1972	4657	10423	6.85	5766	101131	0.34	1960
1973	299882	1375594	12.54	1075712	129431	0.09	96814
1974	39518	182136	5.59	142618	102743	0.22	31376
1975	65752	431210	4.49	365458	146506	0.12	43855
1976	11761	32232	6.92	20471	142190	0.21	4299
1977	117445	1341984	4.48	1224539	203732	0.18	220417
1978	50004	140516	3.56	90512	257719	0.58	52497
1979	92746	224052	3.41	131306	82266	0.30	39392
1980	16939	31854	2.71	14915	74036	0.70	10441
1981	129457	761059	6.48	631602	310234	0.67	423173
1982	4557	65197	1.30	60640	87435	0.22	13341
1983	23867	107905	1.16	84038	62004	0.85	71432
1984	45205	63501	3.75	18296	107484		0
1985	234219	350141	2.70	115922	128967	0.33	38254
1986	28584	29885	6.56	1301	1161	0.25	325
1987	148294	190779	7.99	42485	822	0.80	33988
1988	179807	247504	5.48	67697	402	0.15	10155
1989	384799	1196979	5.11	812180	220591		0
1990	97034	143469	5.02	46435	3719	0.25	11609
1991	141119	526938	3.55	385819	4036	0.40	154328
1992	65617	296821	1.65	231204	4789	0.70	161843
1993	887000	1297000	3.37	410000	21715	0.70	287000
1994	29831	202000	2.08	172169	1021	0.90	154952
1995	122710	137000	0.97	14290	2646	0.55	7860
1996	87569	95000	1.45	7431	355	0.35	2601
1997	266000	1673000	1.89	1407000	36875	0.77	1083390
1998	30952	190000	6.37	159048	1291	0.78	124057
1999	24532	171000	1.39	146468	149	0.50	73234
2000					5141		

Table 13. Summary of harvest rate estimates for Sakinaw sockeye caught in Johnston Strait (Areas 11, 12 & 13) and Georgia Strait (Area 16) commercial gillnet and seine fisheries for the periods 1986-89 and 1992-94.

	7 Day Migration				14 Day Migration			
	Sakinaw		Early		Sakinaw		Early	
Year	BC 16	Fishway	Stuart	Average	BC 16	Fishway	Stuart	Average
1986	0.06	0.13	0.00	0.06	0.15	0.28	0.00	0.14
1987	0.10	0.09	0.00	0.06	0.31	0.30	0.03	0.22
1988	0.12	0.15	0.00	0.09	0.32	0.38	0.00	0.23
1989	0.62	0.70	0.03	0.45	0.67	0.74	0.05	0.49
1992	0.73	0.58	0.01	0.44	0.73	0.58	0.02	0.44
1993	0.98		0.01	0.49	0.96		0.02	0.49
1994	0.82		0.00	0.41	0.82		0.00	0.41
Average	0.49	0.33	0.01	0.29	0.56	0.46	0.02	0.35

Table 14. Cumulative number of vessels and days fished by gillnets (GN) and seines (SN) in Areas 11, 12, 13 and 16 during the Sakinaw sockeye migration (3rd week of June (6/3) to 2nd week of September (9/2)) each year. No seine fisheries in Area 11 and Area 16 fisheries generally restricted to Sabine Channel.

		AREA 11		AREA 12				AREA 13				AREA 16			
		GN		GN		SN		GN		SN		GN		SN	
	WEEK	Vessels	Days	Vessels	Days	Vessels	Days	Vessels	Days	Vessels	Days	Vessels	Days	Vessels	Days
1972	5/1-9/2		0	1604	39	610	39	0	26	0	26	0	0	0	0
1973	5/1-9/2		58	1172	47	833	47	211	39	252	39	0	0	0	0
1974	5/1-9/2		44	1470	41	848	41	196	33	247	33		44		32
1975	5/1-9/2		52	607	47	611	47	131	39	281	39	49	44	55	44
1976	5/1-9/2	0	0	1159	43	1189	43	153	33	275	33		30	0	0
1977	5/1-9/2		24	1197	39	1197	39	415	31	634	31	89	28	65	28
1978	5/1-9/2	183	20	1798	37	1373	37	287	36	870	28	100	23	89	11
1979	5/1-9/2	80	17	1069	26	901	26	270	26	526	26	0	0	0	0
1980	5/1-9/2	97	13	1250	22	1340	23	248	23	571	24	83	8	179	8
1981	5/1-9/2	55	11	1330	30	1726	29	213	30	609	29	287	7	108	0
1982	5/1-9/2	195	12	1522	23	1358	22	177	23	440	22	129	16	237	18
1983	5/1-9/2	243	19	1284	23	1703	19	203	23	729	19	393	15	117	13
1984	5/1-9/2	115	12	1077	16	859	15	105	16	356	15	95	15	109	14
1985	5/1-9/2	139	14	1532	24	1262	22	203	24	462	22	233	14	76	13
1986	5/1-9/2	222	15	1641	15	734	12	101	15	201	12	93	9	60	10
1987	5/1-9/2	249	10	1271	12	824	9	95	12	414	9	412	8	89	7
1988	5/1-9/2	129	5	390	7	300	7	35	7	131	7	100	4	59	5
1989	5/1-9/2	836	19	2050	30	1524	19	204	30	610	19	195	16	82	16
1990	5/1-9/2	805	15	1518	19	832	10	100	19	288	9	102	11	235	8
1991	5/1-9/2	393	18	1755	25	1067	8	116	25	453	8	385	11	39	6
1992	5/1-9/2	597	11	907	14	668	4	118	11	229	4	166	10	70	3
1993	5/1-9/2	437	14	1803	21	1179	8	303	21	411	8	1000	17	262	7
1994	5/1-9/2	554	17	1532	17	1142	3	203	17	469	3	399	16	7	1
1995	5/1-9/2	140	3	1156	6	1015	5	223	6	322	5	0	0	0	0
1996	5/1-9/2	26	4	273	4	110	1	72	4	39	1	0	0	0	0
1997	5/1-9/2	213	12	1474	13	1344	7	203	13	487	7	5	4	173	3
1998	5/1-9/2	0	0	218	2	181	1	32	2	84	1	0	0	0	0
1999	5/1-9/2	0	0	251	2	0	0	21	2	0	0	0	0	0	0
2000	5/1-9/2	0	0	471	9	201	6	92	4	68	3	0	0	40	2
2001	5/1-9/2	39	2	284	4	97	3	71	3	65	2	0	0	0	0

Table 15. Pairwise Fst statistics for mitochondrial DNA (below diagonal, data from Wood et al. in prep.) and microsatellite DNA (above diagonal, from Nelson et al. in press).

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

Figures

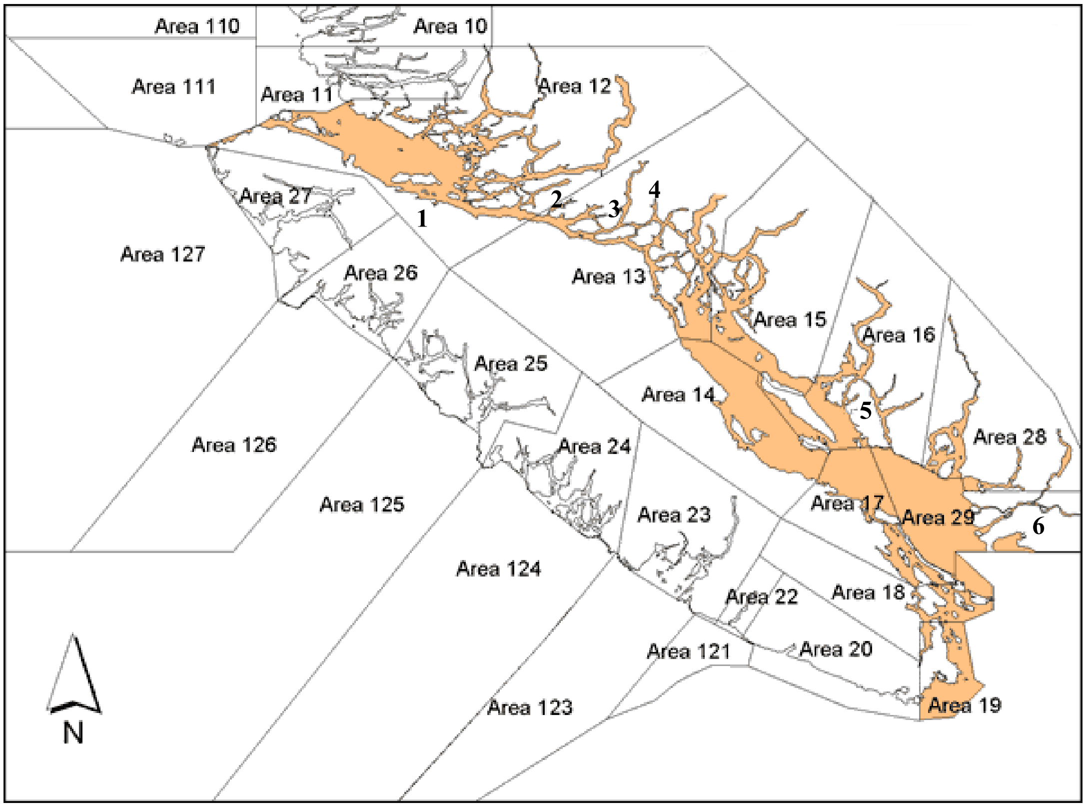


Figure 1. Inner South Coast Region Statistical Areas 12 to 19, 28 and 29. Johnstone Strait includes Areas 11 to 13. Georgia Strait includes Areas 14 to 19, and 28 and 29. Major Inner South Coast sockeye populations: 1) Nimpkish River, 2) Fulmour Lake, 3) Heydon Lake, 4) Phillips Lake, 5) Sakinaw Lake, and 6) Fraser River.

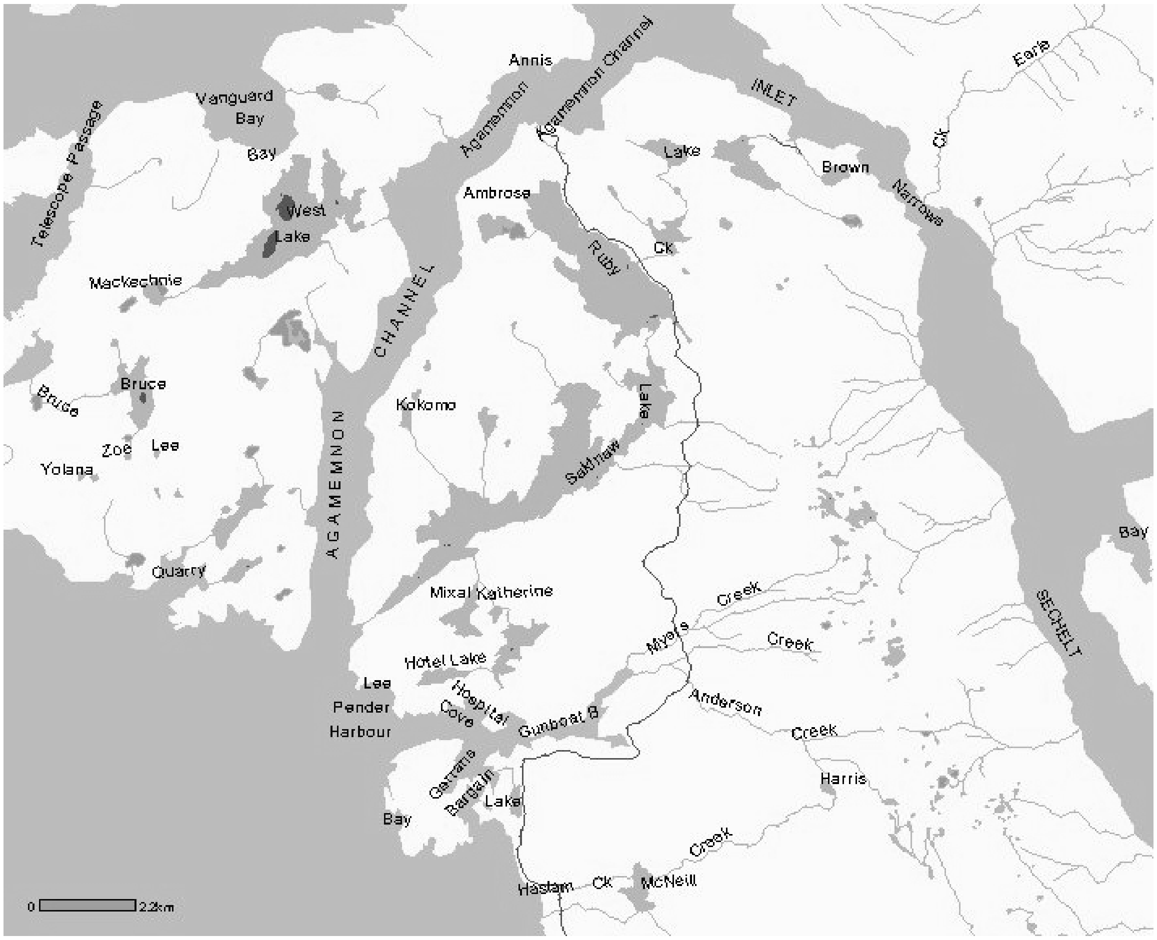


Figure 2. Location of Sakinaw Lake on the Sechelt Peninsula. Dark line is Highway 101.

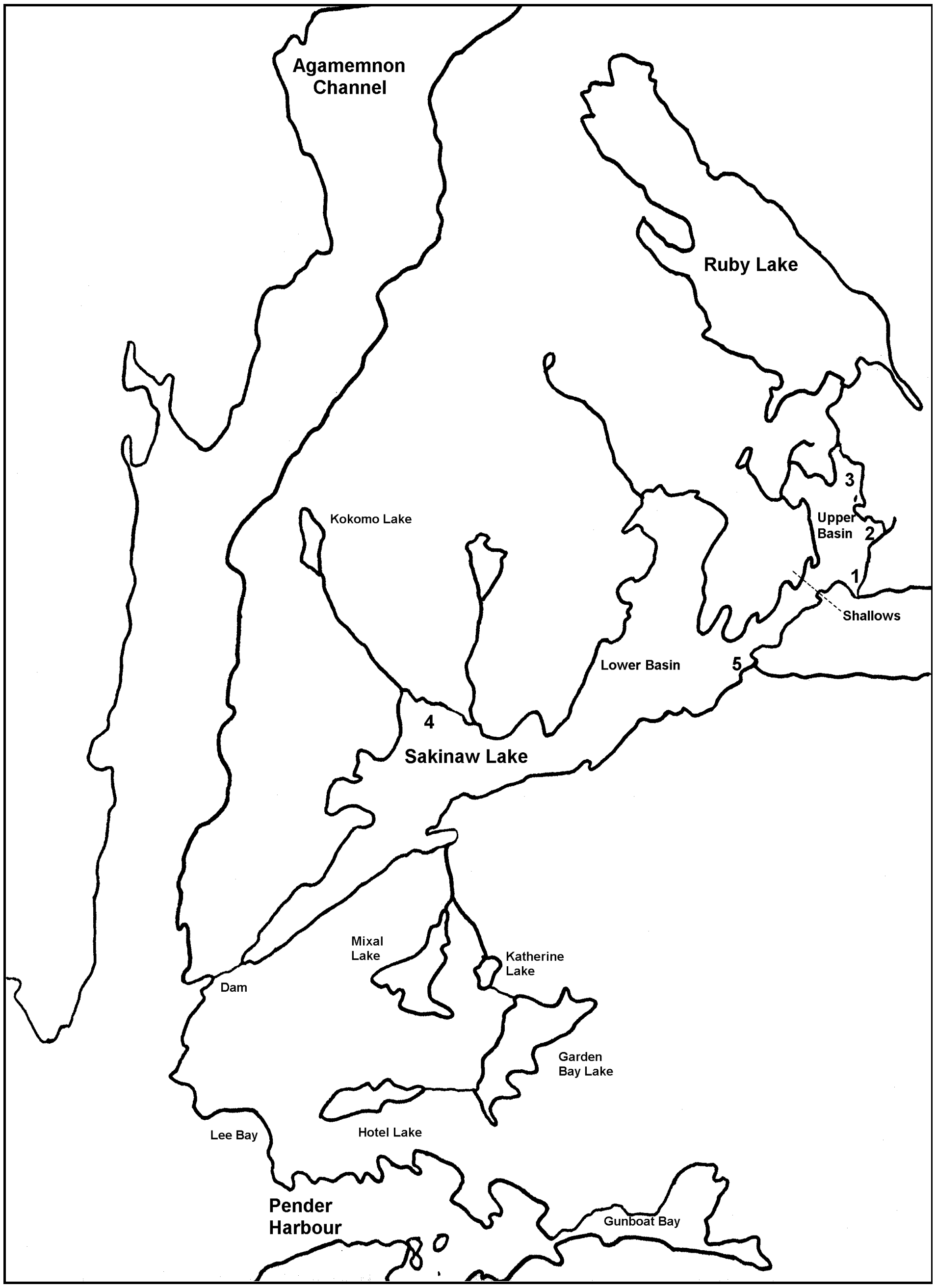


Figure 3. Sakinaw Lake, its tributaries and sockeye spawning beaches: Beach 1 (Sharon's); Beach 2 (Haskins); Beach 3 (Ruby Creek Bay); Beach 4 (Kokomo Creek Bay) and Beach 5 unnamed.

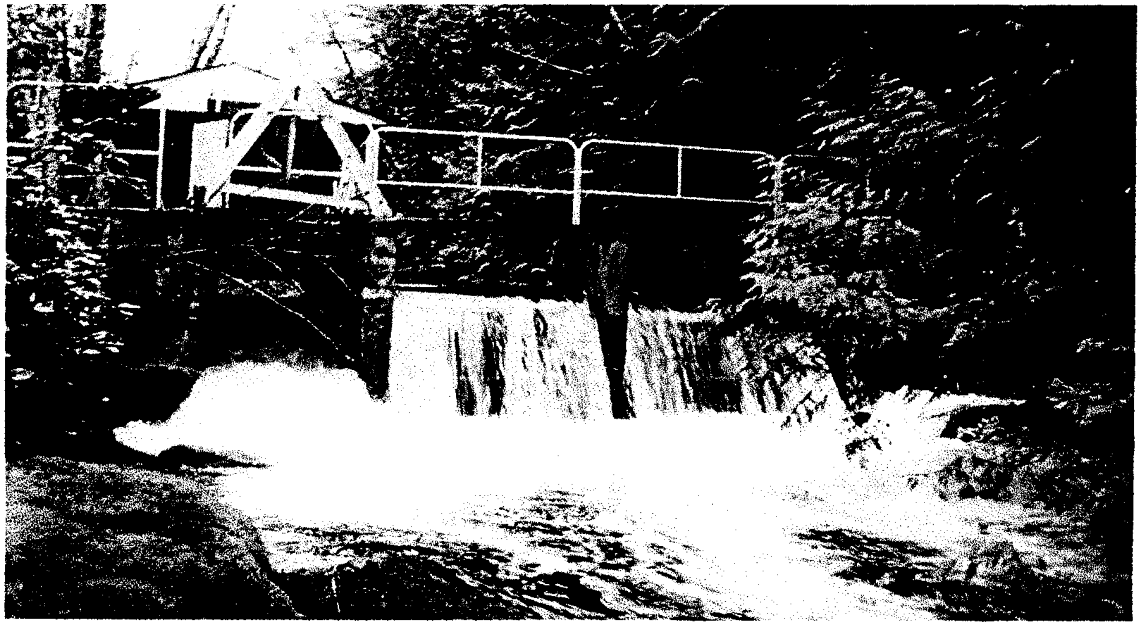


Figure 4. The dam structure located at the outflow of Sakinaw Lake. The structure was constructed around 1957 and has a fishway built into it on the north side.

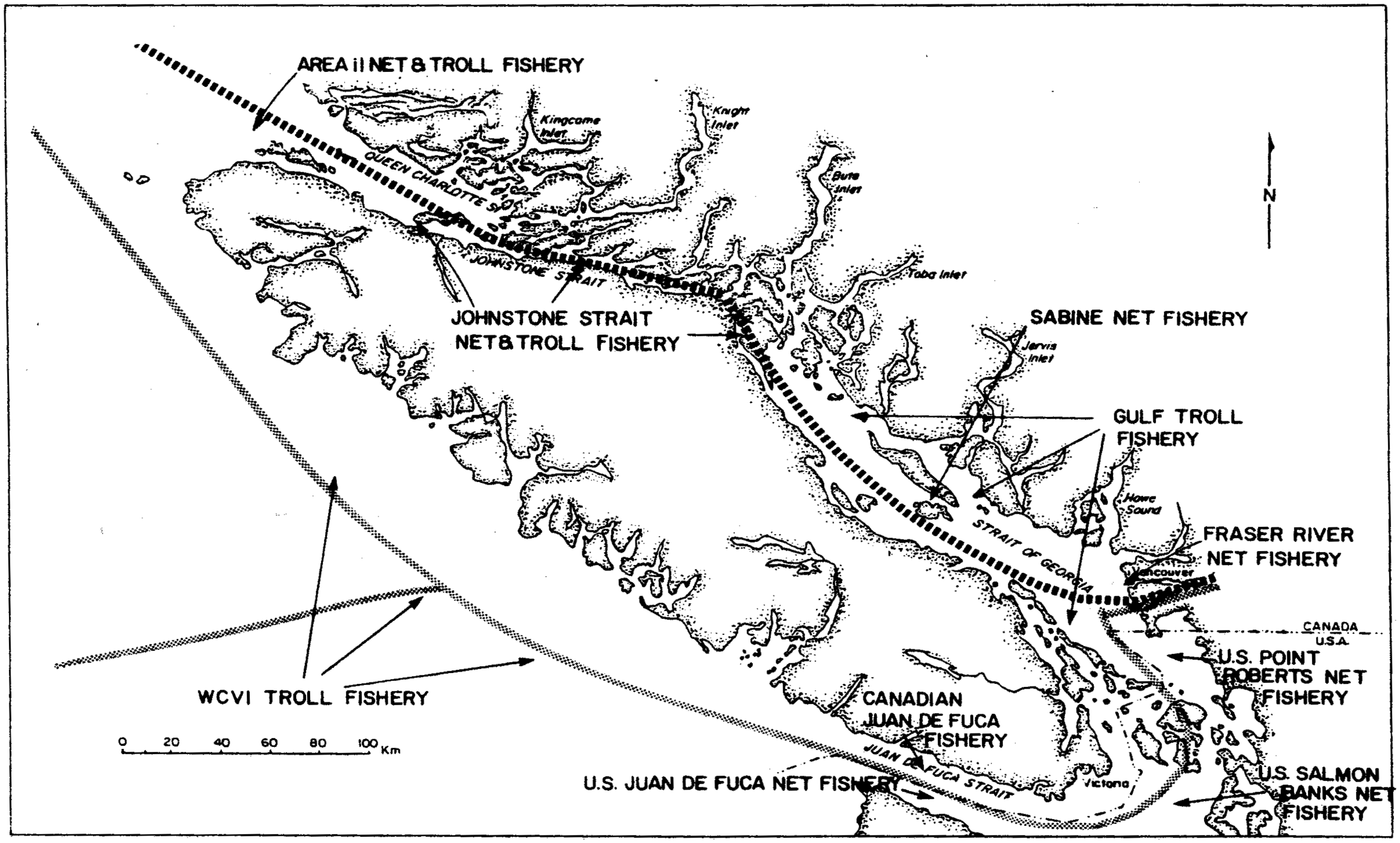


Figure 5. Major fisheries directed at Fraser River sockeye along the northern (Johnstone Strait) and southern (Juan de Fuca Strait) approach routes.

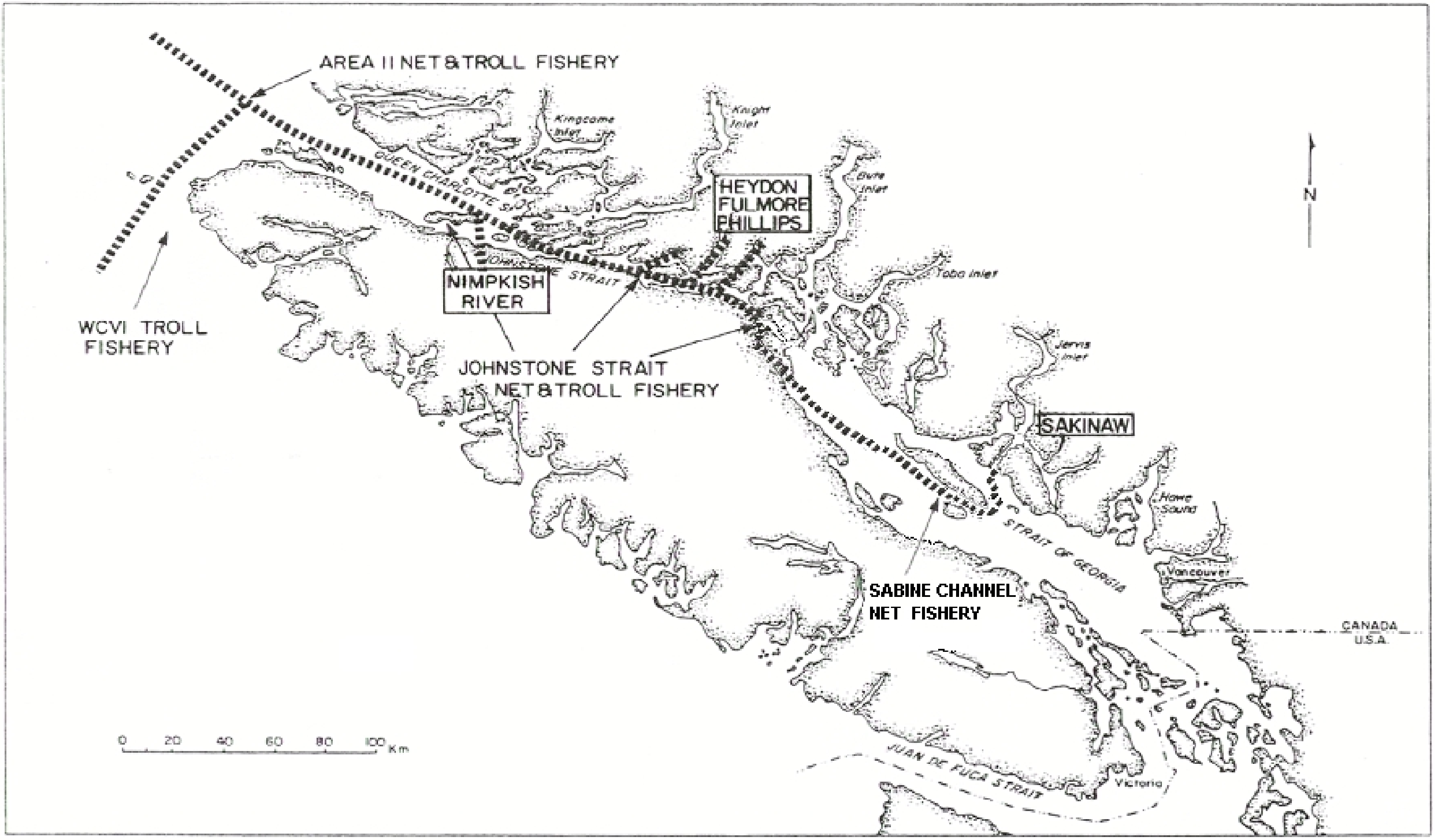


Figure 6. Major approach route and fisheries for Non-Fraser sockeye stocks (Nimpkish, Heydon, Fulmore, Phillips and Sakinaw). Sakinaw sockeye are harvested in the Johnstone Strait and Sabine Channel net fisheries.

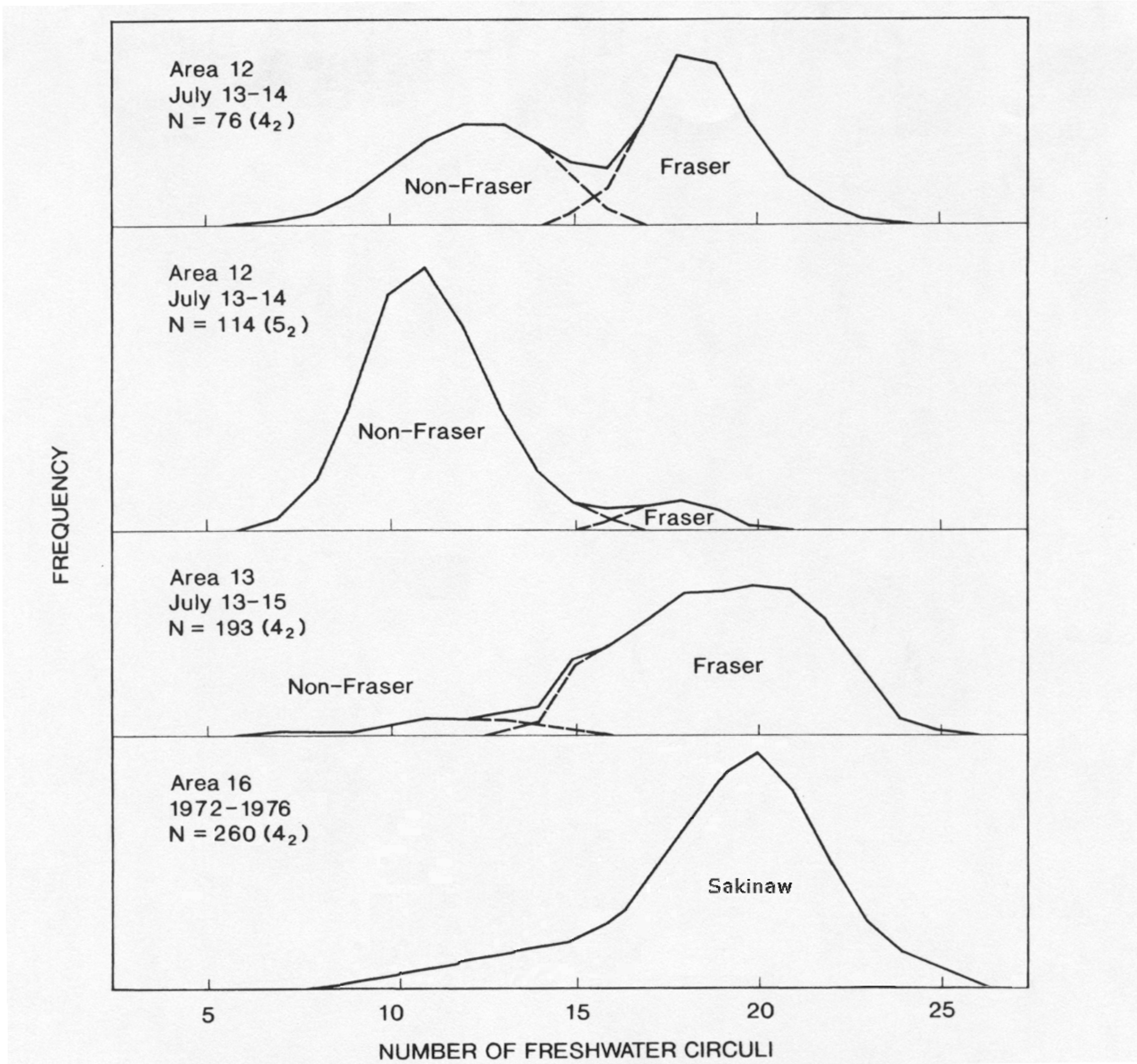


Figure 7. Smoothed freshwater scale circuli frequencies for sockeye salmon from Johnstone and Skainaw Lake. Non-Fraser and Fraser circuli frequencies are from 1959 Johnstone Strait sockeye catches (after Henry 1961). The solid upper line on each non-Fraser and Fraser graph is the composite frequency for the total sample. Note that the non-Fraser component of the samples is predominated by age (5_2) fish. Smoothed freshwater scale circuli frequencies for 1972 – 1976 Sakinaw sockeye circuli frequencies are from fishway samples.

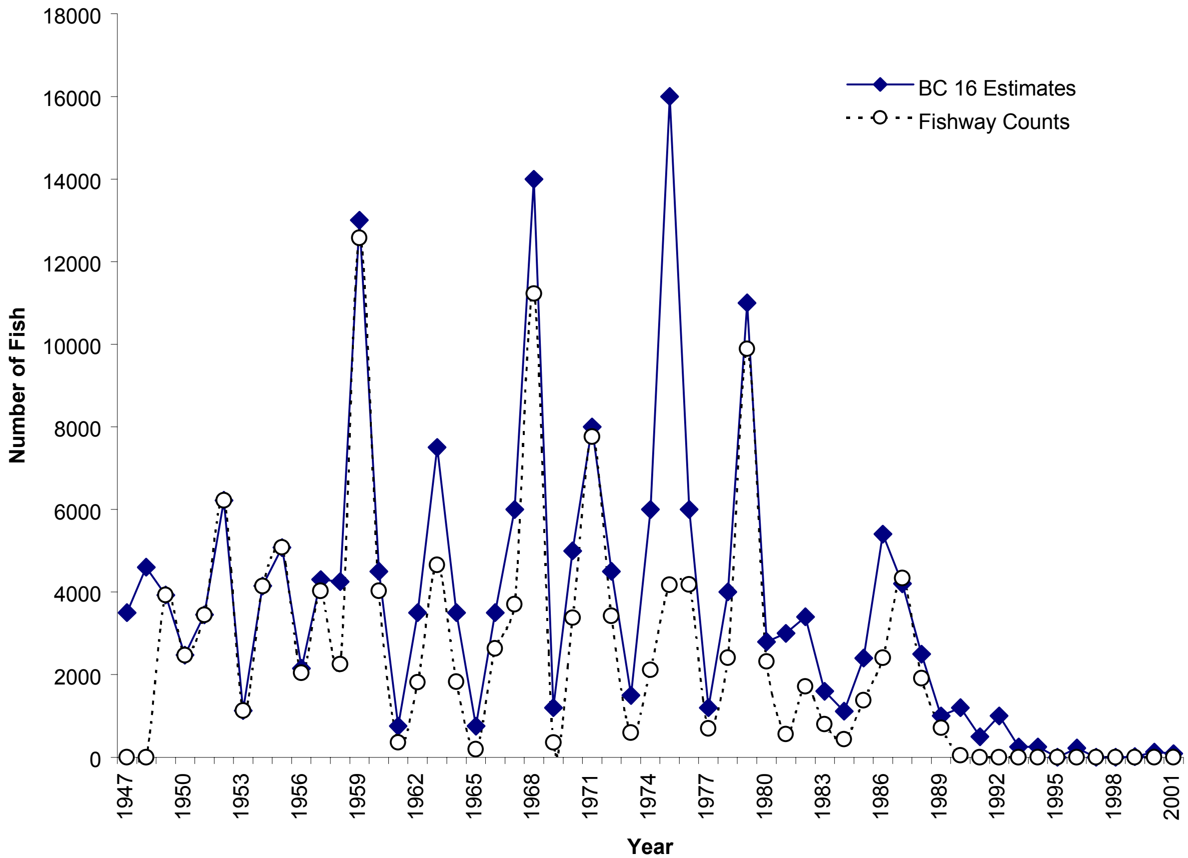


Figure 8. Sakinaw Lake sockeye escapement estimates for 1947 to 2001. SEDS database estimates are from the BC 16 Reports. Fishway counts are from the fisheries guardian's daily logs.

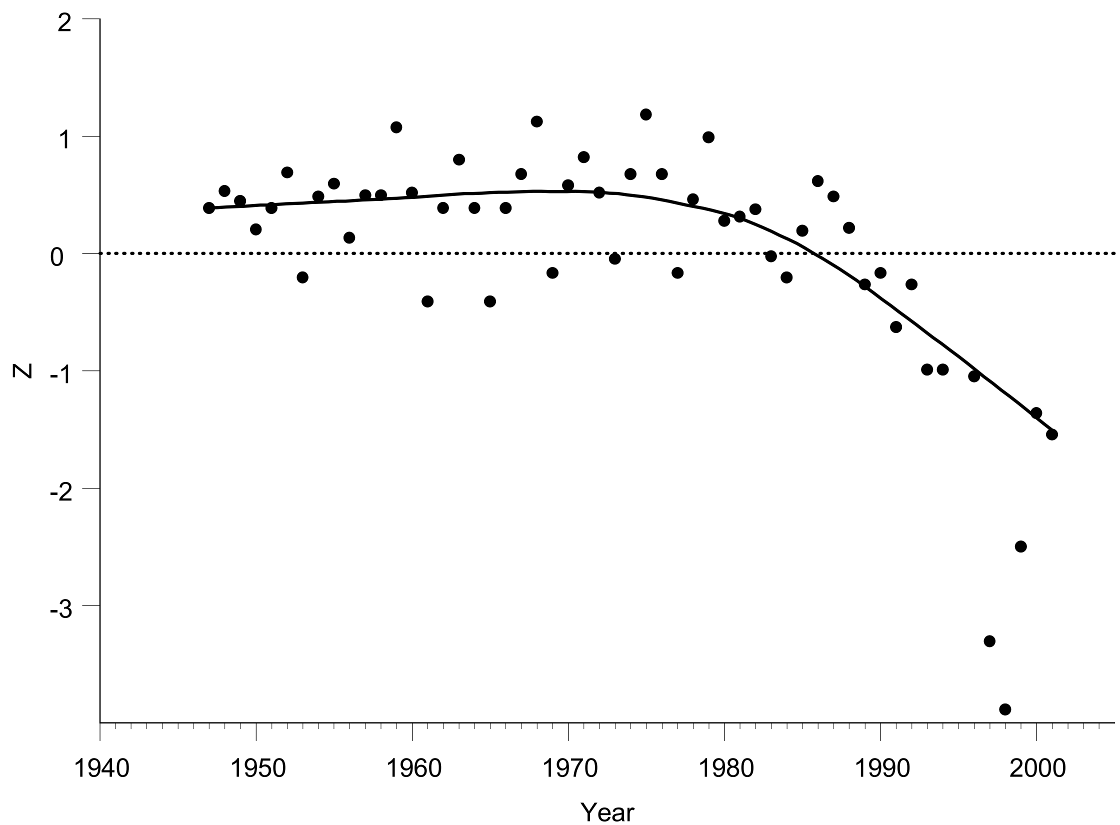


Figure 9. Standardized escapements for Sakinaw sockeye from 1947 to 2001. Escapement estimates from BC 16 reports. Escapement estimates transformed to logarithms prior to standardization. Escapement estimates for 1999 to 2001 from lake dive surveys of spawning grounds. Dashed line represents the mean overall escapement (3660).

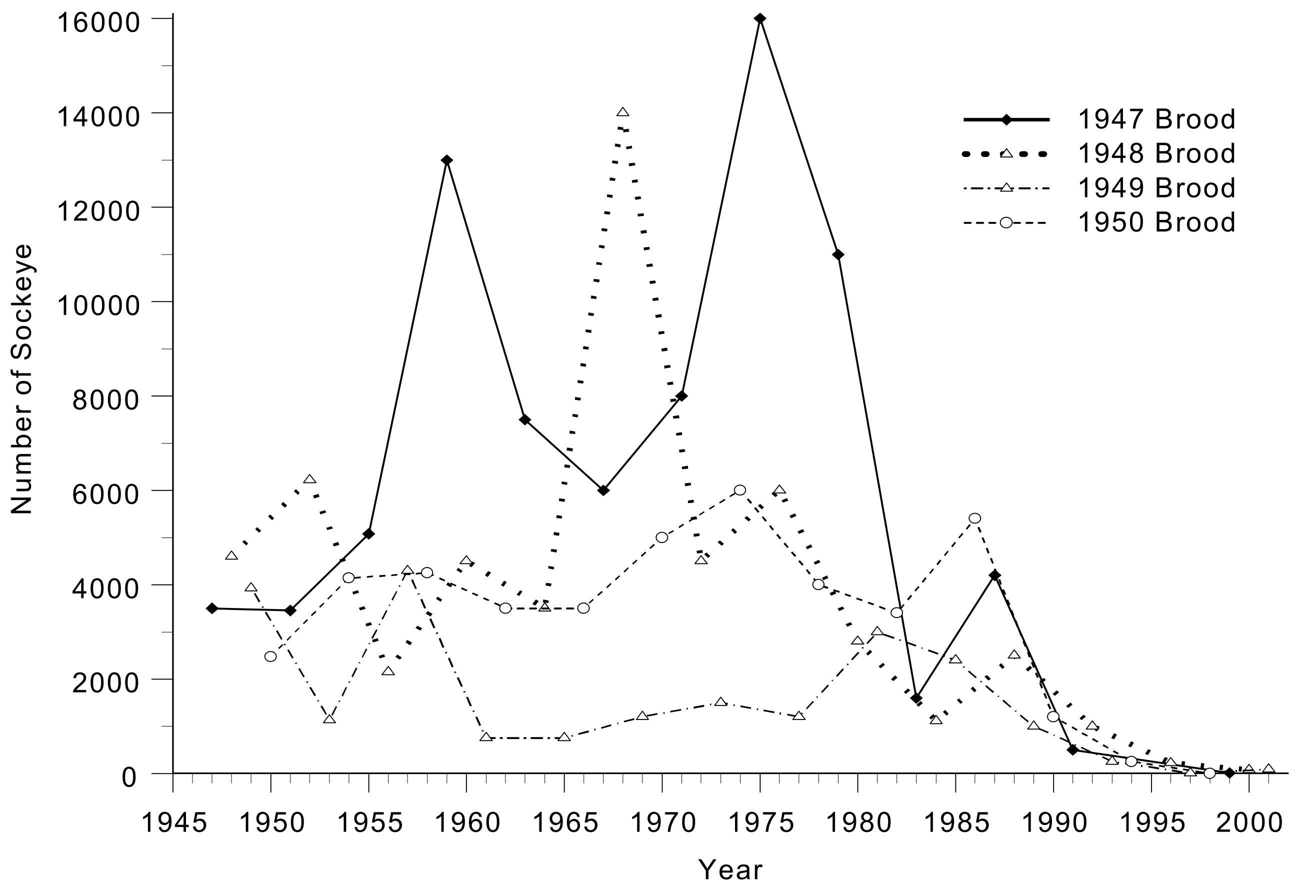


Figure 10. Sakinaw sockeye escapements by brood year. Sakinaw sockeye escapements are dominated by age 4 fish.

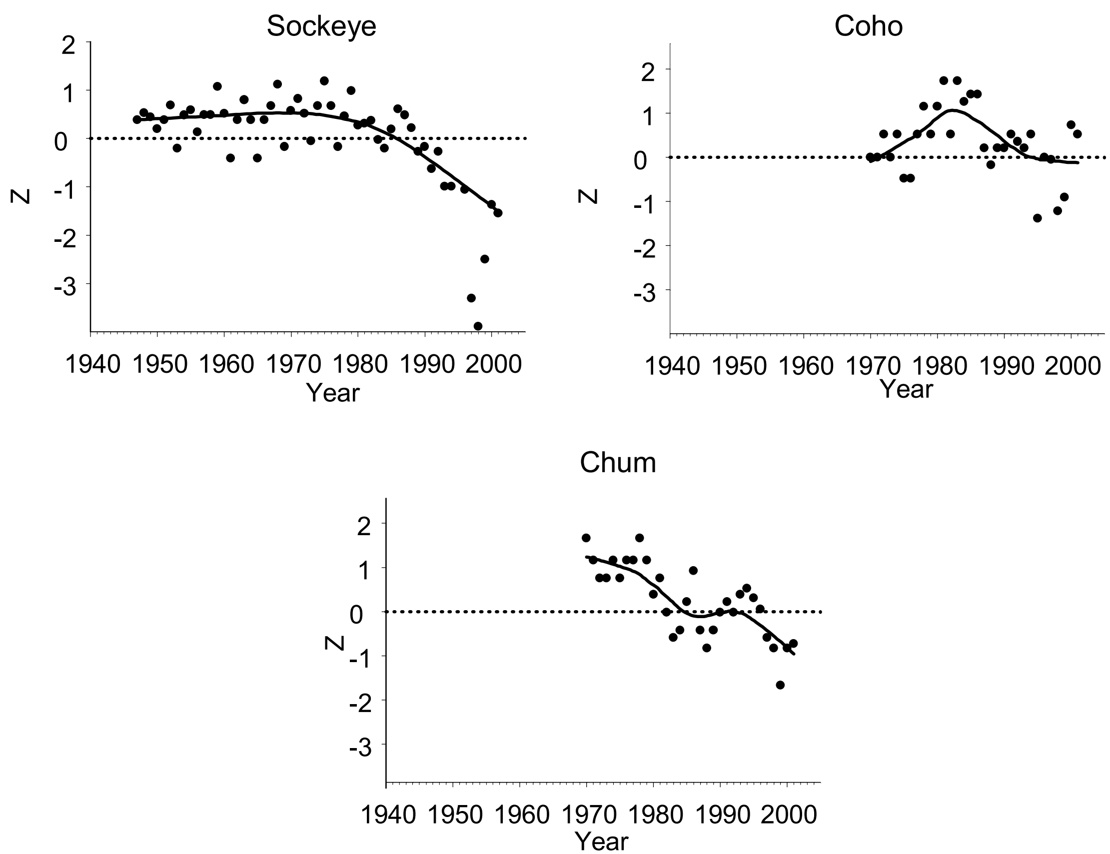


Figure 11. **Standardized escapements for Sakinaw sockeye, coho and chum from 1947 to 2001. Escapement estimates from BC 16 reports. Escapement estimates transformed to logarithms prior to standardization. Dashed line represents the mean overall escapement for sockeye (3660), coho (1409) and chum (494).**

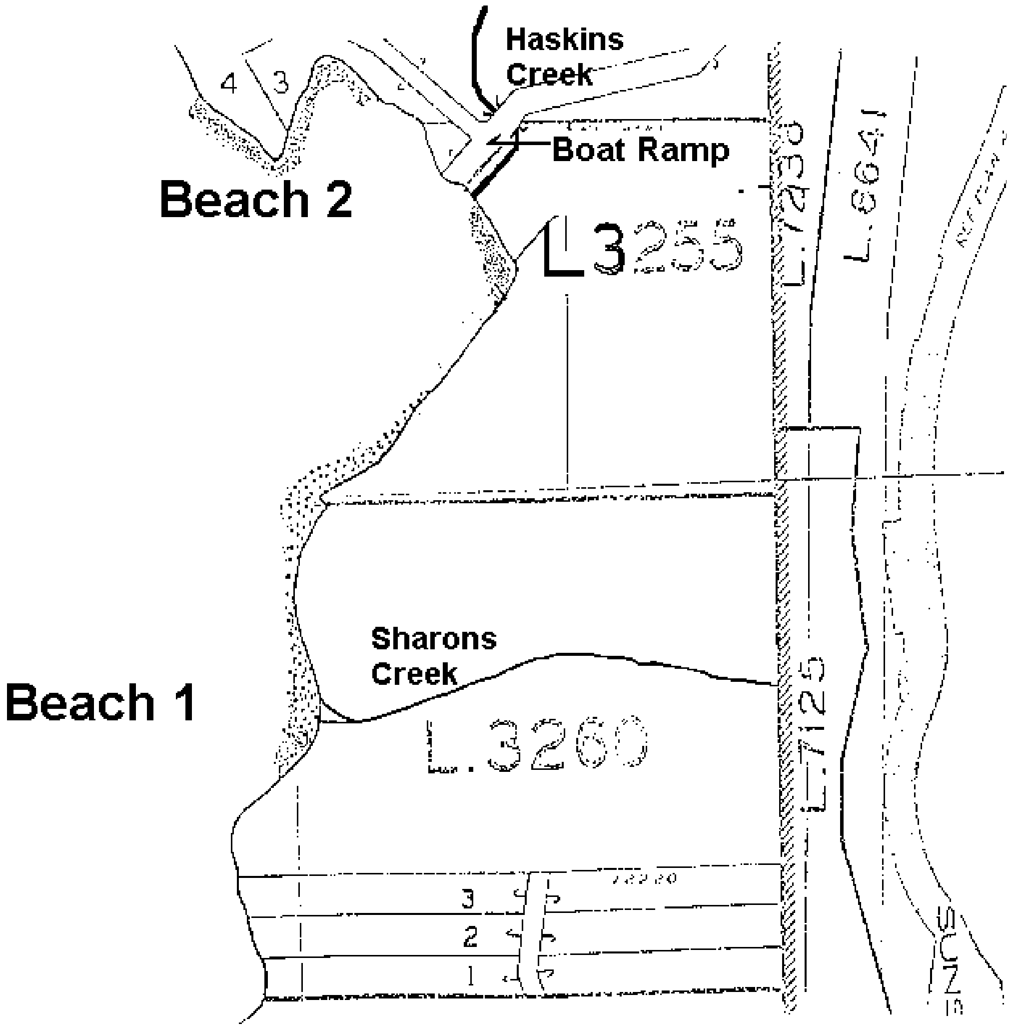


Figure 12. Locations of sockeye spawning for Beach 1 (Sharon's) and Beach 2 (Haskins) in Sakinaw Lake. Shaded areas indicate active spawning locations in 1979.

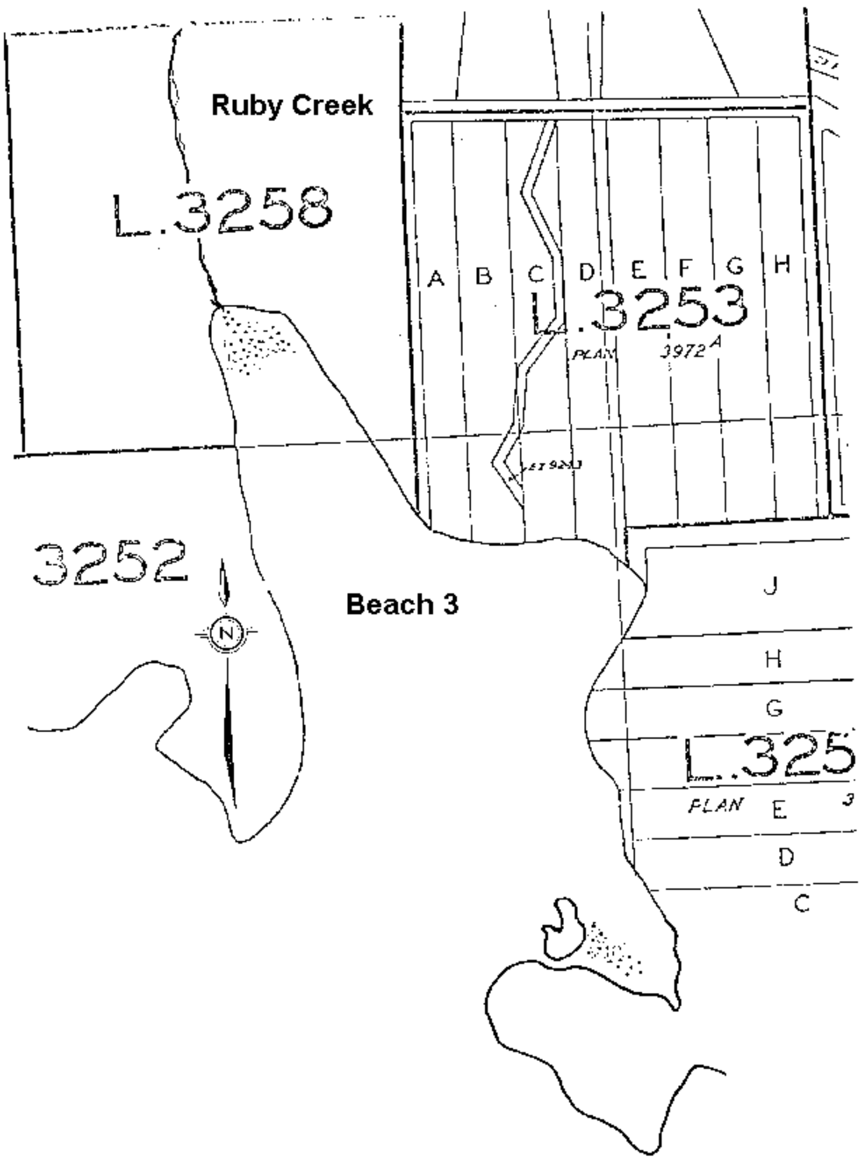


Figure 13. Locations of sockeye spawning for Beach 3 (Ruby Creek Bay) in Sakinaw Lake. Shaded areas indicate active spawning locations in 1979.

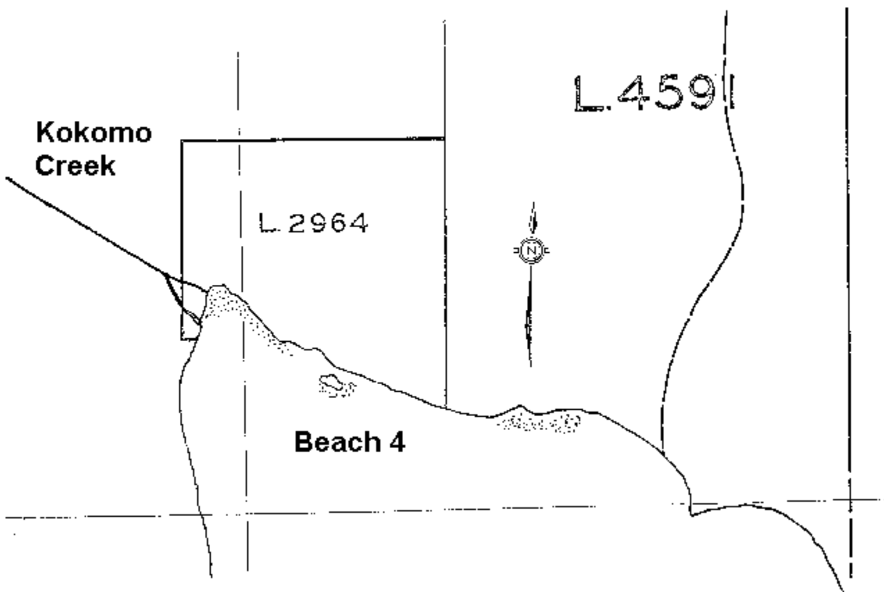


Figure 14. Locations of sockeye spawning for Beach 4 (Kokomo Creek Bay) in Sakinaw Lake. Shaded areas indicate active spawning locations in 1979.

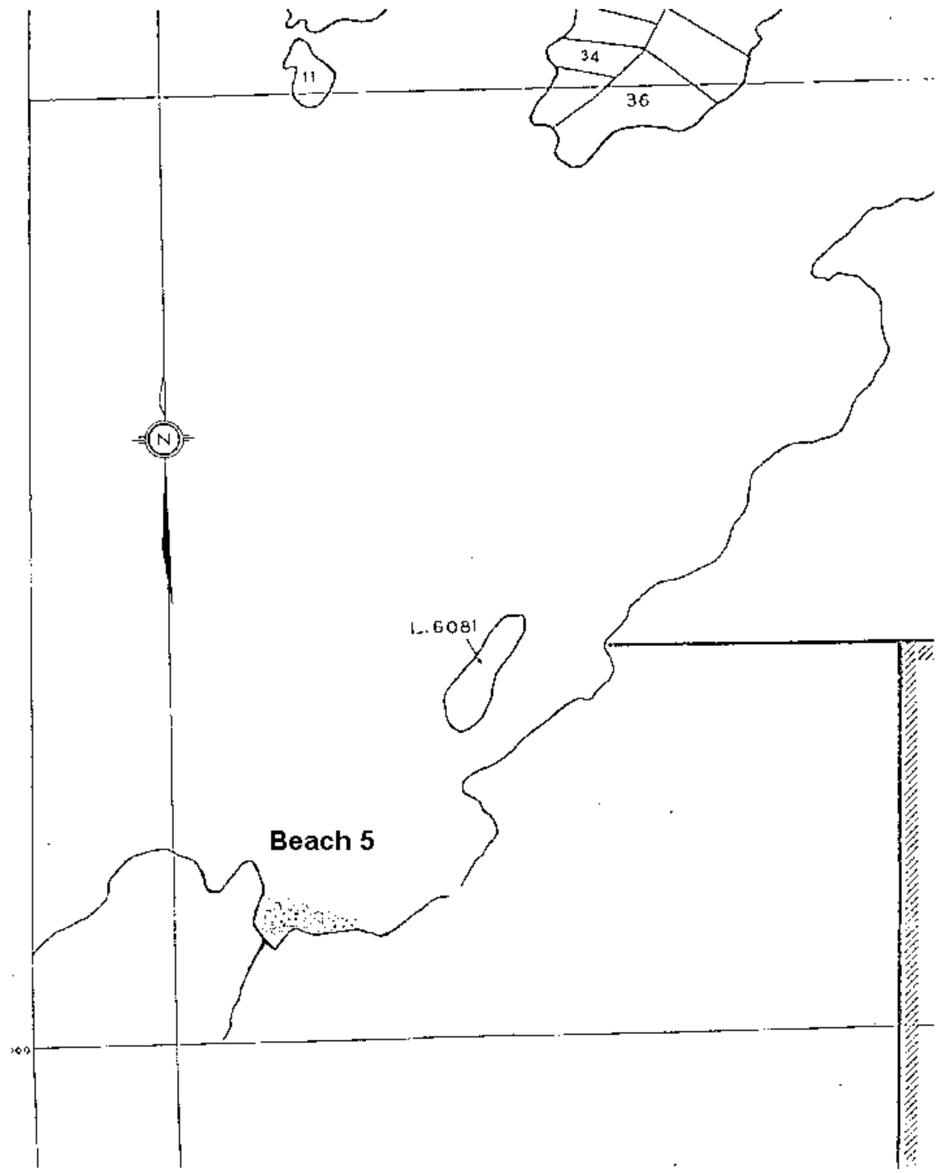


Figure 15. Location of sockeye spawning Beach 5 in Sakinaw Lake. Shaded areas indicate active spawning locations in 1979.

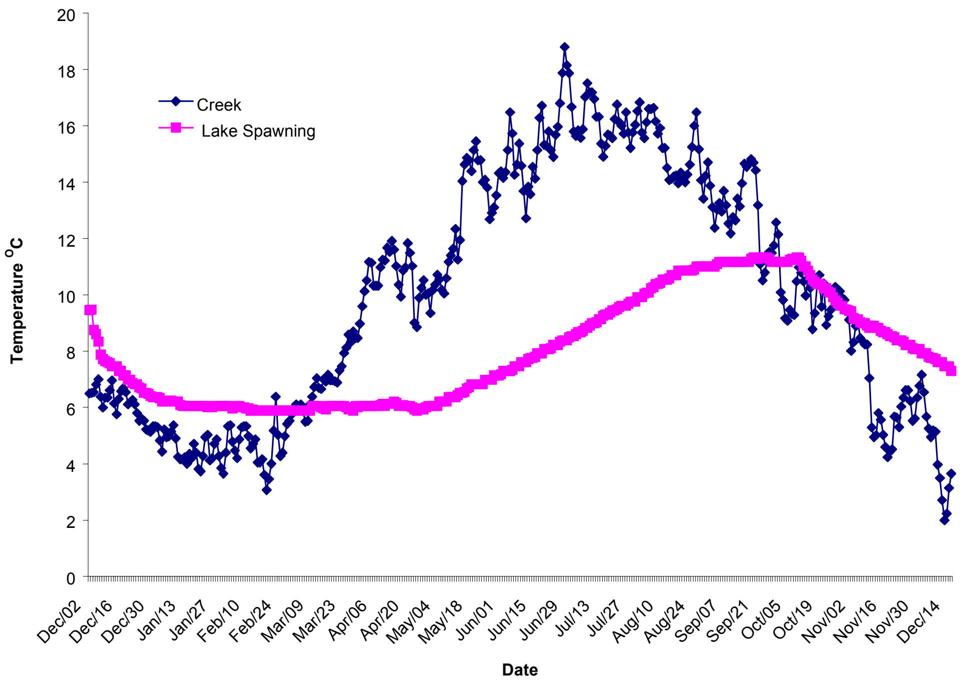


Figure 16. Mean in-gravel water temperatures (° C) for Mixal Creek and Sakinaw Lake sockeye spawning Beach 1. Temperatures recorded 4 times per day from December 2, 1999 to December 14, 2000.

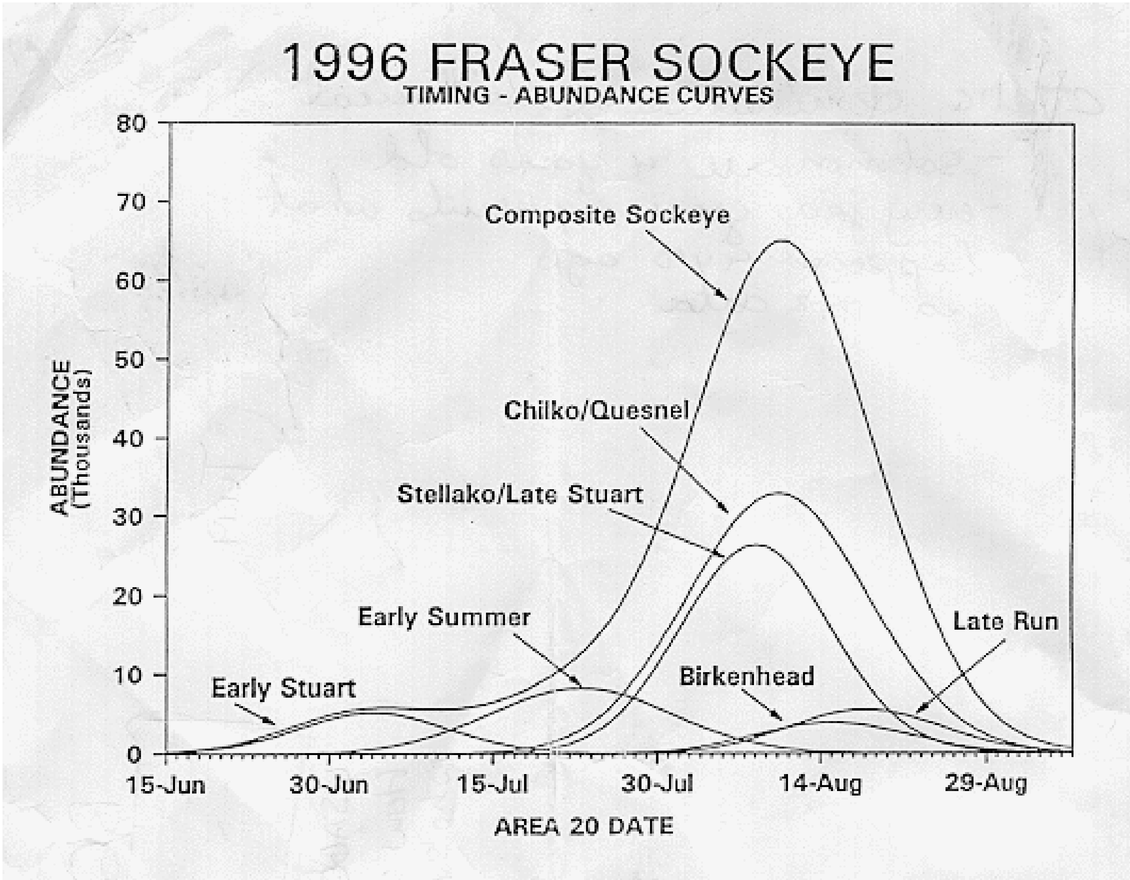


Figure 17. Smoothed run timing abundance curves for Fraser River sockeye entering Juan de Fuca Strait (Area 20) in 1996. Note run timing into Johnstone Strait would be 7 days earlier for all stocks.

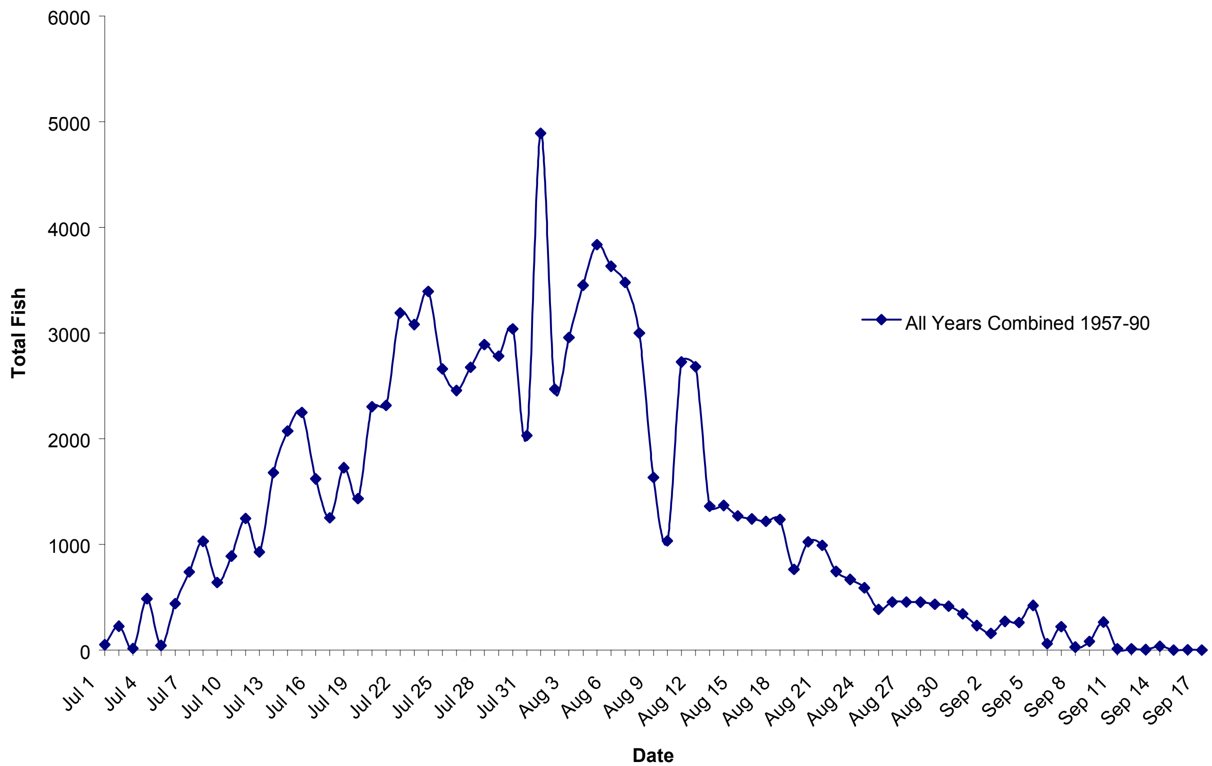


Figure 18. Cumulative number of Sakinaw sockeye through the fishway by day for the years 1957 to 1990.

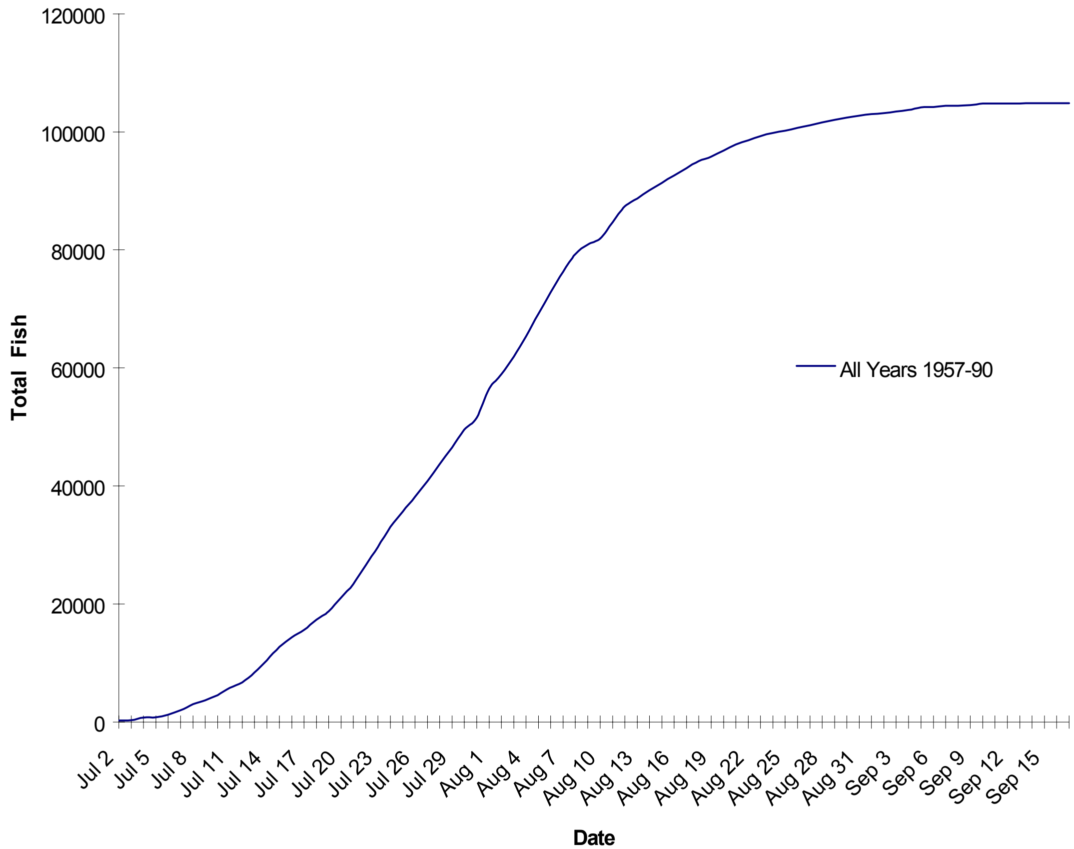


Figure 19. Cumulative run timing curve for Sakinaw sockeye by day through the fishway for the years 1957 to 1990.

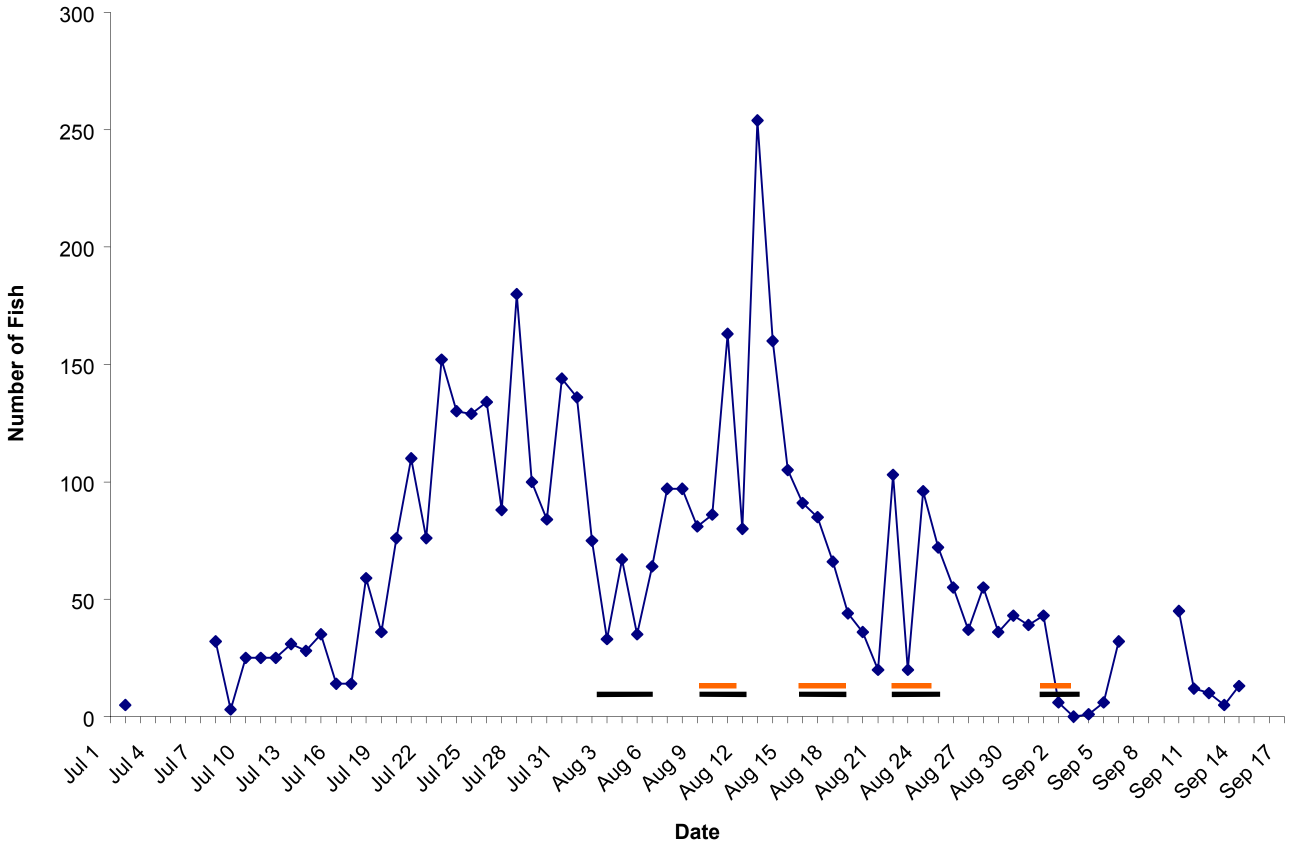
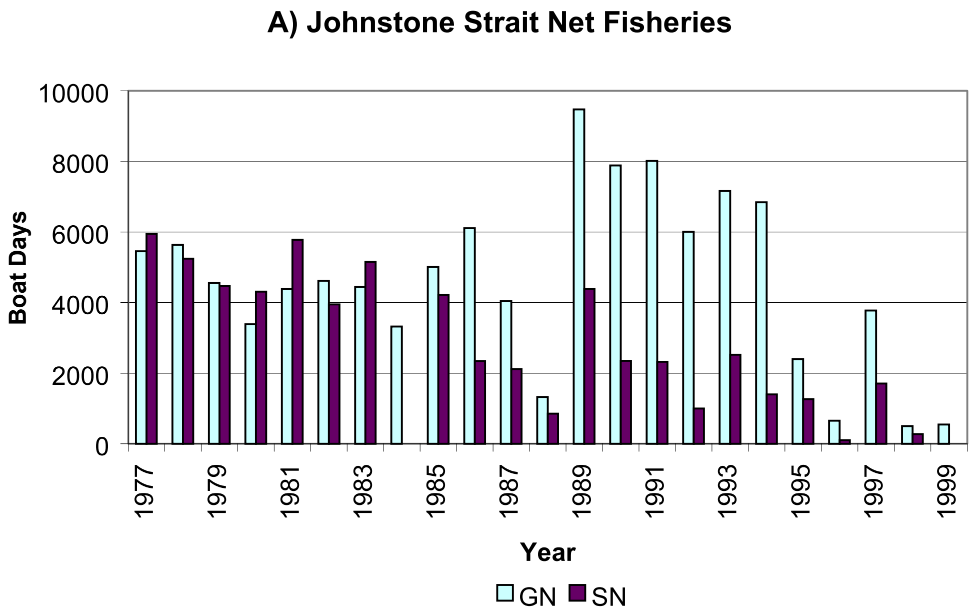


Figure 20. Number of Sakinaw sockeye through the fishway by day for 1987. Black bars indicated days fished in Johnstone Strait by seines and gillnets (Aug 2-5; Aug 9-12; Aug 16-19; Aug 22-25; and Sept 1-3 inclusive). Red bars indicate days fished in Area 16 (Sabine Channel) by seines and gillnets (Aug 9-11; aug 16-19; Aug 22-24; and Sept 1-2 inclusive).



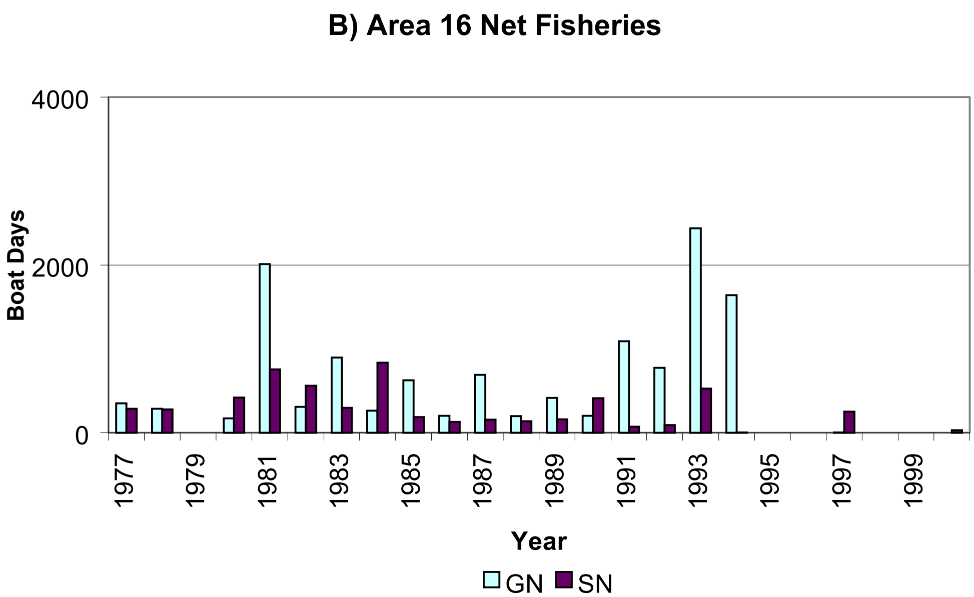


Figure 21. Number of boat days fished (product total days open and total vessel number) in the Johnstone Strait and Georgia Strait sockeye and pink salmon net fisheries by year. A) Johnstone Strait and B) Area 16 sockeye net fisheries (GN – gillnet; SN – seine) during weeks 7/1 to 9/2.

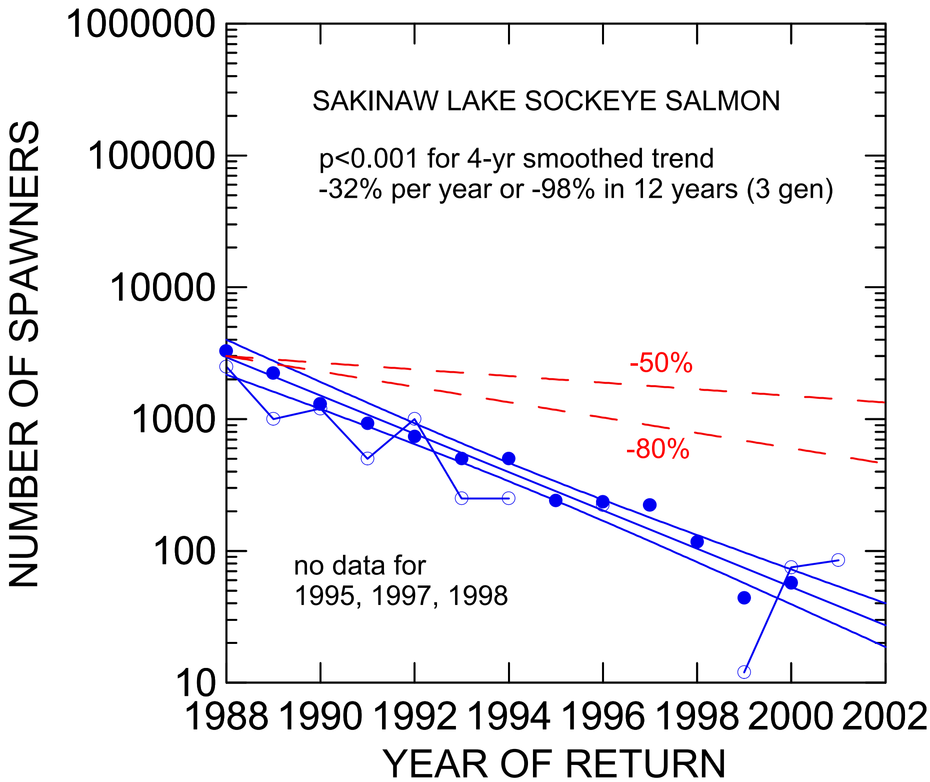


Figure 22. Declining trend of Sakinaw Lake sockeye compared with the IUCN Criterion A which is a threshold rate of decline that would justify designation as "Threatened" or "Endangered" by COSEWIC. Open circles are annual escapement estimates. Filled circles are 1-generation smoothed data. Solid line regression data with 90% CI are for a 3-gen or 10-yr window, whichever is longer. Dashed lines represent the IUCN/COSEWIC thresholds and are computed for a 3-generation window (12 years). No data for 1995, 1997 and 1998.

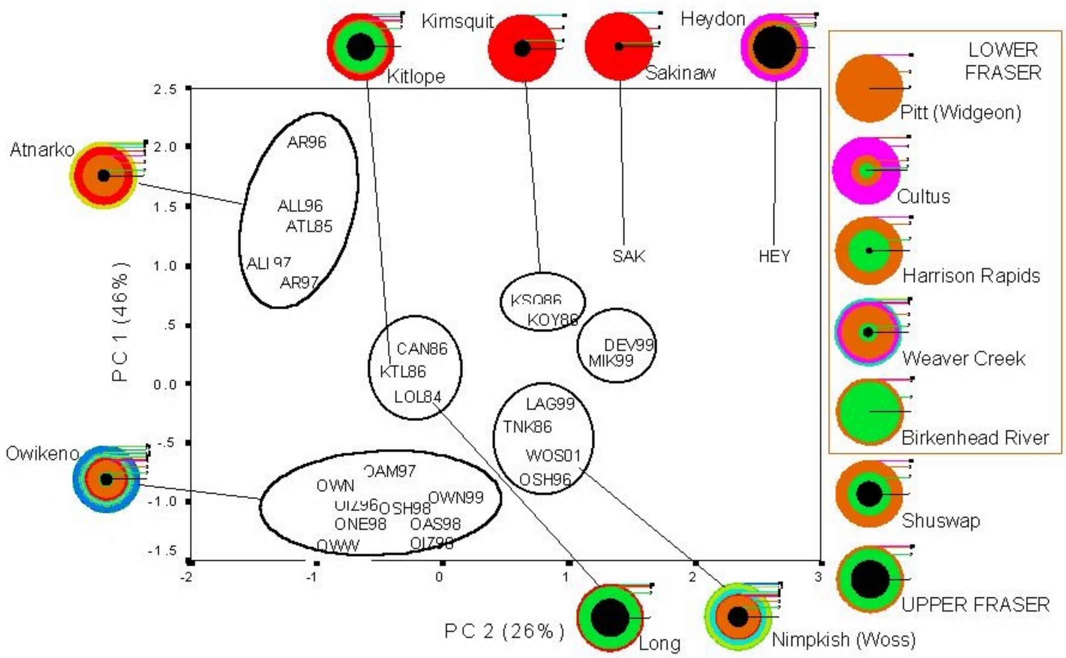


Figure 23. Principal components analysis of Cavalli-Sforza and Edwards' genetic distance between central coast sockeye populations based on differentiation at 10 microsatellite DNA loci (from Nelson et al. in press). Pie diagrams indicate relative frequencies of mitochondrial DNA haplotypes (denoted by colour). Fraser River populations are included for comparison because they were the source of attempted transplants to Sakinaw Lake.

Appendices

Appendix 1. The estimated harvest rate for Early Stuart sockeye in Johnstone Strait and Area 16 based on a 7 day migration time from Area 11 to Area 16 for the years 1987 to 1989 and years 1992 to 1994. Estimated proportions Early Stuart sockeye in the Round Island test fishery catches (Area 12) determined by scale racial analysis (Gable and Cox-Rogers 1993; PSC unpublished data). Return is the potential estimated Early Stuart catch in Johnstone Strait from Table 11. Diversion Rate from Table 11. Abundance is the product of the potential return through Johnstone Strait and the diversion rate. Harvest rate is total estimated ES catch in Johnstone divided by the abundance of ES in Johnstone Strait.

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
7/1	07/05/86	11												
7/2	07/12/86													
7/3	07/19/86	19	166			0.022	0.022	0.022						
7/4	07/26/86	598	367						0.022					
7/5	08/02/86	1516	585											
8/1	08/09/86	17417	63177	33096										
8/2	08/16/86	41994	213873	70178	14657									
8/3	08/23/86	95874	655706	82762	18933									
8/4	08/30/86	10195	586474	146712	20879									
9/1	09/06/86	521	51946	23955	8275									
Totals		168134	1572294	356703	62744	0	4	0	0	4	29885	0.25	7471	0.001
7/1	07/04/87													
7/2	07/11/87					0.609	0.609	0.609						
7/3	07/18/87		170			0.182	0.182	0.182	0.609					
7/4	07/25/87	71	581			0.150	0.150	0.150	0.182					
7/5	08/01/87	113	674			0.055	0.055	0.055	0.150					
8/1	08/08/87	32332	192544	61331					0.055					
8/2	08/15/87	38898	473259	137812	25533									
8/3	08/22/87	11464	149203	146543	58165									
8/4	08/29/87	2266	110313	46304	14577									
9/1	09/05/87		19210	11669	2996									
9/2	09/12/87	1												
Totals		85145	945954	403659	101271	17	156	0	0	172	190779	0.80	152623	0.001

Appendix 1 Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
7/2	07/09/88		82											
7/3	07/16/88	26												
7/4	07/23/88	102	192			0.000	0.000	0.000						
7/5	07/30/88	247	4485	1735		0.000	0.000	0.000	0.000					
8/1	08/06/88	13	318			0.000	0.000	0.000	0.000					
8/2	08/13/88	3502	42059	22686	4702	0.000	0.000	0.000	0.000					
8/3	08/20/88	2059	34858	6489	1587				0.000					
8/4	08/27/88	9	8595	7415										
9/1	09/03/88													
9/2	09/10/88	1												
Totals		5959	90589	38325	6289	0	0	0	0	0	247504	0.15	37126	0.000
6/2	06/17/89													
6/3	06/24/89		46			0.905	0.905	0.905						
6/4	07/01/89		284			0.873	0.873	0.873	0.905					
7/1	07/08/89	12	3021	844		0.899	0.899	0.899	0.873					
7/2	07/15/89	14	27780	3060		0.391	0.391	0.391	0.899					
7/3	07/22/89	24	22077	11937	1268				0.391					
7/4	07/29/89	13043	125494	6062	5625									
7/5	08/05/89	84376	598319	36974	8048									
8/1	08/12/89	98483	599220	146442	74623									
8/2	08/19/89	176065	1395318	421124	27828									
8/3	08/26/89	17980	446575	112904	16085									
8/4	09/02/89	9385	125932	53917	34648									
9/1	09/09/89	2187	8010	18032	276									
9/2	09/16/89	5	2	6744										
Totals		401574	3352078	818040	168401	16	13572	1955	495	16038	1196979	0.41	490761	0.033

Appendix 1 Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
6/3	06/20/92		7											
6/4	06/27/92		17			0.638	0.638	0.638						
7/1	07/04/92		368			0.637	0.637	0.637	0.638					
7/2	07/11/92		169			0.495	0.495	0.495	0.637					
7/3	07/18/92	201	1029			0.588	0.588	0.588	0.495					
7/4	07/25/92	864	2134			0.115	0.115	0.115	0.588					
7/5	08/01/92	1517	2510			0.018	0.018	0.018	0.115					
8/1	08/08/92	34958	241701	53378					0.018					
8/2	08/15/92	271121	489664	271418	51721									
8/3	08/22/92	37289	237920	117708	100539									
8/4	08/29/92	123	599	0										
9/1	09/05/92		0	28										
9/2	09/12/92		0	0										
Totals		346073	976118	442532	152260	244	1224	0	0	1469	296821	0.70	207775	0.007
6/3	06/19/93													
6/4	06/26/93		21			0.786	0.786	0.786						
7/1	07/03/93		145			0.948	0.948	0.948	0.786					
7/2	07/10/93		379			0.934	0.934	0.934	0.948					
7/3	07/17/93		265			0.918	0.918	0.918	0.934					
7/4	07/24/93		19665	1240		0.312	0.312	0.312	0.918					
7/5	07/31/93		26423	3935					0.312					
8/1	08/07/93	2	349065	91902	24996									
8/2	08/14/93	428504	2354368	385313	53592									
8/3	08/21/93	134583	2159316	494351	41811									
8/4	08/28/93	908	69176	29619	150404									
9/1	09/04/93	1912	476698	206658	498105									
9/2	09/11/93	4225	68614	39582	13901									
Totals		570134	5524135	1252600	782809	0	6891	387	0	7279	1297000	0.70	907900	0.008

Appendix 1 Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
7/1	07/02/94													
7/2	07/09/94													
7/3	07/16/94		101			0.346	0.346	0.346						
7/4	07/23/94		920			0.127	0.127	0.127	0.346					
7/5	07/30/94		15141						0.127					
8/1	08/06/94	34028	50054	3382										
8/2	08/13/94	106865	776471	310530	35994									
8/3	08/20/94	121980	1451408	539160	51584									
8/4	08/27/94	69526	936961	329420	17022									
9/1	09/03/94	38896	231724	121749	43166									
9/2	09/10/94	2223	4108	484										
9/2	09/17/94		2377	0										
Totals		373518	3469265	1304725	147766	0	152	0	0	152	202000	0.90	181800	0.001
6/3	06/21/97		9			0.785	0.785	0.785						
6/4	06/28/97		270			0.965	0.965	0.965	0.785					
7/1	07/05/97		1655			0.969	0.969	0.969	0.965					
7/2	07/12/97		16402	10904		0.893	0.893	0.893	0.969					
7/3	07/19/97		399	0		0.709	0.709	0.709	0.893					
7/4	07/26/97	408	5990	838		0.290	0.290	0.290	0.709					
7/5	08/02/97	8155	207628	78811					0.290					
8/1	08/09/97	29741	421083	132297										
8/2	08/16/97	58875	1241217	426951										
8/3	08/23/97	9219	724801	249287	17445									
8/4	08/30/97	6492	464037	287544	31									
9/1	09/06/97		456955	67518	104754									
9/2	09/13/97		160118	39313	5659									
Totals		112890	3700564	1293463	127889	118	18535	9983	0	28637	1673000	0.77	1288210	0.022

Appendix 1 Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
											Return	Diversion	Abundance	Harvest
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total			JST	Rate
7/1	07/04/98													
7/2	07/11/98													
7/3	07/18/98		266			0.197	0.197	0.197						
7/4	07/25/98		788	237					0.197					
7/5	08/01/98	326	141411	23751										
8/1	08/08/98	1245	305335	207356										
8/2	08/15/98	1995	59769	3712										
8/3	08/22/98	337	8127	3087										
8/4	08/29/98		1554	675										
9/1	09/05/98													
Totals		3903	517250	238818	0	0	53	0	0	53	190000	0.78	148200	0.000
7/1	07/03/99		64											
7/2	07/10/99		20											
7/3	07/17/99		29			0.337	0.337	0.337						
7/4	07/24/99		36						0.337					
7/5	07/31/99	1286	20029	3402										
8/1	08/07/99		11545	12923										
8/2	08/14/99		15807	3804										
8/3	08/21/99		4	556										
8/4	08/28/99			548										
9/1	09/04/99			614										
Totals		1286	47534	21847	0	0	10	0	0	10	171000	0.50	85500	0.000

Appendix 2. The estimated harvest rate for Early Stuart sockeye in Johnstone Strait and Area 16 based on a 14 day migration time from Area 11 to Area 16 for the years 1987 to 1989 and years 1992 to 1994. Estimated proportions Early Stuart sockeye in the Round Island test fishery catches (Area 12) determined by scale racial analysis (Gable and Cox-Rogers 1993; PSC unpublished data. Return is the potential estimated Early Stuart catch in Johnstone Strait from Table 11. Diversion Rate from Table 11. Abundance is the product of the potential return through Johnstone Strait and the diversion rate. Harvest rate is total estimated ES catch in Johnstone divided by the abundance of ES in Johnstone Strait.

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
7/1	07/05/86	11												
7/2	07/12/86													
7/3	07/19/86	19	166			0.022	0.022							
7/4	07/26/86	598	367					0.022						
7/5	08/02/86	1516	585						0.022					
8/1	08/09/86	17417	63177	33096										
8/2	08/16/86	41994	213873	70178	14657									
8/3	08/23/86	95874	655706	82762	18933									
8/4	08/30/86	10195	586474	146712	20879									
9/1	09/06/86	521	51946	23955	8275									
Totals		168134	1572294	356703	62744	0	4	0	0	4	29885	0.25	7471	0.001
7/1	07/04/87													
7/2	07/11/87					0.609	0.609							
7/3	07/18/87		170			0.182	0.182	0.609						
7/4	07/25/87	71	581			0.150	0.150	0.182	0.609					
7/5	08/01/87	113	674			0.055	0.055	0.150	0.182					
8/1	08/08/87	32332	192544	61331				0.055	0.150					
8/2	08/15/87	38898	473259	137812	25533				0.055					
8/3	08/22/87	11464	149203	146543	58165									
8/4	08/29/87	2266	110313	46304	14577									
9/1	09/05/87		19210	11669	2996									
9/2	09/12/87	1												
Totals		85145	945954	403659	101271	17	156	3384	1409	4965	190779	0.80	152623	0.033

Appendix 2. Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance	Harvest
7/2	07/09/88		82											
7/3	07/16/88	26												
7/4	07/23/88	102	192			0.000	0.000							
7/5	07/30/88	247	4485	1735		0.000	0.000	0.000						
8/1	08/06/88	13	318			0.000	0.000	0.000	0.000					
8/2	08/13/88	3502	42059	22686	4702	0.000	0.000	0.000	0.000					
8/3	08/20/88	2059	34858	6489	1587			0.000	0.000					
8/4	08/27/88	9	8595	7415					0.000					
9/1	09/03/88													
9/2	09/10/88	1												
Totals		5959	90589	38325	6289	0	0	0	0	0	247504	0.15	37126	0.000
6/2	06/17/89													
6/3	06/24/89		46			0.905	0.905							
6/4	07/01/89		284			0.873	0.873	0.905						
7/1	07/08/89	12	3021	844		0.899	0.899	0.873	0.905					
7/2	07/15/89	14	27780	3060		0.391	0.391	0.899	0.873					
7/3	07/22/89	24	22077	11937	1268			0.391	0.899					
7/4	07/29/89	13043	125494	6062	5625				0.391					
7/5	08/05/89	84376	598319	36974	8048									
8/1	08/12/89	98483	599220	146442	74623									
8/2	08/19/89	176065	1395318	421124	27828									
8/3	08/26/89	17980	446575	112904	16085									
8/4	09/02/89	9385	125932	53917	34648									
9/1	09/09/89	2187	8010	18032	276									
9/2	09/16/89	5	2	6744										
Totals		401574	3352078	818040	168401	16	13572	8153	3338	25079	1196979	0.41	490761	0.051

Appendix 2. Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
6/2	06/13/92													
6/3	06/20/92		7											
6/4	06/27/92		17			0.638	0.638							
7/1	07/04/92		368			0.637	0.637	0.638						
7/2	07/11/92		169			0.495	0.495	0.637	0.638					
7/3	07/18/92	201	1029			0.588	0.588	0.495	0.637					
7/4	07/25/92	864	2134			0.115	0.115	0.588	0.495					
7/5	08/01/92	1517	2510			0.018	0.018	0.115	0.588					
8/1	08/08/92	34958	241701	53378				0.018	0.115					
8/2	08/15/92	271121	489664	271418	51721				0.018					
8/3	08/22/92	37289	237920	117708	100539									
8/4	08/29/92	123	599	0										
9/1	09/05/92		0	28										
9/2	09/12/92		0	0										
Totals		346073	976118	442532	152260	244	1224	948	918	3335	296821	0.7	207775	0.016
6/3	06/19/93													
6/4	06/26/93		21			0.786	0.786							
7/1	07/03/93		145			0.948	0.948	0.786						
7/2	07/10/93		379			0.934	0.934	0.948	0.786					
7/3	07/17/93		265			0.918	0.918	0.934	0.948					
7/4	07/24/93		19665	1240		0.312	0.312	0.918	0.934					
7/5	07/31/93		26423	3935				0.312	0.918					
8/1	08/07/93	2	349065	91902	24996				0.312					
8/2	08/14/93	428504	2354368	385313	53592									
8/3	08/21/93	134583	2159316	494351	41811									
8/4	08/28/93	908	69176	29619	150404									
9/1	09/04/93	1912	476698	206658	498105									
9/2	09/11/93	4225	68614	39582	13901									
Totals		570134	5524135	1252600	782809	0	6891	2366	7805	17063	1297000	0.70	907900	0.019

Appendix 2. Continued

Date		Catch				% Early Stuart Catch					Early Stuart			
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	Return	Diversion	Abundance JST	Harvest Rate
7/1	07/02/94													
7/2	07/09/94													
7/3	07/16/94		101			0.346	0.346							
7/4	07/23/94		920			0.127	0.127	0.346						
7/5	07/30/94		15141					0.127	0.346					
8/1	08/06/94	34028	50054	3382					0.127					
8/2	08/13/94	106865	776471	310530	35994									
8/3	08/20/94	121980	1451408	539160	51584									
8/4	08/27/94	69526	936961	329420	17022									
9/1	09/03/94	38896	231724	121749	43166									
9/2	09/10/94	2223	4108	484										
9/2	09/17/94		2377	0										
Totals		373518	3469265	1304725	147766	0	152	0	0	152	202000	0.9	181800	0.001
6/3	06/21/97		9			0.785	0.785							
6/4	06/28/97		270			0.965	0.965	0.785						
7/1	07/05/97		1655			0.969	0.969	0.965	0.785					
7/2	07/12/97		16402	10904		0.893	0.893	0.969	0.965					
7/3	07/19/97		399	0		0.709	0.709	0.893	0.969					
7/4	07/26/97	408	5990	838		0.290	0.290	0.709	0.893					
7/5	08/02/97	8155	207628	78811				0.290	0.709					
8/1	08/09/97	29741	421083	132297					0.290					
8/2	08/16/97	58875	1241217	426951										
8/3	08/23/97	9219	724801	249287	17445									
8/4	08/30/97	6492	464037	287544	31									
9/1	09/06/97		456955	67518	104754									
9/2	09/13/97		160118	39313	5659									
Totals		112890	3700564	1293463	127889	118	18535	34007	0	52661	1673000	0.8	1288210	0.041

Appendix 3. Harvest rate estimates for Sakinaw sockeye caught in Area 11, Johnston Strait (Areas 12 & 13) and Georgia Strait (Area 16) commercial gillnet and seine fisheries for the periods 1986-89 and 1992-94 with a 7 day migration from Area 11 to Area 16. Data presented by statistical week (month/week). Estimated proportions of non-Fraser sockeye in the Round Island test fishery catches (Area 12) determined by scale racial analysis (Gable and Cox-Rogers 1993; PSC unpublished data). Proportions assumed constant for each area and a 7 day migration time used from Area 11 to Area 16. Sakinaw present in all four areas and the proportion of Sakinaw in the non-Fraser is assumed to increase by area (Areas 11 & 12 - 8%; Area 13 - 20%: Area 16 - 40%) based on 1975 PSC data. Sakinaw sockeye escapement estimates from BC16 reports and fishway counts. Harvest rate calculated as catch divided by catch plus escapement.

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Harvest Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
7/1	07/05/86	11																
7/2	07/12/86																	
7/3	07/19/86	19	166			0.40	0.40	0.40										
7/4	07/26/86	598	367			0.18	0.18	0.18	0.40									
7/5	08/02/86	1516	585			0.06	0.06	0.06	0.18									
8/1	08/09/86	17417	63177	33096					0.06									
8/2	08/16/86	41994	213873	70178	14657				0.06									
8/3	08/23/86	95874	655706	82762	18933													
8/4	08/30/86	10195	586474	146712	20879													
9/1	09/06/86	521	51946	23955	8275													
Totals		168134	1572294	356703	62744					16	13	0	333	362	5400	2414	0.063	0.131
7/1	07/04/87																	
7/2	07/11/87																	
7/3	07/18/87	26	170			0.36	0.36	0.36										
7/4	07/25/87	102	581			0.33	0.33	0.33	0.36									
7/5	08/01/87	247	674			0.04	0.04	0.04	0.33									
8/1	08/08/87	13	192544	61331					0.04									
8/2	08/15/87	3502	473259	137812	25533				0.04									
8/3	08/22/87	2059	149203	146543	58165													
8/4	08/29/87	9	110313	46304	14577													
9/1	09/05/87		19210	11669	2996													
9/2	09/12/87	1																
Totals		5959	945954	403659	101271					4	22	0	417	444	4200	4339	0.096	0.093

Appendix 3. Continued

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Harvest Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
7/2	07/09/88		82															
7/3	07/16/88	26				0.35	0.35	0.35										
7/4	07/23/88	102	192			0.38	0.38	0.38	0.35									
7/5	07/30/88	247	4485	1735		0.39	0.39	0.39	0.38									
8/1	08/06/88	13	318			0.03	0.03	0.03	0.39									
8/2	08/13/88	3502	42059	22686	4702				0.03									
8/3	08/20/88	2059	34858	6489	1587													
8/4	08/27/88	9	8595	7415														
9/1	09/03/88																	
9/2	09/10/88	1																
Totals		5959	90589	38325	6289					12	147	136	53	348	2500	1912	0.122	0.154
6/2	06/17/89																	
6/3	06/24/89		46			0.06	0.06	0.06										
6/4	07/01/89		284			0.07	0.07	0.07	0.06									
7/1	07/08/89	12	3021	844		0.07	0.07	0.07	0.07									
7/2	07/15/89	14	27780	3060		0.06	0.06	0.06	0.07									
7/3	07/22/89	24	22077	11937	1268	0.03	0.03	0.03	0.06									
7/4	07/29/89	13043	125494	6062	5625				0.03									
7/5	08/05/89	84376	598319	36974	8048				0.03									
8/1	08/12/89	98483	599220	146442	74623				0.03									
8/2	08/19/89	176065	1395318	421124	27828				0.03									
8/3	08/26/89	17980	446575	112904	16085													
8/4	09/02/89	9385	125932	53917	34648													
9/1	09/09/89	2187	8010	18032	276													
9/2	09/16/89	5	2	6744														
Totals		401574	3352078	818040	168401					0	192	113	1325	1630	1000	707	0.620	0.697
6/2	06/13/92																	
6/3	06/20/92		7			0.36	0.36	0.36										
6/4	06/27/92		17			0.36	0.36	0.36	0.36									
7/1	07/04/92		368			0.58	0.58	0.58	0.36									
7/2	07/11/92		169			0.27	0.27	0.27	0.58									
7/3	07/18/92	201	1029			0.33	0.33	0.33	0.27									
7/4	07/25/92	864	2134			0.16	0.16	0.16	0.33									
7/5	08/01/92	1517	2510			0.12	0.12	0.12	0.16									
8/1	08/08/92	34958	241701	53378					0.12									
8/2	08/15/92	271121	489664	271418	51721				0.12									
8/3	08/22/92	37289	237920	117708	100539													
8/4	08/29/92	123	599	0														
9/1	09/05/92		0	28														
9/2	09/12/92		0	0														
Totals		346073	976118	442532	152260					31	101	0	2524	2656	1000	1912	0.726	0.581

Appendix 3. Continued

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Exploitation Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
6/3	06/19/93																	
6/4	06/26/93		21			0.08	0.08	0.08										
7/1	07/03/93		145			0.05	0.05	0.05	0.08									
7/2	07/10/93		379			0.05	0.05	0.05	0.05									
7/3	07/17/93		265			0.03	0.03	0.03	0.05									
7/4	07/24/93		19665	1240		0.06	0.06	0.06	0.03									
7/5	07/31/93		26423	3935		0.11	0.11	0.11	0.06									
8/1	08/07/93	2	349065	91902	24996	0.12	0.12	0.12	0.11									
8/2	08/14/93	428504	2354368	385313	53592				0.12									
8/3	08/21/93	134583	2159316	494351	41811													
8/4	08/28/93	908	69176	29619	150404													
9/1	09/04/93	1912	476698	206658	498105													
9/2	09/11/93	4225	68614	39582	13901													
Totals		570134	5524135	1252600	782809					0	3732	2343	3710	9785	250		0.975	
7/1	07/02/94																	
7/2	07/09/94																	
7/3	07/16/94		101			0.32	0.32	0.32										
7/4	07/23/94		920			0.08	0.08	0.08	0.32									
7/5	07/30/94		15141						0.08									
8/1	08/06/94	34028	50054	3382					0.08									
8/2	08/13/94	106865	776471	310530	35994				0.08									
8/3	08/20/94	121980	1451408	539160	51584													
8/4	08/27/94	69526	936961	329420	17022													
9/1	09/03/94	38896	231724	121749	43166													
9/2	09/10/94	2223	4108	484														
9/2	09/17/94		2377	0														
Totals		373518	3469265	1304725	147766					0	8	0	1099	1108	250		0.816	

Appendix 4. Harvest rate estimates for Sakinaw sockeye caught in Area 11, Johnston Strait (Areas 12 & 13) and Georgia Strait (Area 16) commercial gillnet and seine fisheries for the periods 1986-89 and 1992-94 with a 14 day migration from Area 11 to Area 16. Data presented by statistical week (month/week). Estimated proportions of non-Fraser sockeye in the Round Island test fishery catches (Area 12) determined by scale racial analysis (Gable and Cox-Rogers 1993;PSC unpublished data). Proportions assumed constant for each area and a 14 day migration time used from Area 11 to Area 16. Sakinaw present in all four areas and the proportion of Sakinaw in the non-Fraser is assumed to increase by area (Areas 11 & 12 - 8%; Area 13 - 20%: Area 16 - 40%) based on 1975 PSC data. Sakinaw sockeye escapement estimates from BC16 reports and fishway counts. Harvest rate calculated as catch divided by catch plus escapement.

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Harvest Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
7/1	07/05/86	11								0	0	0	0	0				
7/2	07/12/86									0	0	0	0	0				
7/3	07/19/86	19	166			0.40	0.40			8	66	0	0	0				
7/4	07/26/86	598	367			0.18	0.18	0.40		106	65	0	0	0				
7/5	08/02/86	1516	585			0.06	0.06	0.18	0.40	86	33	0	0	0				
8/1	08/09/86	17417	63177	33096				0.06	0.18	0	0	1881	0	0				
8/2	08/16/86	41994	213873	70178	14657				0.06	0	0	0	833	0				
8/3	08/23/86	95874	655706	82762	18933				0.06	0	0	0	1076	0				
8/4	08/30/86	10195	586474	146712	20879					0	0	0	0	0				
9/1	09/06/86	521	51946	23955	8275					0	0	0	0	0				
Totals		168134	1572294	356703	62744					16	13	376	764	1169	5400	2414	0.178	0.326
7/1	07/04/87									0	0	0	0	0				
7/2	07/11/87									0	0	0	0	0				
7/3	07/18/87	26	170			0.36	0.36			9	62	0	0	0				
7/4	07/25/87	102	581			0.33	0.33	0.36		34	192	0	0	0				
7/5	08/01/87	247	674			0.04	0.04	0.33	0.36	10	28	0	0	0				
8/1	08/08/87	13	192544	61331				0.04	0.33	0	0	2506	0	0				
8/2	08/15/87	3502	473259	137812	25533				0.04	0	0	0	1043	0				
8/3	08/22/87	2059	149203	146543	58165				0.04	0	0	0	2377	0				
8/4	08/29/87	9	110313	46304	14577					0	0	0	0	0				
9/1	09/05/87		19210	11669	2996					0	0	0	0	0				
9/2	09/12/87	1								0	0	0	0	0				
Totals		5959	945954	403659	101271					4	22	501	1368	1896	4200	4339	0.311	0.304

Appendix 4. Continued.

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Harvest Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
7/2	07/09/88		82							0	0	0	0	0				
7/3	07/16/88	26				0.35	0.35			9	0	0	0	0				
7/4	07/23/88	102	192			0.38	0.38	0.35		39	74	0	0	0				
7/5	07/30/88	247	4485	1735		0.39	0.39	0.38	0.35	97	1759	680	0	0				
8/1	08/06/88	13	318			0.03	0.03	0.39	0.38	0	9	0	0	0				
8/2	08/13/88	3502	42059	22686	4702			0.03	0.39	0	0	0	132	0				
8/3	08/20/88	2059	34858	6489	1587				0.03	0	0	0	45	0				
8/4	08/27/88	9	8595	7415						0	0	0	0	0				
9/1	09/03/88									0	0	0	0	0				
9/2	09/10/88	1								0	0	0	0	0				
Totals		5959	90589	38325	6289					12	147	260	755	1175	2500	1912	0.320	0.381
6/2	06/17/89																	
6/3	06/24/89		46			0.06	0.06			0	3	0	0	0				
6/4	07/01/89		284			0.07	0.07	0.06		0	21	0	0	0				
7/1	07/08/89	12	3021	844		0.07	0.07	0.07	0.06	1	223	62	0	0				
7/2	07/15/89	14	27780	3060		0.06	0.06	0.07	0.07	1	1535	169	0	0				
7/3	07/22/89	24	22077	11937	1268	0.03	0.03	0.06	0.07	1	616	333	70	0				
7/4	07/29/89	13043	125494	6062	5625			0.03	0.06	0	0	0	157	0				
7/5	08/05/89	84376	598319	36974	8048				0.03	0	0	0	225	0				
8/1	08/12/89	98483	599220	146442	74623				0.03	0	0	0	2084	0				
8/2	08/19/89	176065	1395318	421124	27828				0.03	0	0	0	777	0				
8/3	08/26/89	17980	446575	112904	16085				0.03	0	0	0	0	0				
8/4	09/02/89	9385	125932	53917	34648					0	0	0	0	0				
9/1	09/09/89	2187	8010	18032	276					0	0	0	0	0				
9/2	09/16/89	5	2	6744						0	0	0	0	0				
Totals		401574	3352078	818040	168401					0	192	89	279	0	1000	707	0.000	0.000
6/2	06/13/92																	
6/3	06/20/92		7			0.36	0.36			0	2	0	0	0				
6/4	06/27/92		17			0.36	0.36	0.36		0	6	0	0	0				
7/1	07/04/92		368			0.58	0.58	0.36	0.36	0	214	0	0	0				
7/2	07/11/92		169			0.27	0.27	0.58	0.36	0	46	0	0	0				
7/3	07/18/92	201	1029			0.33	0.33	0.27	0.58	66	340	0	0	0				
7/4	07/25/92	864	2134			0.16	0.16	0.33	0.27	139	343	0	0	0				
7/5	08/01/92	1517	2510			0.12	0.12	0.16	0.33	185	306	0	0	0				
8/1	08/08/92	34958	241701	53378				0.12	0.16	0	0	0	0	0				
8/2	08/15/92	271121	489664	271418	51721				0.12	0	0	0	6310	0				
8/3	08/22/92	37289	237920	117708	100539				0.12	0	0	0	0	0				
8/4	08/29/92	123	599	0						0	0	0	0	0				
9/1	09/05/92		0	28						0	0	0	0	0				
9/2	09/12/92		0	0						0	0	0	0	0				
Totals		346073	976118	442532	152260					31	101	521	505	0	1000	1912	0.000	0.000

Appendix 4. Continued

Date		Catch				% Non - Fraser in Test Fishery				Non - Fraser Catch					Escapement		Exploitation Rate	
Week	Ending	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Area 11	Area 12	Area 13	Area 16	Total	BC 16	Fishway	BC 16	Fishway
6/3	06/19/93									0	0	0	0	0				
6/4	06/26/93		21			0.08	0.08			0	2	0	0	0				
7/1	07/03/93		145			0.05	0.05	0.08		0	8	0	0	0				
7/2	07/10/93		379			0.05	0.05	0.05	0.08	0	17	0	0	0				
7/3	07/17/93		265			0.03	0.03	0.05	0.05	0	8	0	0	0				
7/4	07/24/93		19665	1240		0.06	0.06	0.03	0.05	0	1138	37	0	0				
7/5	07/31/93		26423	3935		0.11	0.11	0.06	0.03	0	2894	228	0	0				
8/1	08/07/93	2	349065	91902	24996	0.12	0.12	0.11	0.06	0	42583	10066	1447	0				
8/2	08/14/93	428504	2354368	385313	53592			0.12	0.11	0	0	47005	5870	0				
8/3	08/21/93	134583	2159316	494351	41811				0.12	0	0	0	5101	0				
8/4	08/28/93	908	69176	29619	150404					0	0	0	0	0				
9/1	09/04/93	1912	476698	206658	498105					0	0	0	0	0				
9/2	09/11/93	4225	68614	39582	13901					0	0	0	0	0				
Totals		570134	5524135	1252600	782809					0	3732	4587	585	0	250		0.000	
7/1	07/02/94																	
7/2	07/09/94									0	0	0	0	0				
7/3	07/16/94		101			0.32	0.32			0	32	0	0	0				
7/4	07/23/94		920			0.08	0.08	0.32		0	70	0	0	0				
7/5	07/30/94		15141					0.08	0.32	0	0	0	0	0				
8/1	08/06/94	34028	50054	3382					0.08	0	0	0	0	0				
8/2	08/13/94	106865	776471	310530	35994				0.08	0	0	0	2749	0				
8/3	08/20/94	121980	1451408	539160	51584				0.08	0	0	0	3939	0				
8/4	08/27/94	69526	936961	329420	17022					0	0	0	0	0				
9/1	09/03/94	38896	231724	121749	43166					0	0	0	0	0				
9/2	09/10/94	2223	4108	484						0	0	0	0	0				
9/2	09/17/94		2377	0						0	0	0	0	0				
Totals		373518	3469265	1304725	147766					0	8	0	2675	2683	250		0.915	