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Recovery Potential Assessment for the Sakinaw Lake Sockeye Salmon (*Oncorhynchus nerka*) (2017)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Sakinaw Sockeye (*Oncorhynchus nerka*) was first assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Endangered in an emergency assessment in 2002, which was confirmed in another assessment in 2003. The status was assessed in another emergency assessment and again confirmed as Endangered in 2006. For various reasons the species has never been listed on the *Species at Risk Act* (SARA). The species was reassessed by COSEWIC in 2016 and the status of Endangered was re-affirmed. Following the COSEWIC assessment in 2003 a national recovery strategy was developed. Although not formally endorsed by the Government of Canada, many of the recovery measures were undertaken to ensure survival or recovery of the species. The Recovery Potential Assessment (RPA) presented here provides the necessary background information, population status and mitigation options to advise a SARA listing decision. Sakinaw Sockeye experience a variety of threats and limiting factors throughout their life history. Predation of eggs, and predation during migration through Sakinaw Creek as smolts and returning adults, and during the early marine phase, is believed to be a limiting factor. Fry to smolt survival is low for hatchery fish (13%) and believed to be low (~19%) for wild fish, despite Sakinaw Lake being a very productive lake. Domestication due to the captive brood program is also a concern. The greatest limiting factor is very low marine survival (<0.5%), for which there are no clear mitigation measures. Population Viability Analysis (PVA) indicated that even a two fold increase in freshwater survival would not be sufficient to achieve recovery with current marine survival. Under current conditions, the survival of Sakinaw Sockeye requires human intervention through hatchery supplementation. Fisheries management plans implemented during the 1990s have been effective in reducing exploitation of Sakinaw Sockeye. The average exploitation rate for Sakinaw Sockeye was 5% from 2011 to 2015 and the PVA indicated that further decreasing exploitation would have no effect on increasing the probability of recovery. Given the high early life history stage mortality and the extremely low marine survival of Sakinaw Sockeye, minimum allowable harm should be permitted at this time, and be reduced below current levels of harm to the extent possible.

INTRODUCTION

CONTEXT

Sakinaw Lake Sockeye Salmon ("Sakinaw Sockeye") was first assessed by COSEWIC in 2002 as an emergency assessment and recommended as Endangered. The status was re-examined and confirmed in May 2003 (COSEWIC 2003). The status was re-examined and confirmed in another emergency reassessment in April 2006. In 2015 a pre-COSEWIC review of the Sakinaw Sockeye was conducted by Fisheries and Oceans Canada (DFO) (DFO 2015a) to inform a re-assessment. As per section 24 of SARA, COSEWIC reviewed the classification of Sakinaw Sockeye Salmon in April 2016. The status of Sakinaw Sockeye Salmon was confirmed as Endangered (COSEWIC 2016). The following reason for designation was provided: "This population experienced a very large decline in the 1980s and 1990s because of low ocean survival and over-fishing. Broodstock from Sakinaw Lake are maintained in a captive-breeding program that produced fry and smolts released into the lake beginning in 2000. Despite these introductions, almost no adults returned to the lake in 2006-2009. Smolts from the captive-breeding program continued to be introduced and adults returned to the lake in 2010 through 2014. Some of these fish spawned successfully on historical spawning beaches, demonstrating that the program was having some success in re-establishing the population. However, the number of wild-hatched fish is very small. Threats from development around the lake, low ocean survival, and the fishery continue."

When COSEWIC designates aquatic species as Threatened or Endangered, DFO, as the responsible jurisdiction under SARA, is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the feasibility of its recovery.

This Recovery Potential Assessment (RPA) is the formulation of scientific advice and allows for the consideration of peer-reviewed scientific analyses into SARA processes. The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, development of a recovery strategy and action plan, and to support decision-making with regards to the issuance of permits, agreements and related conditions, as per section 73, 74, 75, 77 and 78 of SARA. The advice generated via this process will also update and/or consolidate any existing advice regarding this species. DFO's (2014a) *Guidance for the Completion of Recovery Potential Assessments (RPA) for Aquatic Species at Risk* was followed for the completion of this report.

Designatable Units (DUs) are defined by COSEWIC as "a population or group of populations… [that] has attributes that make it 'discrete' and evolutionarily 'significant' relative to other populations" (COSEWIC 2013). Sakinaw Sockeye satisfies both of these criteria for a DU. Sakinaw Sockeye are also defined as a Conservation Unit (CU) under Canada's Policy for Conservation of Wild Pacific Salmon (DFO 2005). A CU is a group of wild salmon sufficiently isolated from other groups that, if extirpated is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations.

When Sakinaw Sockeye was first assessed by COSEWIC, the rate of decline was 99% over 3 generations between 1988 and 2002 (COSEWIC 2003). Many factors have been identified as contributing to this decline, including low marine survival, overfishing, habitat degradation and poor management of the fishway and dam. A recovery team was engaged to establish recovery goals and actions for Sakinaw Sockeye. An immediate recovery goal was "to stop the decline of the Sakinaw Lake Sockeye Salmon population and re-establish a self-sustaining, naturally spawning population, ensuring the preservation of the unique biological characteristics of this population” (Sakinaw Sockeye Recovery Team 2005). An enhancement program was initiated in 2001 followed by a captive brood program to release fry into the lake with the goal of increasing the number of smolts migrating into the ocean. Escapements declined drastically until 2006 when 0 or 1 adult returned to the lake each year from 2006 to 2009. The population was extirpated in the wild given that the generation time for Sockeye is four years. The population is now entirely derived from hatchery-origin fish. The timeline and objectives of the Recovery Team were as follows:

- 2004–2007: increase the annual number of spawners (including those removed for hatchery bloodstock) to no fewer than 500;
- 2008–2011: increase the number of naturally[1] produced spawners to no fewer than 500 annually, and;
- 2012–2017: ensure that by 2017, the mean population abundance in any four- year period exceeds 1000 naturally produced spawners, with no fewer than 500 naturally produced spawners in a year (Sakinaw Recovery Team 2005).

The objective of this report is to provide up-to-date information, and associated uncertainties, to address the 22 elements described in the Terms of Reference with the best science advice possible given the information that can be assembled for Sakinaw Sockeye (DFO 2014a).

HISTORY OF ACESSS TO SAKINAW LAKE

Sakinaw Lake drains into ocean via Sakinaw Creek (Figure 1). Sakinaw Creek was determined to be critical to the survival of Sakinaw Sockeye (Godbout et al. 2004). The lake outlet was partially or completely blocked by dams built for logging purposes and water storage between 1911 and the 1930s, when they were removed (G. McBain, DFO, pers. comm.). This likely reduced the access for migrating Sockeye Salmon; however, based on historic escapement counts the damming does not appear to have had a negative effect on the population. As part of logging activities near Sakinaw Lake during the first half of the 20th century, the lake was used as a log dump, millpond and booming ground. A permanent dam and fishway were constructed on the outlet in 1952 by DFO and lake levels have been regulated since then to store water for the Sockeye migration (COSEWIC 2003, DFO 2015a). The permanent dam imposed a limitation on fluctuation of the depth of the lake. Without the dam the lake would fluctuate +/- 60 cm (G. McBain, DFO, pers. comm.).

Migration into Sakinaw Lake via the dam and fishway at the lake outlet would have been impeded due to no staff being assigned to operate the dam and fishway from 1990 to 1999. When staff were reassigned to operate the dam and fishway in 1999, a beaver dam was completely blocking the fishway. A fishway trap at the dam was deployed from 1987 to 1988 to block the night migration of Sockeye Salmon so the Fisheries Officers could count the returning adults in the morning. This caused mortality to returning adults as the adults had to wait overnight in warm (23 °C) water and were easy targets to River Otter predation. The fishway trap was not used for several years and then removed in 1996-97. In 1995, DFO installed two rock weirs downstream of the dam to increase the pool depth below the fishway by two metres and reduce the jumps into the fishway from eight 30 cm jumps to less than three 30 cm (DFO

[1] Throughout this document “wild salmon” are defined as per *Canada’s Policy for Conservation of Wild Salmon* (DFO 2005). A salmon is wild if it has spent its entire life cycle in the wild and originates from parents that were also produced by natural spawning and continuously lived in the wild. “Natural salmon” are the offspring of hatchery-reared fry that successfully spawned in the wild.

2015a). Historically, the Sechelt First Nation had also constructed a fish weir with stones at the mouth of Sakinaw Creek to harvest Sakinaw Sockeye.

BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

Element 1: Summarize the biology of Sakinaw Sockeye.

Element 2: Evaluate the recent species trajectory for abundance, distribution and number of populations.

Element 3: Estimate the current or recent life-history parameters for Sakinaw Sockeye.

BIOLOGY

Reproduction

Sakinaw Sockeye are anadromous, although there are also fully freshwater populations referred to as "Kokanee" which occur in Sakinaw Lake. Sakinaw Sockeye spawn along the shoreline of the lake where there are sources of upwelling groundwater (Murray and Wood 2002). Most Sakinaw Sockeye mature at 4 years old, after spending two years at sea. A very small proportion of Sakinaw Sockeye will mature at 3 (3%) and 5 (10%) years of age (Murray and Wood 2002). The majority of the population migrates through Johnstone Strait and the Strait of Georgia. Adults wait near the mouth of Sakinaw Creek for suitable high tides and darkness to access the creek. Adults enter Sakinaw Lake via Sakinaw Creek between June and September with the peak occurring at the end of July (Figure 1). Adult spawners hold in the lake for up to four months before spawning (Murray and Wood 2002).

The average fecundity of Sakinaw Sockeye females collected for broodstock in 1986, 1987, 2000 and 2001 was 2,796 (n=69; Murray and Wood 2002). Recent fecundity estimates for Sakinaw Sockeye females collected from the spawning grounds averaged 1,512 (range 0 to 3,096; n=72; brood years (BY) 2000-2002, 2004-2005 and 2010). However, fecundity estimates from individuals collected from the spawning grounds should be viewed with caution as individuals may have been partially or fully spawned out. Only including data from 2000 to 2005, and excluding individuals that were partially or totally spawned, the average was 2,049 (± 240 eggs, SD) eggs per female. These values fall in the lower range for fecundity for most Sockeye populations of 2,000 to 5,200 eggs (Burgner 1991).

Historically, there are five known spawning beaches in Sakinaw Lake, three in the upper basin (Sharon's, Haskins and Ruby) and two in the lower basin (Prospectors and Kokomo) of the lake (Figure 3). Since the 1990s, spawning only occurs at the upper basin beaches, although 2001 surveys showed that Ruby has had very limited use. Spawning occurs mainly near upwelling groundwater in underwater valleys associated with creeks but the creeks' inlets have migrated back and forth along the beaches over time. The remaining beaches appeared to be of poor quality for spawning (surveys as reported in Murray and Wood 2002). Dive surveys during 2003 and 2004 assessed nine different sites around the lake. Suitable spawning habitat and conditions were identified, yet some sites appeared not to be used, likely as a result of being overgrown with vegetation.

Spawning occurs predominantly between mid-November and mid-December, but can occur as late as January (Murray and Wood 2002). Females build redds in gravel substrate and bury the eggs immediately after male fertilization. Sakinaw Sockeye redds are approximately 0.75 m wide and 1.25 m long (0.94 m^2) (J. Wilson, unpublished data). The area required for lake spawning Sockeye is approximately 2.5 m^2 to 3.0 m^2 when taking in consideration female Sockeye size and the space required between two redds (Foerster 1968).

Eggs incubate in gravel and incubation time depends largely on the water temperature (Hart 1973). Incubation time can vary from as little as 50 days up to 5 months. Temperature logger data from Sakinaw Sockeye redds indicates that they experience an average temperature of 7°C. Alevin emerge from the hatched eggs and will spend 3 to 5 weeks in the gravel (Hart 1973). Free-swimming fry (25 to 32 mm in length) emerge from the gravel in early May and move to the limnetic zone (well-lit, surface waters) and feed primarily on zooplankton (Burgner 1991). 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 (Murray and Wood 2002).

By March of the following year the juveniles start to become smolts and move out of the lake via the creek to the Strait of Georgia (Figure 4). Most of the smolts move northwest through the Strait of Georgia and through Johnstone Strait to the Pacific Ocean (Wood et al. 2012). Sakinaw Sockeye become scattered over the northeast Pacific Ocean, mainly east of 170°E longitude and shallower than 160 m depth (Manzer 1964, Hart 1973). Generally, Canadian Sockeye remain south of the Aleutian Islands and move northward during the summer and south during the winter (Hart 1973).

There are genetically distinct Kokanee occurring in Sakinaw Lake, but they have not been characterized at microsatellite loci (Withler et al. 2014). It has not been possible to determine whether hybridization is occurring.

Feeding and Diet

After Sakinaw Sockeye fry emerge from the gravel in early May, they move near the lake shoreline in the littoral zone to visually feed and then shift with age to deeper waters of the limnetic zone (Murray and Wood 2002). As fry and smolts they feed primarily on copepods (*Cyclops, Epischura,* and *Diaptomus*), cladocerans (*Bosmia, Daphnia* and *Diaphanosoma*), insect larvae and small fishes (Carlson 1974, Burgner 1991). As adults at-sea their diet consists of euphausids, amphipods, copepods and young fishes (Hart 1973, Morrow 1980).

Length and Weight

Sakinaw Sockeye smolts are large relative to other populations of Sockeye Salmon but relatively small as adults (Gustafson et al. 1997). 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 20.9 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 of the migration and smaller ones at the end of the migration (Murray and Wood 2002).

Natural and hatchery smolts measured at the Sakinaw Creek dam from 2003 to 2016 had an average fork length of 128.0 mm (13.6 mm SD) and 126.9 mm (18.8 mm SD), respectively. Smolt length data are presented in Table 1 and Figure 5.

Length at maturity (adult fork length) data is available from 2001 wild-caught adults for the captive brood program, and from 2004, 2005, and 2011 fish tunnel video measurements. Average length for 178 animals between 2001 and 2013 is 55 cm (range 28-84 cm). Average length of spawners collected in 2001 for broodstock was 45 cm (10 fish); 47 cm for 5 males, and 43 cm for 5 females. 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 (Murray and Wood 2002).

DISTRIBUTION

The majority of out-migrating smolts move north through Johnstone Strait (Wood et al. 2012). A tagging study of hatchery raised Sakinaw Sockeye smolts detected 35% to 37% of tagged smolts at the detection array at the north end of Texada Island in 2004 and 2006 (Wood et al. 2012). Further along their migration corridor, 10% to 18% of the tagged smolts were detected just north of Port Hardy. Comparatively, 4% to 24% of tagged Sockeye smolts moved south of Sakinaw Lake to areas such as Howe Sound, the Fraser River and Puget Sound. Of the individuals tagged, only 1% to 7% traveled passed the array in Juan de Fuca Strait (Wood et al. 2012).

The same study used Kokanee from Sakinaw Lake to determine the migratory path of Sakinaw Sockeye (Wood et al. 2012). Twenty-three to 35% percent of the tagged Kokanee smolts were detected at the north end of Texada Island and 6% to 18% were detected near Port Hardy during 2005 and 2006, respectively. Ten to 30% of tagged Kokanee smolts were detected at the “inside lines” (i.e. Howe Sound) and 4% to 21% were detected in Juan de Fuca Strait (Wood et al. 2012). Using Kokanee, a freshwater species, as a surrogate for Sakinaw Sockeye should be interpreted cautiously as they are not likely a true representation of how an anadromous species would behave in the marine environment.

As adults, Sakinaw Sockeye forage in the north Pacific Ocean with other Sockeye salmon populations (Figure 6). During their first year at sea, BC Sockeye Salmon have been caught along the Alaska Peninsula during summer and fall (Tucker et al. 2009), and near the Aleutian Islands during winter (Farley et al. 2011). Fraser River Sockeye Salmon have been captured in the Bering Sea (Beacham et al. 2014). Juvenile Sockeye from the Fraser River, and adjacent areas, make up the largest proportion of the Sockeye stock composition along the Alaska Peninsula during fall. This suggests that these stocks migrate as far westward as 175°E during their first year at sea (Beacham et al. 2014). However, there is uncertainty and variability associated with their distribution.

During return migration, Sakinaw Sockeye occur in the north end of the Strait of Georgia, in Johnstone Strait, Juan de Fuca Strait, the South Gulf Islands and Puget Sound (Table 2). The majority of the fish return around the north end of Vancouver Island and pass through Johnstone Strait.

The distribution of adults in Sakinaw Lake is unknown but it is believed that they hold in deep water before moving to the spawning beaches (Sakinaw Sockeye Recovery Team 2005).

ABUNDANCE

Numbers of mature Sakinaw Sockeye spawners varied from 750 to 16,000 from 1947 to 1987 and showed no apparent trend (Figure 7, Table 3). After 1987, escapements declined drastically until 2006 when 0 or 1 adult returned to the lake each year from 2006 to 2009. The population was extirpated in the wild given that the generation time for Sockeye is four years (DFO 2015a).

A captive brood program was initiated during the collapse of the population to supplement the declining returns. Wild adults (n=84) were used to establish this captive population from escapement from 2002 to 2005 (Withler et al. 2014). Genetic material indicated that all spawners used to establish the captive brood program were Sakinaw Sockeye.

Hatchery fry are released annually into the upper and/or lower basin of Sakinaw Lake, with subsequent smolt enumeration and adult returns assessment. The entire Sakinaw Sockeye population is now descended from the captive population. Sockeye Salmon fry from the hatchery releases (wild brood) began returning to Sakinaw Lake as adults in 2005 (7 adults counted). One spawner was counted in 2009 that was of captive brood origin and 29 were counted at the fishway in 2010 that were of similar origin. Between 2011 and 2016, an annual average of 328 (range 114 to 555) captively-bred fry returned as adults to the lake. Some of these fish were observed spawning on historical beaches. Hatchery adults that returned and spawned in 2011 produced natural origin spawners in 2015. During 2015 and 2016 an average of 130 natural adult fish have returned to the lake. Hatchery fry from the captive brood program continue to be produced to supplement natural recruitment while escapements remain low. Hatchery fry released between 2001 and 2016 varied from 0 to 1,373,822 fry (Figure 8; Table 4). Smolts counted out-migrating from the lake between 2003 and 2015 range from 13 smolts in 2005 to 252,535 smolts in 2011 (DFO 2015a) (Table 4).

Hatchery-released fish are marked with an adipose fin clip prior to release to allow identification of smolts and returned adults as being of hatchery or natural spawner origin. All spawner returns in 2012 and 2013 are assumed to have originated from the hatchery as hatchery fry were not clipped between 2009 and 2011 (Figure 8 and Figure 9). Twenty-nine reintroduced adults spawned naturally in the lake in 2010, but resulting smolts were not discernable from hatchery fish (Withler et al. 2014). Clipping resumed in 2012.

LIFE HISTORY PARAMETERS

Growth and Natural Mortality

There are no natural egg to fry survival data for Sakinaw Sockeye. In 2013, DFO examined egg to fry survival (from eyed-egg stage) in boxes buried in gravel at 21 sites on four spawning beaches in Sakinaw Lake (Haskins beach and three subareas of Sharon's beach: Snag, Fraser's and Morgan's). Average egg to fry survival was 78%, ranging from 0% to 100%. The high average survival is likely due to the protected conditions within the boxes, which would protect the eggs from predation and therefore is not indicative of the true conditions. Bradford (1995) conducted a review of natural Sockeye life stage survival rates and found egg to fry survival rates of 9%. The same study by Bradford found an average Sockeye egg to smolt survival rate of 2%.

Average hatchery fry to smolt survival in Sakinaw Lake (BY 2001, 2002, 2004-2014) is 13.8% (range 1.4% to 32.2%) (Figure 10). The survival rate of hatchery fry has no relationship with the number of fry released (Figure 11). However, the number of fry released has a positive relationship with the number of hatchery smolts counted at the dam in Sakinaw Creek (Figure 12). There are no data on the survival rate of wild fry to smolt for Sakinaw Sockeye.

The average smolt to adult survival rate for Sockeye Salmon (not specific to the Sakinaw population) has been reported to be between 4.5% and 7% (Foerster 1968, Bradford 1995). These values are likely indicative of healthy populations that had not been negatively affected yet by the general decreases in marine survival experienced by salmon since the mid-1990's. Murray and Wood (2002) reported Sakinaw Sockeye smolt to adult marine survival for 1992 and 1995 (BY) smolt counts and 1996 and 1999 escapements (not separated into fishery and natural mortality) estimated at 0.83%. Data from recent years shows a smolt to adult survival (marine survival) average of 0.23% (BY 2001, 2004-2012) for hatchery and 0.49% (BY 2001, 2002, 2004-2006, 2011, 2012) for natural origin Sockeye Salmon (Figure 13, Table 4). It is unknown how much of this is due to natural mortality. Current Sakinaw Sockeye survival rates from smolt to adult are not sufficient to sustain the population (Withler et al. 2014), and continued hatchery supplementation is required to prevent another extirpation event until survival in the marine environment improves (DFO 2015a).

Adult Sakinaw Sockeye spawners hold in the lake for up to four months before spawning (Murray and Wood 2002). In-lake mortality during holding is unknown, but is assumed to be low

(≤10%) (DFO 2015a). Dive counts have been conducted, but are often unreliable estimates of fish abundance, and associated in-lake survival, when abundance is high because some fish may be missed on dive surveys and not all beaches are surveyed. However, in years with low returns, when thorough dive counts were conducted (2004 and 2005), the number of fish counted at the fishway and later during dive surveys suggest that mortality is low (DFO 2015a).

Smolts per spawner from natural spawning has ranged between 1.3 (2004) and 50.4 (2013) from 2003 to 2015 with an average of 18.8. To put in context, Cultus Lake Sockeye Salmon have an average of 75 natural origin smolts per female spawner (Ackerman et al. 2014). The average for Sakinaw wild and natural smolts per hectare has been 6.0 from BY 2001 to 2014 (not including years where there were no wild or natural spawners). Cultus Lake Sockeye Salmon has averaged 1,646 smolts per hectare from BY 1925 to 2003.

Again, all spawner returns in 2012 and 2014 are assumed to have originated from the hatchery as hatchery fry were not clipped for the releases in 2009 through 2011. There were also one or no natural spawners between 2006 and 2009. Twenty-nine adults returned in 2010 and 24 were removed for brood supplementation. The remaining 5 were not accounted for, and because the captive brood fry releases were not clipped, it is unknown whether there was any contribution from these fish to the population.

Stock-recruit Parameters

A standard Ricker stock-recruit model was fit to spawner-natural and wild origin recruit data for all years where exploitation estimates were available (see Table 5 and Table 6). Ricker parameter estimates are in Table 7.

HABITAT AND RESIDENCE REQUIREMENTS

Element 4: Describe the habitat properties that Sakinaw sockeye needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify by how much the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any.

Element 5: Provide information on the spatial extent of the areas in Sakinaw sockeye's distribution that are likely to have these habitat properties.

Element 6: Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

SPAWNING HABITAT

Similar to other salmon, Sakinaw Sockeye requires different habitats at varying stages of its life cycle. Adults spawn on beaches near creeks or other sources of groundwater. Spawning occurs near alluvial fans and where the gravel is small enough to be easily dislodged by digging (Foerster 1968). The perimeter of Sakinaw Lake is approximately 35 km long (Shortreed et al. 2003). In 1979 a lakeshore survey showed that only a small portion of the shoreline was suitable for beach spawning due to the presence of creek inflows. Sharon's beach occupies 300 m of shoreline and extends 100 m north and 200 m south of the southerly boundary of Lot L3255 (Figure 14). Ninety-five percent of the spawning occurs within this area. It is divided into four distinct sub-beaches, including Fraser's, Snag, Morgan's and Sharon's, which are in the order of use for spawning. The densest spawning occurs at the south end of the beach near the creek outflow and at the north end of the beach adjacent to the Lot L3260 and Lot L3255 boundary (Murray and Wood 2002).

Haskins Beach is located between the inlet of Boat Ramp creek at the end of Sakinaw Lake Road and the inlet of Haskins Creek. The shoreline between the two creeks is approximately 75 meters long. The creeks were diverted in the early 1960s by a previous land owner when the property was to be developed as a campground and marina. The original creek mouth is located at the midpoint of the area between the two creeks. The original creek mouth is the primary spawning area with some secondary spawning occurring near the new creek outlets (G. McBain, DFO, pers. comm.).

The amount of quality Sockeye spawning habitat in Sakinaw Lake was visually estimated to be 6,000 m^2 by a DFO diver in 1979 (Elvidge 1980[2]). In 2015, a habitat mapping study estimated approximately 3,000 m^2 of suitable spawning habitat with varying quality (DFO 2015a). This more recent study used a GPS unit and is higher quality data than the 1979 study; therefore, it is difficult to determine if the quantity of habitat has actually decreased since 1979. The quality of habitat within the 3,000 m^2 varies due to the presence of woody debris, slope and substrate type. The five known spawning beaches identified in Section 2.2 possess the habitat properties required for spawning (Figure 3).

Sharon's beach, including the four sub-beaches, occupies 300 m of shoreline. In 2001, it was estimated that areas used by Sockeye at Sharon's beach, including the four sub-beaches, had declined by 85% to 900 m^2 (Murray and Wood 2002). The difference can likely be attributed to the 1979 surveys being visual and the 2001 survey using GPS. The majority of spawning occurs at these beaches; therefore, it is believed that this is the highest quality spawning habitat available to Sakinaw Sockeye. In 2015, there was an estimated 175 m^2 of potential spawning habitat at Haskins beach with only 35 m^2 in use.

Another minor former spawning area is surrounding the outflow to Ruby Creek (100 m^2). The spawning area is too shallow for most Sockeye and is also used by Cutthroat Trout. The redds in this area are further from shore relative to other spawning areas but occur within a shallower depth range (2 to 7 m) (Murray and Wood 2002). Currently, this spawning area is not heavily used with a maximum of 6 fish using the area in a good year (G. McBain, DFO, pers. comm.).

Sockeye Salmon require water with sufficient dissolved oxygen (DO) concentrations to survive. Sockeye eggs, and the alevin that emerge from the eggs, require clean gravel with sufficient water flow to deliver DO and remove metabolic wastes (Murray and Wood 2002). Sockeye Salmon early life stages (egg and fry) require DO levels to be greater than 8.0 mg/L to survive while larger life stages require 4.0 mg/L (US EPA 1987). BC's recommended criteria for the protection of aquatic life states that the interstitial DO concentration be 8 mg/L[3] for all life stages (BC Ministry of Environment 1997). All transects surveyed in 2003 at Sharon's, Haskins and Ruby beach, except for one at Haskins, had interstitial DO levels above these criteria (G3 Consulting Ltd. 2003). All transects had ambient water DO concentrations above these criteria. Sakinaw Sockeye preferentially selected areas with higher (≥8 mg/L) DO levels for redd construction (G3 Consulting Ltd. 2002). Substrate type and level of compactness influences DO levels. Areas with gravel substrate (2 mm to 64 mm diameter) that did not have an overlying organic debris layer had notably higher DO levels as did less compact areas (G3 Consulting Ltd. 2002).

During February and March, 2013, DFO collected DO measurements at Sharon's (sub-beaches: Morgan's, Fraser's and Snag) beach and Haskins beach (Table 8). Spawning beach

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[2] Elvidge, R. 1979. Current findings of the 1979 study to determine the impact of foreshore development on sockeye spawning in Sakinaw Lake. DFO Internal report. 13 p.

[3] 30 day mean

groundwater quality was still above the concentrations described above, except for at Morgan's beach during the first two surveys conducted in February.

Spawning on all beaches occurs between 0.25 m and 25 m depth with 3 m to 10 m depth having the greatest density of redds. Based on spawning habitat area estimates (3,000 m^2) and Sockeye redd size (0.94 m^2) and the area required to spawn (2.5 to 3 m^2), there is space for 1,000 to 1,200 females to spawn simultaneously. Spawning habitat is not currently limiting and other spawning habitat restoration/ enhancement opportunities exist at the spawning beaches.

The Ruby beach spawning area has had limited use (0 to 6 annual spawners) during the last 30 years. It is believed to be negatively impacted by the level of lake flooding and subsequent infilling with soft sediment and aquatic vegetation, greatly reducing the quality of the spawning habitat. Spawning at Kokomo and Prospectors beaches is known to have occurred in the past (1979) but does not currently. Although there are historical observations of Sockeye spawning occurring at Prospectors beach, it has been noted that this beach does not have similar habitat properties to the other beaches and there is some doubt whether it was ever a Sockeye spawning beach due to a very thick layer of mud (J. Wilson, pers. comm.). It is possible that the area surveyed in 1979 is not the exact same area as what has been surveyed more recently.

DFO has undertaken recent restoration efforts to enhance spawning habitat at known beaches (Sharon's and Haskins), including clearing of fallen trees from original flooding, woody debris, large rocks and accumulated sediment and loosening of compacted gravel from marked redds (DFO 2015a).

FRESHWATER REARING HABITAT

The lake covers an area of 6.9 km^2 and has a mean depth of 43 m with a maximum depth of 140 m. The euphotic zone is approximately 15 m in depth (Shortreed et al. 2003). Sakinaw Lake is unique compared to most other lakes in that it has layers that do not mix (i.e., meromictic), with a 30 m freshwater layer overlying an anoxic, salt water layer. The lake's upper basin is not meromictic (Shortreed et al. 2003). The upper 7 m (thermocline) of the water column becomes very warm (23 °C) during the summer and decreases to 5 °C at 40 m depth (Shortreed et al. 2003). From 10 to 20 m depth the temperature is between 6 °C and 13 °C. In early October of 1977, Stockner and Shortreed (1978) found a surface temperature of 16.5 ºC and thermocline depth of 10.0 m, suggesting that the seasonal thermocline in Sakinaw Lake has a prolonged duration.

Juvenile Sockeye Salmon prefer temperatures of 11 °C to 15 °C while their optimum temperature for growth with unlimited food is 15 °C (Beschta et al. 1987). Juveniles will migrate to avoid temperatures above 17 °C and as a result the amount of lake rearing volume available to juvenile Sockeye might be smaller during 'warm' periods (COSEWIC 2003, Sakinaw Sockeye Recovery Team 2005).

At all stages of their life cycle Sakinaw Sockeye require a sufficient food supply. When Sockeye fry emerge from the gravel they generally move to deeper waters with age to feed on zooplankton in the upper 20 m (Murray and Wood 2002, Sakinaw Sockeye Recovery Team 2005).

Sakinaw Lake is a very productive lake relative to other coastal BC lakes, but less productive relative to Fraser River system lakes (Stockner and Shortreed 1978, Shortreed et al. 2000). Chlorophyll *a* concentrations greater than 2 mg/m^3 have been observed (Shortreed et al 2003). Zooplankton biomass can exceed 1000 mg/m^3 during summer and 500 mg/m^3 during fall (Shortreed et al. 2003, Hume et al. 2005). Zooplankton biomass peaks at 15 m depth (Shortreed et al. 2003).

Shortreed et al. (2000) used a photosynthetic rate model to estimate that Sakinaw Lake could support 2.5 million smolts, assuming no competition, but this is believed to be an overestimation (Kim Hyatt, DFO, Nanaimo, BC, pers. comm.). Further data analysis, and perhaps data collection, is needed to determine the carrying capacity of Sakinaw Lake.

Sockeye fry are planktivorous and feed pelagically. Little is known about deep water use by feeding fry. Deeper water habitat for rearing of juveniles occurs throughout the lake. In the upper basin there is no anoxic monimolimnion (saltwater layer) so it is possible that all depths are used. However, depths below 30 m in the lower basin are anoxic (Shortreed et al. 2003). The shoreline is not used by Sakinaw Sockeye fry.

SAKINAW CREEK AND FISHWAY

Sakinaw Creek has been identified as recommended critical habitat (Murray and Wood 2002, Godbout et al. 2004) as it connects Sakinaw Lake to the Strait of Georgia. Adult Sakinaw Sockeye only spawn in Sakinaw Lake, therefore they require that particular lake to survive. Sakinaw Creek is required for smolt migration out of the lake and adult migration into the lake (Figure 1).

The only barriers to access occur within Sakinaw Creek and at the mouth of the creek. Adult Sakinaw Sockeye can only migrate up the creek during high tides and predominantly only do this during the night. Otherwise, water levels within the creek below the fishway are too low for adults to swim up the creek. The fishway also acts as a barrier if it is not operated correctly and the doorway is closed which blocks adult migration, although it is believed that some adults have jumped over the weir in the past.

Smolts leaving the system pass through piping at the weir where they are collected in a box and enumerated. If the smolt enumeration program is operational the weir does not act as a migration barrier for smolts as staff maintains the piping and release the smolts after being counted.

MARINE REARING HABITAT

Marine habitat requirements for Sakinaw Sockeye are similar to other Pacific salmon species. They require unrestricted ocean corridors and feeding grounds of appropriate temperature and productivity (Foerster 1968; Burgner 1991). The majority of Johnstone Strait, Strait of Georgia and Juan de Fuca Strait have the nearshore habitat properties required by Sakinaw Sockeye smolts and adults. Although climate-driven natural variability in ocean productivity will influence the survival of Sakinaw Sockeye, management of habitat in marine areas other than the migratory corridor is unlikely to be possible, and we do not discuss these habitats further. In the ocean they are typically found in waters between 3.3 °C and 13.3 °C (Azumaya et al. 2007) and shallower than 15 m depth. The upper salinity limit for Sockeye is 34.5 psu (Azumaya et al. 2007).

Element 7: Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence.

Under SARA, a residence is defined as a dwelling-place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating (SARA section 2.1). DFO's Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk (DFO 2015b) uses the following four conditions to determine when the concept of a residence applies to an aquatic species:

1. there is a discrete dwelling-place that has structural form and function similar to a den or nest,
2. an individual of the species has made an investment in the creation, modification or protection of the dwelling-place,
3. the dwelling-place has the functional capacity to support the successful performance of an essential life-cycle process such as spawning, breeding, nursing and rearing, and
4. the dwelling place is occupied by one or more individuals at one or more parts of its life cycle.

Based on the guidelines above, redds most closely match the criteria for a residence because they are constructed and used in consecutive years. Redds have a structural form and function of a nest, the female has invested energy in its creation, redds are essential for successful incubation and hatching of the eggs, and redds can contain hundreds to a few thousand eggs from a female salmon. As mentioned previously, spawning beaches have been identified in Sakinaw Lake. Redds located within these areas could be considered residences.

THREATS AND LIMITING FACTORS TO SURVIVAL AND RECOVERY OF SAKINAW SOCKEYE

Element 8: Assess and prioritize the threats to the survival and recovery of Sakinaw Sockeye.

Element 9: Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities.

Element 10: Assess any natural factors that will limit the survival and recovery of Sakinaw Sockeye.

Element 11: Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps.

To assess and prioritize the threats and limiting factors to the survival and recovery of Sakinaw Sockeye a threats and limiting factors analysis workshop was held (December 15th and 16th, Nanaimo, BC). An expert panel including: DFO research scientists; salmon stock assessment biologists; Salmon Enhancement Program managers and hatchery staff; Fisheries Management; representatives from Sechelt First Nation; Sunshine Coast biologists familiar with Sakinaw Sockeye; and a representative from the Sakinaw Lake Community Association, met during this workshop and discussed the various threats, limiting factors and activities that affect the Sakinaw Sockeye population and habitat. Threats and limiting factors were scored based on current and future biological risk. Biological risk is determined from two variables: Exposure and Impact. The term “exposure” is synonymous with the term “likelihood” which is used in some risk assessment methodologies, while the term “impact” is synonymous with the term “consequence.” Current biological risk is based on present day biological risk. Future biological risk is based on conditions anticipated 50 years into the future. The certainty/confidence associated with the current biological risk was also scored. Mitigation options to address the higher risk limiting factors and activities were also proposed. Mitigation and monitoring of threats and limiting factors that currently exists are also described below. A summary of the workshop is provided in APPENDIX A – SAKINAW SOCKEYE THREATS AND LIMITING FACTORS WORKSHOP SUMMARY. Scores from the workshop were later adapted to DFO’s (2014b)

Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk scoring matrices.

Threats are defined as anthropogenic activities that negatively affect the productivity of Sakinaw Sockeye. Limiting factors are defined as natural (i.e. abiotic or biotic) factors that negatively affect their productivity.

For completeness and due to the magnitude that limiting factors affect the survival and recovery of Sakinaw Sockeye, the potential ecological impacts of limiting factors are also discussed below.

THREATS

Habitat Degradation

Habitat integrity degraded sufficiently to negatively impact all juvenile stages, smolt staging, rearing or early seaward migration requirements

Habitat degradation affects terminal migration and spawning, freshwater incubation, and freshwater rearing. This threat was scored as a low population-level threat risk (Table 9).

Ecological Impacts: Degradation of freshwater habitat was not identified as a possible factor affecting Sakinaw Sockeye productivity during the threats analysis workshop; however, it was by COSEWIC (2016). Sakinaw Lake was used as a log dump, millpond and booming ground as part of logging activities in the area. The majority of this impact occurred in the 1950s and 1960s and productivity remained relatively high after this. These activities lead to the accumulation of debris on spawning beaches by covering potential spawning gravel or by increasing incubation losses because of siltation and poor gravel porosity which interferes with the delivery of oxygenated water and the removal of metabolic wastes (Murray and Wood 2002). Groundwater dissolved oxygen concentration at Sakinaw Lake spawning beaches is sufficiently high enough for Sockeye Salmon egg incubation (Table 8). Forestry is ongoing within the Sakinaw catchment. Impacts from recent forestry are considered to be negligible.

Upland development and other shoreline development that affects creek inflow volume and routes, and groundwater supply will reduce spawning habitat quality. Upland development also has the potential to cause erosion of stream banks and increase the transport of fine sediment and debris into the lake. Therefore, shoreline and upland development have the potential to decrease the quality and stability of spawning gravel which would decrease egg and alevin survival. The removal of riparian vegetation may contribute to lake warming, which may increase adult and egg mortality. However, spawning and holding depth is believed to be deep enough to not be affected by relatively small increases in water temperature. There has been no development near any spawning beaches since the 1960s and that only occurred adjacent to Haskins Beach; therefore, this activity is considered a negligible threat.

Rain on snow events increase sediment and surface water run-off. In 1992 a large spawn was buried under tons of material washed out of the creek at Sharon’s beach during a spring rain on snow flood event (Murray and Wood 2002).

Historically, Sockeye Salmon spawning occurred at 5 beaches in Sakinaw Lake (Sharon’s, Haskins, Ruby, Kokomo and Prospectors)(Figure 3). Currently, spawning only occurs at the four sub-beaches at Sharon’s and at Haskins. A survey at Ruby beach in 2001 found that it was not being used. Ruby, Kokomo and Prospectors beaches are of poor quality for spawning (surveys as reported in Murray and Wood 2002). During 2003 and 2004, dive surveys assessed nine different sites around the lake. Suitable spawning habitat and conditions were identified, yet some sites appeared not to be used. The upland area from Sharon’s Beach has been owned by the same family since 1952, and has shown no impacts by residential development or logging. Spawning habitat at this site, however, has been affected by falling trees and heavy woody debris. DFO has undertaken recent restoration efforts to enhance spawning habitat at known beaches (Sharon's and Haskins), including clearing of fallen trees from original flooding, woody debris, large rocks and accumulated sediment and loosening of compacted gravel from marked redds.

In the 1960s, Haskins Creek and Boat Ramp Creek were moved to allow for property development and to build a boat ramp, respectively (Figure 3). They used to share a common entrance into the lake and the original creek channel is still visible in the lake about halfway between the newer mouths of the two creeks. Spawning Sakinaw Sockeye still frequent the remnant creek channel as it is about 6 m deep and likely still has groundwater flow in the original channel bed, providing an attractant for fish to the area.

Spawning habitat has been affected by maintaining lake levels with the dam. The lake outlet has been partially or completely blocked since the early 1900s by dams built for log and water storage. A permanent dam and fishway were constructed by DFO on the outlet in 1952. Since then, lake levels have been regulated to store water for the Sockeye migration and indirectly the developing recreational and cottage community. Maintaining the lake levels within a relatively stable and unnatural range has led to increased vegetation, fine sediment and accumulation of woody debris on the spawning beaches, particularly at Ruby and Prospectors beaches. The degradation of beach habitat was confirmed by a local resident who stated that the gravel and beach at Ruby Lake were much cleaner in her youth and there used to be less aquatic vegetation than there is now (S. Bushell, Sakinaw Lake, pers. comm. from Murray and Wood 2002). The bay at Ruby beach has visible gravel at a depth of <1m and Coho and Cutthroat regularly spawn there but it is rare to see a Sockeye in that shallow of water, although a few have been seen in the area over the years. The lake bottom drop off at Ruby beach is where one would expect spawning to occur, based on Sakinaw Sockeye use of other beaches, but the vegetation is now too thick and the beach is no longer usable (G. McBain, DFO, pers. comm.). Restoration work at spawning beaches, since the sockeye population declined, has improved the extent of spawning habitat.

Overall, freshwater habitat degradation is currently believed to have a low population-level threat risk.

Ongoing Monitoring: Annual dive surveys are conducted at the spawning grounds in Sakinaw Lake and the condition of the spawning habitat is assessed to determine whether additional habitat restoration is required.

Knowledge Gaps: Spawning ground dive surveys have never gone deep enough to determine whether spawning occurs at depths deeper than 12 m. If extra dive time was possible it would be beneficial to dive on the main spawning beaches during peak spawning to see if the beaches are used at deeper depths.

Dive surveys conducted in 1979 by DFO identified the outflow to Penny Lake (immediately adjacent to Kokomo beach) as a spawning site (DFO 1980) but this site has never been surveyed since.

Co-occurring Species: Kokanee spawn at similar beaches to the Sockeye, therefore, degradation to Sockeye Salmon spawning habitat is likely degradation to the kokanee habitat as well.

Fishing

Increased adult mortality due to terminal fisheries

Fishing was scored as a low population-level threat risk (Table 9).

Ecological Impacts: Sockeye Salmon migrate back to Sakinaw Lake through Johnstone Strait. They share this migration corridor with other Sockeye Salmon populations including those returning to lakes in the vicinity of Johnstone Strait (Nimpkish, Heydon, Phillips and Village Bay lakes) and the “northern diversion” component of Sockeye returning to the Fraser River. The northern diversion refers to the proportion of returning Fraser Sockeye migrating through Johnstone rather than Juan de Fuca Strait.

The overall intensity of mixed-stock fishing in Johnstone and Georgia straits generally increased until the late 1990s in response to high abundance and high diversion rates of Fraser River Sockeye Salmon through Johnstone Strait. Although fishing effort as measured by fishing days has declined, technology has increased the efficiency of seining. Gillnet fishing effort also increased in the 1980s. Murray and Wood (2002) provide a detailed description of the fishery. However, increased fishing effort in mixed-stock fisheries does not necessarily imply increased fishing mortality on small populations like Sakinaw Sockeye. Fishing effort is regulated based on test-fishing indices of the abundance of large Fraser River Sockeye populations.

Sakinaw Sockeye have been killed both as directed catch in terminal fisheries and as incidental catch in mixed-stock fisheries targeting larger populations of Sockeye and Pink Salmon (*O. gorbuscha*). Various estimates of Sakinaw Sockeye exploitation rate have been made (Starr et al. 1984, Murray and Wood 2002, and M. Folkes, DFO, unpublished data, D. O’Brien, DFO, unpublished data). A summary of exploitation rate estimates is provided in Table 6. Starr et al. (1984) concluded from run reconstruction analyses that total exploitation rates on Sakinaw Sockeye varied from 20 to 67%, averaging 41% between 1970 and 1982. Murray and Wood (2002) estimated exploitation rates on Sakinaw Sockeye to average from 49 to 57% (depending on assumption about migration rate) between 1986 and 1989, and 89 to 99% between 1993 and 1994. Additional estimates of exploitation rate for Sakinaw Sockeye Salmon were done by Folkes et al. (2006, 2012, 2013 all unpublished data). The 2004 exploitation rate was estimated at 15% and the 2005 rate at 4%. Following the extirpation of the population in the wild between 2006 and 2009 and returns of fish from the captive breeding program in 2010 and 2011, the estimated exploitation rate in 2010 was between 15 and 21% depending on the assumption around the smoothing of the daily harvest rates. The average exploitation rate for Sakinaw Sockeye was 5% from 2011 to 2015. Inevitably, fishing mortality will continue to be a threat to any rebuilding of the Sakinaw Sockeye population despite the reductions in fisheries since 1998 aimed at protecting threatened populations of various salmonids.

Ongoing Monitoring: Salmon test fishery samples are collected annually and analyzed for DNA, age, and sex.

Knowledge Gaps: There is uncertainty in the exploitation rate estimates. Analyses of test fishery data to determine exploitation rate have a lot of uncertainty during years with very low returns (e.g. 1999 onward). There has also been no sensitivity analysis of exploitation rates to changes in migration timing. The estimates also assumed a 100% northern diversion of Sakinaw returns.

The number of Sakinaw Sockeye caught by Aboriginal groups in food, social and ceremonial (FSC) fisheries is unknown because there is no sampling program (e.g. DNA sampling) for fish caught in these fisheries.

Co-occurring Species: Fraser River Sockeye and Pink Salmon are predominantly targeted during the fishery.

Pollution

Elevated mortality or sub-lethal effects due to aquatic pollutants (LF31)

This threat was determined to be a medium population-level risk with low confidence (Table 9).

Ecological Impacts: With the current volume of hydrocarbons shipped in the Johnstone Strait and the Strait of Georgia it is likely that the small volumes of aquatic pollutants that are shipped by barge or in small vessels (e.g. tug boat, fishing vessel), relative to tankers, would only pose a medium threat. A hydrocarbon release could negatively affect the migratory habitat (marine rearing habitat) of smolts and adults.

If marine shipping traffic were to increase in the future then the risk level would increase as well. There is the potential for shipping of oil and gas to increase from the Vancouver area in the future, which will increase the probability that a spill will occur. Again, this threat will have the greatest effect if the spill overlaps spatially and temporally with fish migration routes. Due to tidal action, oil spill modeling shows that larger spills that could potentially occur near Vancouver would affect the Vancouver area, south to the Gulf Islands and into Juan de Fuca Strait (Rosenberger 2013).

Activities that Threaten Habitat: Activities within the Georgia Basin, such as shipping, farming and industry contribute pollutants to the marine environment as a result of collisions, spills, loss of ships at sea, coastal runoff and direct water discharge. The effects of these activities are believed to be very low within Sakinaw Lake but they likely have a larger effect in the Georgia Basin.

Knowledge Gaps: The fate in water and ecological effects of hydrocarbons such as bitumen are unknown. The degree of pollutant concentration, bioaccumulation and effects are largely unknown in the Georgia Basin.

Co-occurring Species: This threat would negatively affect Coho Salmon, Kokanee that migrate to the ocean, and sea-run Cutthroat Trout, if they occur in Sakinaw Lake. Abating this threat would reduce the magnitude of the effect on these populations if a spill were to occur. It would also likely increase the productivity of these species due to chronic, sub-lethal effects that can occur due to aquatic pollutants.

LIMITING FACTORS

Competition and Predation

Large losses due to predation during terminal migration and spawning (LF1)

Losses of adult Sockeye Salmon to predation were determined to be a high population-level threat risk. Confidence in the risk was high (Table 10). Among potential mammalian predators are River Otters, seals, Sea Lions, Mink, bears and Killer Whales (DFO 2015a). River Otters and seals have been an ongoing concern in the estuary, though seals do not enter the creek or lake.

Ecological Impacts: River Otters were identified as the greatest predation concern overall. They feed on adult Sockeye Salmon in Sakinaw Creek and fishway. It is unknown how many Sockeye Salmon are killed annually within Sakinaw Creek or in the estuary. However, during 2011, 37 kills of adult Sakinaw Sockeye were observed on video at the fishway and 8 other fish were observed being chased. In 2012, approximately 25 fish were observed being killed (J. Wilson, pers. comm.), and during 2015, 5 were killed and 2 were observed being chased. It is likely that more are killed each year but the total number is unknown. While the Sakinaw Sockeye returns are so low, the depensatory nature of mortality due to River Otters is a concern.

Ongoing Monitoring: Staff is present during the night at the fishway for adult migration. Predators are scared away from the creek when they are observed.

Knowledge Gaps: There are no data on the number of River Otters or other predators within the area and it is unknown exactly how many Sakinaw Sockeye are killed by River Otters or other predators each year.

Co-occurring Species: Kokanee that migrate to sea and sea-run Cutthroat would be negatively affected by this limiting factor. If this limiting factor was abated then these species would benefit.

Predation on eggs and alevins during freshwater incubation(by sculpins, Cutthroat Trout, Peamouth Chub, Coho, birds, etc.) (LF14)

Predation on Sakinaw Sockeye eggs and alevin was scored as a high population-level risk with low confidence in the scoring (Table 10).

Ecological Impacts: Fish predators of Sockeye eggs and alevin include Cutthroat Trout, juvenile Coho and Chinook Salmon, Prickly Sculpin and Peamouth Chub. Depensatory mortality is likely occurring as the number of spawners has drastically decreased and the number of spawning beaches has also decreased, thus concentrating predators at two spawning beaches. Peamouth Chub and Sculpin predation on Sakinaw Sockeye eggs has been observed at high levels in Sakinaw Lake (J. Wilson, pers. comm.). Cutthroat Trout have been seen milling about the spawning beaches (D. Bates, Sechelt First Nation biologist, pers. comm.).

Knowledge Gaps: The effect of competition on the Sakinaw Sockeye population is unknown. Sculpin predation on Sockeye eggs has been shown to be as high as 25% in an Alaskan lake (Foote & Brown 1998).

Co-occurring Species: It is unknown where Kokanee spawn in Sakinaw Lake. It is likely that at least a portion of the population spawns along beaches and experience predation on their eggs from. Therefore, this limiting factor would affect Kokanee as well and if it abated it would benefit their productivity.

High levels of competition or predation (from native or exotic spp.) reduce lake carrying capacity for wild fry-smolts (LF21)

A reduction in the lake carrying capacity for wild fry-smolt survival due to high levels of competition was determined to be a medium population-level risk (Table 10). Confidence was low for current biological risk. Hatchery fry to smolt survival averages 14% and natural origin survival is estimated to be 19%, which is relatively low compared to other coastal BC lakes. The reason(s) for these relatively low survival rates is unknown. Based on the primary and secondary productivity of Sakinaw Lake, fry and smolt carrying capacity of the lake should not be a factor (Shortreed et al. 2000, Hume et al. 2005).

Ecological Impacts: Cutthroat Trout are important predators of young Sockeye Salmon year-round (Foerster 1968). From 1965 to 1987 the British Columbia Fish and Wildlife Branch stocked Sakinaw Lake with over a quarter million juvenile (0.6 to 30.3 g) Cutthroat Trout. Increased Cutthroat Trout populations in Sakinaw Lake would have increased the mortality rate on Sakinaw Salmon fry and smolts (Murray and Wood 2002). As Cutthroat Trout grow larger they occupy the limnetic zone and become increasingly piscivorous (Nowak et al. 2004). The magnitude of the effect of Cutthroat Trout on Sakinaw Sockeye is unknown. In Lake Washington, Washington, Sockeye Salmon fry only made up 1% of the winter and spring diet of Cutthroat Trout (Nowak et al. 2004). The same study found no fry predation in Cutthroat Trout larger than 400 mm and the authors suggest that Sockeye Salmon fry that move to the limnetic zone may reduce their risk of predation and thereby avoid littoral predators, such as small Cutthroat Trout, juvenile Coho salmon, rainbow trout, and Prickly Sculpin. In contrast, it also been observed that 40% of the diet of Cutthroat Trout in Lake Ozette, Washington consisted of Sockeye Salmon during spring and summer (Beauchamp et al. 1995). Furthermore, it is possible that in the absence of an abundant Sockeye Salmon population, the Kokanee population may have increased to fill the historical niche of juvenile Sockeye Salmon, creating greater competition (Beauchamp et al. 1995).

Knowledge Gaps: There has not been a limnetic survey of the lake since 2004 (Hume et al. 2005) so the abundance of Cutthroat Trout, Kokanee and other potential predators and competitors is unknown.

Co-occurring Species: If this factor abated it would likely result in negatively affecting the population size and/or productivity of Cutthroat Trout.

Variable food-web structure (species changes) leads to sub-average carrying capacity for fry-smolts (LF18)

This factor was scored as a medium population-level risk. Confidence was low for the current biological risk (Table 10).

Ecological Impact: As previously mentioned there is a fry to smolt survival issue in the lake. Mysids (*Neomysis* spp.), freshwater shrimp, are a competitor of Sockeye Salmon fry (Hyatt 2004, Hyatt et al. 2005) but were only present within the Upper Basin at very low density ($0.05/m^3$) during a 2004 limnetic survey of Sakinaw Lake (Hume et al. 2005). A limnetic survey has not been conducted since so seasonal and annual variability is unknown. Furthermore, the trawl net used during the survey was only able to detect presence or absence and was not ideal for quantitative sampling (Hume et al. 2005).

Knowledge Gaps: There is no evidence that food availability is affecting survival; however, it is a knowledge gap due to the lack of a data time series.

Co-occurring Species: Other species, such as Coho Salmon, Kokanee and Cutthroat Trout, are likely negatively affected by this limiting factor. If it abated, these species would likely be more productive.

Predator abundance and assumed levels of predation on smolts and adults exceed reference range. State change is associated with reduced survival and well below average adult returns (LF33)

Predation on smolts was scored a high population-level risk with high confidence (Table 10).

Ecological Impacts: Seals and Sea Lions are seen in the estuary and believed to be increasing in abundance in the area which would increase mortality for Sakinaw Sockeye smolts and adults (S. Quinn, Sechelt First Nations, pers. comm.). There is a seal haul out at Daniel Point, which used to have a fish farm nearby during the 1980’s but had to close due to a seal and Sea Lion predation problem (D. Bates, FSCI Biological Consultants, pers. comm.). Depensatory mortality could be a factor. If predation by seals and Sea Lions was abated, it could likely increase early marine survival of Sakinaw Sockeye.

Knowledge Gaps: Data are limited on the abundance of seals and Sea Lions in the estuary and Johnstone Strait. It is unknown how many Sakinaw Sockeye are taken by seals and Sea Lions.

Co-occurring Species: This limiting factor likely affects Coho Salmon, Kokanee that migrate to the ocean, and sea-run Cutthroat Trout, if they occur in Sakinaw Lake. Reducing this factor would increase the productivity of these species.

Competition exceeds historic reference range and is associated with density dependent growth or survival outcomes that are negative for Sakinaw Sockeye (LF29)

Competition with other species was scored as a high population-level risk. Confidence was low (Table 10).

Ecological Impacts: Competition at sea between Pink and Sockeye Salmon is believed to have a negative effect on Sockeye Salmon recruitment (Ruggerone et al. 2003, Ruggerone and Connors 2015). Furthermore, during their first year at sea, early marine scale growth of two Fraser river Sockeye Salmon populations (Chilko and Birkenhead lakes) has been shown to be negatively correlated with regional abundances of juvenile Pink Salmon (McKinnell and Reichardt 2012). High levels of competition in the marine environment would reduce the productivity of Sakinaw Sockeye. It is likely that there is a near-field (Georgia Basin) effect and a far-field (Gulf of Alaska) effect. Reducing competition would likely increase Sakinaw Sockeye productivity.

Knowledge Gaps: It is unknown to what extent this limiting factor affects Sakinaw Sockeye and what competition was historically.

Co-occurring Species: It is uncertain whether abating this factor would increase the productivity of Coho Salmon.

Parasitism

Parasitism incidence reduces the lake carrying capacity for wild fry-smolts (LF22)

A reduction in the lake carrying capacity for wild fry-smolt survival due to high rates of parasitism was determined to be a medium population-level risk. Confidence was low for current population-level risk (Table 10).

Ecological Impacts: Hatchery fry to smolt survival averages 14% and natural origin survival is estimated to be 19%, which is relatively low compared to other coastal BC lakes. Smolts measured at the fence are large relative to other smolt populations and their length has not changed over time (Figure 5). Furthermore, on average, 3.5% of smolts counted at the dam have a lamprey scar (Figure 15). Although this rate of parasitism is very low, it is possible that a significant portion of those individuals that are parasitized do not survive to outward migration.

Knowledge Gaps: The abundance of lamprey within Sakinaw Lake is unknown, as is their impact on Sakinaw Sockeye fry and smolts.

Co-occurring Species: Coho Salmon observed at the Sakinaw Creek fishway have a moderate level (25%) of lamprey scarring. Abating this limiting factor would increase Coho Salmon productivity as well as other species that are also likely affected by parasitism, such as Kokanee and Cutthroat Trout.

Parasite or pathogen incidence and impacts on growth or survival expressed at epidemic levels associated with below average growth, survival and adult returns (LF35)

Parasites and pathogens characterized as a medium risk. Confidence was low for current biological risk (Table 10).

Ecological Impacts: This limiting factor is likely a predominantly near-field effect in the Strait of Georgia. Smolts leaving Sakinaw Lake are not currently tested for pathogens. The proportion of out-migrating smolts that have had copepods on their gills has been low (< 15%) in most years (Figure 16). The exceptions were in 2005 when only 8 fish were sampled and half had copepods, 2010 when 24% had copepods (392 fish sampled) and 2015 when 41% had them

(302 fish sampled). Copepods would stress the smolts in the freshwater environment as they migrate into the ocean and could potentially be exacerbating the effects of pathogens and other factors affecting marine survival. Reducing the frequency of infestation on Sakinaw Sockeye smolts could increase marine survival but the degree to which the parasite affects Sakinaw Sockeye smolts is unknown. However, salmon infected with similar parasites have shown increased epithelial cell necrosis, gill inflammation, and decreased growth rate and size (Nolan et al. 1999, Ferguson et al. 2012). The proportion of out-migrating smolts with copepods on their gills is presented in Figure 16 and Table 11.

Knowledge Gaps: The number of Sakinaw Sockeye infected with pathogens, if at all, as juveniles or adults is unknown. It is unknown to what extent parasites decrease the survivorship of Sakinaw Sockeye.

Co-occurring Species: The magnitude to which this factor affects co-occurring species is unknown. However, assuming parasites and pathogens occur in Coho Salmon, Kokanee and Cutthroat Trout as well, abating this limiting factor would increase the productivity of these species.

Changing Ocean Conditions

"Warm ocean" food webs favour below average smolt-to-adult survival and below average returns (LF32)

"Warm ocean", i.e. low production food webs were characterized as a high population-level risk with medium confidence (Table 10).

Ecological Impacts: Low production regimes occurring in the Georgia Basin and the northeast Pacific Ocean can negatively affect Sakinaw Sockeye. Marine survival is believed to be the predominant limiting factor in the recovery of Sakinaw Sockeye. The average smolt to adult survival rates are 0.23% for hatchery fish and 0.49% for wild fish, which are insufficient to sustain the population without hatchery supplementation. With all other factors being equal, smolt to adult survival needs to be at least 5.25% to achieve a return per spawner ratio greater than 1. The only early marine survival data available is from 2004 and 2006 (Wood et al. 2012). In 2004 and 2006, 18% and 10%, respectively, of tagged smolts made it from Sakinaw Lake to the north end of Vancouver Island.

It was suggested during the threats and limiting factors analysis workshop that Sakinaw Sockeye experience greater early marine survival relative to other nearby populations because they spend more time in the Strait of Georgia. Wood et al. (2012) found was that Sakinaw Sockeye smolt migration route and timing through the Strait of Georgia was similar to that reported for upper Fraser River Sockeye populations. Due to the unexpectedly high survival of tagged fish that did not leave the Strait of Georgia, the authors concluded that factors outside the Strait of Georgia must be causing the extremely low marine survival of Sakinaw Sockeye smolts that migrate to the north Pacific Ocean.

Knowledge Gaps: It is unknown if or when marine survival for Sakinaw Sockeye will increase. Sakinaw Sockeye appear to have similar variability in marine survival to other Sockeye stocks (e.g. Birkenhead Lake); however, the average marine survival for Sakinaw is relatively depressed (DFO, unpublished data).

Co-occurring Species: Reducing this limiting factor would likely benefit Coho Salmon.

HATCHERY CONSIDERATIONS

Hatchery practices are an important consideration in the survival of Sakinaw Sockeye. Improved hatchery practices can increase the survival of the release Sakinaw Sockeye. The captive breeding program was the only source of Sakinaw Lake Sockeye with which to re-establish a natural population once the original population was extirpated from the lake for an entire four year cycle. Clearly, the hatchery program has been beneficial to maintenance and restoration of the natural Sakinaw Lake Sockeye population to this point.

High mortality of hatchery fry to smolt stage (LF39)

Hatchery fry to smolt mortality was characterized as a medium population-level risk with medium confidence.

Fry released into Sakinaw Lake are reared in Rosewall hatchery. Rosewall hatchery uses a groundwater supply to rear Sakinaw Sockeye fry. Groundwater stays at a consistent low temperature throughout the year, leading to relatively slow fry growth and later releases as compared with hatcheries that source surface water. Ouillet hatchery, which was closed in 2015, also reared Sakinaw Sockeye fry, but sourced its water from a surface supply. Surface water will increase in temperature throughout the spring and summer as air temperature increases. Warmer water temperatures increase the growth rate of Sockeye Salmon fry which allows them to be released earlier relative to fish raised in groundwater. This also acclimatizes them to warmer temperature lake water when they are released during the late spring and summer and increases fry to smolt survival. The fry survival data since 2003 indicate that the earlier June releases from Ouillet (28%) survive at double the rate of the Rosewall fry (14%). The difference in survival is possibly due to the fact that earlier released fish (Ouillet fry) are being released into lake water that is approximately 15 °C compared to late June fish (Rosewall fry) that are being released in 24 °C water.

Low hatchery fry to smolt survival is also possibly due to release strategy. Before 2012 fry were released over warm, shallow water near the shore. It was believed that this was contributing to the low hatchery fry to smolt survival as the fry became trapped in this warm, upper layer of water. Since 2012, fry have been released over deeper water where fish can swim directly downward to cooler water; however, increases in fry to smolt survival have not been observed (Figure 10). Large numbers of dead fry are not seen floating at the surface when they are released over deep water, but large mortality events have been observed when releasing fry at the shoreline. There are no data or known reasons for the Sakinaw Sockeye fry release locations.

High mortality of hatchery smolt to adult stage due to domestication and lowered fitness (LF40)

This factor was scored as a medium population-level risk with high confidence. Hatchery fish generally have lower marine survival relative to the wild population (Berejikian and Ford 2004, Beamish et al. 2012). This is also the case for Sakinaw Sockeye.

The Sakinaw Sockeye population was extirpated from the wild between 2006 and 2009, and all Sakinaw Sockeye Salmon (hatchery and natural origin) now originate from a captive breeding program maintained at Rosewall Creek Hatchery and established with 84 parents between 2002 and 2005 (Withler et al. 2014). Since 2010, small numbers of adult fish from the captive breeding program have returned to Sakinaw Lake in each year. Since 2010, the focus has been to facilitate spawning of reintroduced Sockeye Salmon adults in the lake; no removals of fish for hatchery spawning have occurred. The captive breeding program has been maintained almost entirely by spawning fish propagated in the program itself, although milt was collected from some of the re-introduced male fish that returned to Sakinaw Lake in 2012 and used in the fertilization of eggs from captive females at Rosewall Creek hatchery.

The captive breeding program was the only source of Sakinaw Sockeye with which to re-establish a natural population once the original population was extirpated from the lake for an entire four year cycle. Clearly, the hatchery program has been beneficial to maintenance and restoration of the natural Sakinaw Sockeye population to this point. However, there are genetic concerns associated with captive programs and little evidence for the likelihood of restoring depleted wild populations with hatchery fish, especially if the conditions responsible for the original population decline have not been addressed (Fraser 2008).

Genetic factors of concern during captive rearing include:

- the small amount of genetic diversity remaining in the depleted natural population with which to establish the captive program,
- additional loss of diversity and inbreeding in captivity, and
- domestication, the adaptive alteration of the population conditioned by differential survival of genotypes in the hatchery environment (Frankham 1995).

The genetic diversity of the Sakinaw Sockeye population (measured with microsatellite loci) was decreased by the low number of parents (84) with which the captive breeding program was established. The genetic effective population size was reduced from approximately 500 in 1988 to 100 in the captive breeding program (Withler et al. 2014). There has been no additional loss of microsatellite diversity within the captive breeding program due to measures implemented in the captive program to avoid inbreeding and incorporate diversity from all 84 founding parents into the program (Withler et al. 2014).

Of more concern is the level of domestication that has occurred in the closed captive breeding program since its inception in the early 2000s. Since domestication is the process of the captive population becoming adapted to its current habitat (the hatchery), there is no way to avoid domestication of a captively-bred hatchery-maintained population. Moreover, the degree of domestication, and the associated loss of fitness or adaptation to the wild environment, cannot be measured with microsatellite loci. Fish being released from the program currently have been reared in captivity for at least four generations.

Reduction of domestication may benefit from equalization of family contributions to the brood animals each generation (Allendorf 1993) but minimization of the duration (number of generations) of captive breeding provides the most certain means of limitation (Williams and Hoffman 2009).

Ongoing supplementation of a nascent wild population (such as the re-introduced adult fish now returning to Sakinaw Lake in small numbers each year) with captively-bred individuals may stabilize abundance and minimize inbreeding in early generations of natural population recovery, but delay re-adaptation to the wild environment during natural population recovery (Lynch and O'Hely 2001, Ford 2002). Salmonid domestication has both environmental and genetic components (Ford et al. 2012) and the reduced reproductive success of captive individuals in the wild environment may persist past the first generation of natural spawning (Araki et al. 2009). Realistic accounting for reduced fitness of captive salmon in the wild environment in salmonid population viability analysis indicated that the release of captively-bred individuals into rebuilding wild populations after four to six generations of captivity was as likely to prevent as to facilitate wild population recovery (Bowlby and Gibson 2011). Using this guideline, the Sakinaw Lake captive breeding program may be reaching a point in the near future at which the fish produced are of inadequate fitness to contribute substantially to rebuilding of the wild population. If this point is reached, it may be that the captive program should be viewed as detrimental (a threat) to the rebuilding wild population rather than as a benefit and the question of whether or not the program should continue needs to be addressed. However, until a sufficient number of captively-bred fry released to Sakinaw Lake return to the lake each year to produce sufficient naturally-spawned fry to re-build the population, the hatchery program must be viewed as beneficial to the population.

RECOVERY TARGETS

SURVIVAL AND RECOVERY THRESHOLDS

The terms "survival" and "recovery" are used frequently throughout the *Species at Risk Act* but are not defined within it. Survival and recovery are on a continuum of probability of persistence that ranges from the historical condition when human activity caused no effect to the lowest level where species survival is no longer possible.

As described in the Government of Canada's (2016) *Draft Species at Risk Act Policies: Policy on Survival and Recovery*, "the competent minister(s) will consider that a species at risk has an acceptable chance for survival in Canada when it has surpassed the following criteria, also known as the *survival threshold*.

The listed species is more likely to be above the survival threshold when it is:

- Stable or increasing over a biologically relevant time frame; and,
- Resilient: sufficiently large to recover from periodic disturbance and avoid demographic and genetic collapse; and,
- Widespread or has population redundancy: there are multiple (sub) populations or locations available to withstand catastrophic events and to facilitate rescue if necessary; and,
- Connected: the distribution of the species in Canada is not severely and unnaturally fragmented; and,
- Protected from anthropogenic threats: non-natural significant threats are mitigated; and/or,

As appropriate to its specific life history and ecology in Canada:

- Persistence is facilitated by connectivity with populations outside Canada, and/or habitat intervention for species that are naturally below a survival threshold in Canada."

Recovery cannot be defined by a single value but rather a range of options along a continuum of probability of persistence with lower and upper bounds.

The lower bound for recovery is considered the *minimum recovery threshold.* The minimum recovery threshold is characterized by the following criteria:

- The criteria for survival are met and/or exceeded; and,
- There is representation addressing the historical Canadian distribution of the species, endeavouring to capture the full range of its ecological and genetic diversity; and,
- The condition of the species is improved over when it was first assessed as at risk; and,
- Once achieved, perpetuation of the recovered state is not reliant on significant, direct and ongoing intervention to maintain populations.

The survival of Sakinaw Sockeye requires human intervention through hatchery release programs, and if current conditions change that result in improved marine survival, the current broodstock and fish that are currently spawning in the wild could serve as a basis that would allow for recovery to occur. However, in the absence of the hatchery release program, the species would likely become extinct.

In order to meet the meet the minimum recovery threshold criteria, Sakinaw Sockeye would need to be no longer reliant on human intervention to persist. Recovery targets and stock state indicators are proposed below for recovery planning.

Recovery targets and stock state indicators are proposed below for recovery planning.

Element 12: Propose candidate abundance and distribution target(s) for recovery.

PROPOSED TARGETS

Population recovery targets were initially proposed by the Sakinaw Sockeye Recovery Team (2005) to contribute to recovery planning. The timeline and objectives of the Recovery Team were as follows:

- 2004–2007: increase the annual number of spawners (including those removed for hatchery bloodstock) to no fewer than 500;
- 2008–2011: increase the number of naturally[1] produced spawners to no fewer than 500 annually, and;
- 2012–2017: ensure that by 2017, the mean population abundance in any four- year period exceeds 1000 naturally produced spawners, with no fewer than 500 naturally produced spawners in a year (Sakinaw Recovery Team 2005).

Due to the threats and limiting factors described above, these targets were not achieved. Distribution targets were not originally proposed. Since the initial abundance targets were proposed, extensive literature has been published which provided a basis for reviewing the existing targets (DFO 2005, Holt 2009, Holt et al. 2009, Holt and Bradford 2011, Holt 2012, DFO 2013).

Interim stock state indicators are based on recovery trajectory milestones, as recommended by DFO (2013), as they are a useful tool that can provide a valuable and measurable indicator to ensure rebuilding is occurring (Table 12). Total spawners throughout the text refers to the sum of wild and natural (i.e. not released from hatchery as fry) spawners. An interim stock state indicator for Sakinaw Sockeye of achieving continued growth in the generational average (i.e. population growth) by increasing total spawner abundance relative to the brood year (4 years prior) for at least 3 out of 4 consecutive years after the recovery plan is implemented is proposed. Similarly to 2005 targets, a proposed interim stock state indicator is to increase the average number of total spawners to no fewer than 500 over a four-year period with no fewer than 100 total spawners in a given year. The final interim stock state indicator is increasing the mean number of total spawners to no fewer than 1,000 in any four year period, with no fewer than 500 total spawners in any year is proposed.

Recovery targets based on benchmarks are also proposed (Holt et al. 2009, Holt 2009, Holt and Bradford 2011). First, S_{gen}[4] is proposed, which was determined to be an abundance that has a relatively low probability of extirpation (probability < 25%) over 100 years and (Holt 2009, Holt and Bradford 2011) and delineates between critical and cautious zones (DFO 2009). With respect to Sakinaw Sockeye, this is 2,440 spawners. Second, 80% S_{msy}[5] (4,470 spawners) is proposed as it differentiates between cautious and healthy zones in DFO's Fishery Decision-Making Framework Incorporating the Precautionary Approach (2009) and was also

[4] $S_{MSY} = S_{gen} \cdot \exp(a \cdot (1 - S_{gen}/b))$

[5] 80% $S_{MSY} = 0.8 \cdot (b \cdot (0.5 - 0.07 \cdot a))$

recommended by Holt et al. (2009). These recovery target values were calculated based on the relationship between wild and natural origin adult recruits and all spawners (Figure 17).

The proposed spawning distribution target is the three spawning beaches that Sakinaw Sockeye have most recently used. This includes Sharon's, Haskins and Ruby beaches. Ruby has not been used for spawning since the 1990s. During low abundances Sharon's is only used, and then during years of higher returns, Haskins is used as well. If the population recovered significantly, perhaps Ruby would be used again. It is possible that if the abundance returned to 2,440 or 4,470 spawners, Kokomo and Prospectors beaches would also be used.

POPULATION VIABILITY

MODEL DESCRIPTION

A population viability analysis (PVA) model developed for the Cultus Lake Sockeye population was modified for Sakinaw Lake Sockeye (Korman and Grout 2008). The model is a stochastic simulation model. The model is a two-stage life history model that is used to simulate the numbers of out-migrating smolts and returning adult Sockeye. The first stage predicts the number of smolts as a function of the number of spawners. The second stage predicts the number of pre-fishery recruits, spawners at the dam, and spawners reaching the spawning grounds based on the number of smolts, marine survival, harvest, and pre-spawn mortality rates (Appendix B and Appendix C).

The main intent of the analysis and model was to evaluate the population trajectory under current conditions and to determine freshwater and marine survival rates required to reach stock state indicators and recovery targets. It was also used to determine the efficacy of mitigation options to aid population recovery. The model simulates the abundance of emigrating smolts and returning adults based on a spawner-to-smolt stock recruitment model and density-independent marine survival and pre-spawn mortality rates (Korman and Grout 2008). The model tracks the abundance of 3 stock types (wild, natural and hatchery) resulting from wild and hatchery production. The full description of the original model is provided in Korman and Grout (2008).

The modeling exercise was useful for examining the relative benefits of alternate recovery options, estimating survival rates to have a sustainable population and for highlighting priorities for data collection and research. The total simulation period is 100 years with a 1,000 trials for each 100 year simulation.

Performance measures used to assess population trajectories of the number of spawning Sakinaw Sockeye are defined in Table 13. Modifications made to the Cultus Lake Sockeye model (Korman and Grout 2008) are described in Appendix B.

POPULATION VIABILITY UNDER PRESENT CONDITIONS

Element 13: Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current Sakinaw Sockeye population dynamics parameters.

The fate of Sakinaw Sockeye under current conditions (i.e. life stage survival and exploitation rates, etc.) was modeled. Current conditions included a 0.05 exploitation rate, a 0.1 pre-spawn mortality, a 0.14 hatchery fry to smolt survival rate, and Ricker α and β parameter values of 2.89 and 0.00033, respectively. The captive brood program will be 1900 adults in 2018 with one-third (633) female. The 1900 adults and sex ratio were used all simulations unless otherwise noted.

Under current conditions, Sakinaw Sockeye had a 27% probability of achieving stock state indicator 1, and a 0% probability of reaching all other stock state indicators and recovery targets (Figure 18, Figure 19, Figure 20 and Figure 21).

Element 14: Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.

The current area of spawning habitat is 3,000 m^2 (Table 14). This is enough area for 1,000 to 1,200 females to spawn simultaneously, which is sufficient for the current population with additional area for population growth, and is sufficient spawning habitat area for stock state indicators 2 and 3. To reach the recovery targets of 2,440 and 4,470 spawners (male and female combined), an additional 50 to 660 m^2 is needed for the former and 2,590 to 3,700 m^2 for the latter. Note that the whole population does not spawn simultaneously, thus the estimated spawning habitat required is a maximum.

The last spawning habitat survey was conducted in 2012 and Kokomo and Prospectors beaches were not surveyed (Table 14). It is likely that these two beaches need habitat restoration work before they are suitable for spawning as they have not been used in over 20 years. Therefore, more spawning habitat would need to be restored to achieve both recovery targets (2,440 and 4,470 spawners).

During the fall of 2016, more spawning habitat restoration work was conducted but the area of habitat created is not yet available. There are more opportunities for spawning habitat restoration at Sakinaw Lake. Furthermore, only two of the five historical spawning beaches are currently used but it is believed that the other three beaches would be used once the available spawning habitat at the two currently used beach is fully utilized.

POPULATION VIABILITY SCENARIOS

Element 15: Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.

Population viability scenarios were assessed using the PVA model by varying marine (smolt to spawner) and freshwater (fry to smolt) survival rates (Table 15). Exploitation (5%) and pre-spawn mortality (10%) rates remained constant. The marine survival rate was increased incrementally from 0.49% to 1%, 2%, 3%, 4%, 8% and 12% while freshwater survival was increased by 1.5 and 2 fold for each marine survival rate scenario. The probability of extinction was low for all scenarios due to the continued operation of the captive brood program (Table 15). Increasing freshwater and marine survival increased the probability of increasing the population abundance relative to the previous generation; however the probabilities remained between 25% and 30% for both natural and wild spawners (Figure 19).

Increasing marine survival to 4% with current freshwater survival rates resulted in achieving stock state indicator 2 with 39% probability and stock state indicator 3 with 6% probability. Doubling freshwater survival increased the probability of achieving stock state indicator 2 to a 75% probability at 4% marine survival. Sakinaw Sockeye marine survival has not been observed as high as, or near, 4% in over 15 years (Figure 13) and it is unknown if it will be this high in the future. Increasing marine survival to 8% increased the probability of achieving stock state indicator 2 to 76% (Figure 20). All scenarios for stock state indicator 2 reached a maximum at approximately 80% due to density dependence in smolt production (Ricker β parameter = 0.00033) as spawner and smolt data are only available for when the stock productivity was low. It should be noted that the majority of the spawners in these scenarios are natural spawners and not wild spawners due to density-dependence. In other words, significant numbers of hatchery and natural spawners are returning to spawn at high (8 to 12%) marine survival rates but the natural spawner production of smolts is being limited by the β parameter.

Probabilities for achieving stock state indicator 3 were below 50% for all scenarios (Figure 21). Increasing marine survival to 12% increased the probability of reaching stock state indicator 3 to a maximum of approximately 45%. Increased freshwater survival for a given marine survival rate marginally increased the probability of achieving the target. Again, production was constrained due to density dependence in smolt production.

Probabilities for recovery targets 1 (2,440 spawners) and 2 (4,470 spawners) were 0% for all scenarios. Sakinaw Sockeye abundance has reached these abundances 32 and 16 times since 1947, respectively. However, under current conditions this has zero probability of occurring.

The greatest limiting factor is very low marine survival (<0.5%) and no direct mitigation measures are currently known to improve this factor.

A sensitivity analysis of the Ricker β parameter was performed to determine the magnitude of the effect on recovery probabilities. The parameter was varied between 0.00033, the value determined by the Bayesian Ricker model fit (i.e. current conditions), and 0.00005. A smaller β value equates to a larger spawning stock size at which smolt production is maximized. Probabilities for reaching stock state indicators and recovery targets were sensitive to the β parameter (Figure 22, Figure 23, and Figure 24). Increasing marine survival for a given β value increased the probability of achieving all stock state indicators and recovery targets. For example, for stock state indicator 3, the probability tripled from 0.00033 (6%) to 0.0002 (19%) and nearly doubled from 0.0002 to 0.0001 (36%) for 4% marine survival (Figure 24). There were marginal increases (1 to 3%) in probabilities of achieving indicators and targets decreasing β below 0.0001. Similarly, decreasing the β value increased the probability of achieving the indicators and targets for a given marine survival rate.

A deterministic life history model was also developed (see Appendix E). With current wild fecundity (2,049); freshwater survival (19%), exploitation (5%) and pre-spawn mortality (10%) rates; a 7% marine survival rate is required to achieve > 1 recruits per spawner and positive population growth. This model is strictly for wild fish, with a hypothetical starting population of 500 adults and does not include the captive brood program.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Element 16: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).

Element 17: Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).

Mitigation options and reasonable alternatives were proposed and discussed during the threats and limiting factors workshop. Only threats and limiting factors with mitigation options are discussed. They are presented below and in Appendix A.

THREATS WITH MITIGATION MEASURES

Habitat Degradation

Habitat integrity degraded sufficiently to negatively impact all juvenile stages, smolt staging, rearing or early seaward migration requirements

1. Restrict development, forestry, and other industrial activities upslope of Sakinaw Sockeye spawning habitat to reduce sediment, slope stability and groundwater effects to the spawning beaches.
2. Restore natural fluctuation in lake levels to reduce nearshore benthic vegetation that is decreasing the availability of spawning habitat.
3. Continue annual spawning ground dive surveys to monitor spawning habitat to document changes in habitat quality so that restoration can be done where necessary.

Fishing

Increased adult mortality due to terminal fisheries

1. Develop sampling program with First Nations to determine the number of Sakinaw Sockeye caught by Aboriginal groups in food, social and ceremonial (FSC) fisheries, as it is currently unknown.
2. Continue fisheries management policies that restrict fishing in Johnstone Strait until the end of July when approximately 50% of the Sakinaw Sockeye have returned to Sakinaw Lake.

Pollution

Elevated mortality or sub-lethal effects due to aquatic pollutants (LF31)

1. Sechelt First Nation is involved with a coastal zone planning process that includes the area near the mouth of Sakinaw Creek (S. Quinn, pers. comm.).
2. Develop spill response plans that have adequate resources to quickly respond to a spill.
3. Develop water, land use and industrial waste management plans, and other similar environmental protection plans, to reduce run-off of pollutants from land into the ocean.

LIMITING FACTORS WITH MITIGATION

Competition and Predation

Large losses due to predation (LF1)

1. During the return of adult Sockeye to Sakinaw Lake, Sechelt First Nation fisheries staff currently scare away predators at the fishway, including River Otters, when they are observed near the fishway. Staff presence at the dam is necessary during migration to minimize predation.
2. Staff is needed to adjust the fishway gate to ensure 20 lps of flow and to clear blockages in the fishway and weir.
3. A management plan could be developed by Sechelt First Nation, DFO, and the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development that addresses seals, Sea Lions and River Otters. Trapping of River Otters is a potential mitigation option to increase the number of adult Sakinaw Sockeye reaching the spawning beaches.

Predation on eggs and alevins (by Sculpins, Cutthroat Trout, Peamouth Chub, Coho, birds etc.) (LF14)

1. Predator exclusion cages or tangle nets could be implemented on the spawning beaches to protect the eggs and alevins but more research is needed to see if this is a causal factor for the limited freshwater productivity of Sakinaw Sockeye.

High levels of competition or predation (from native or exotic spp) reduce lake carrying capacity for wild fry-smolts (LF21)

1. A better understanding of potential predator and competitor (e.g. Cutthroat, Kokanee) dynamics is required to see if this is a causal factor for reduced fry to smolt survival. Possible mitigation includes the removal of competitors and predators through increased recreational fishing pressure or removing individuals from their spawning grounds through coordination with local stewardship groups.

Predator abundance and assumed levels of predation on smolts and adults exceed reference range. State change is associated with reduced survival and well below average adult returns (LF33)

1. Same mitigation as large losses due to predation (LF1).

Changing Ocean Conditions

“Warm ocean” food webs favor below average smolt-to-adult survival and below average returns LF32)

1. Releasing more fry into the lake than is being done currently would increase the number of out-migrating smolts and returning adults. However, this does not directly mitigate the limiting factor of poor marine survival. This option would also have a significant increase in financial cost. Similarly, releasing hatchery fish as smolts may increase marine survival; however, this likely has an increased financial cost as well.

HATCHERY CONSIDERATIONS WITH MITIGATION

High mortality of hatchery fry to smolt stage (LF39)

1. A new site has been identified with a suitable well and surface water hatchery for a long-term program in the Pender Harbour area. This will allow fed, clipped fry to be released in mid-June to possibly duplicate the earlier Ouillet survival rates. Construction of a new hatchery at Pender Harbour will cost approximately $250,000 to build and $100,000 annually to operate.
2. Releasing fish over deep water away from the shoreline is also recommended as fry will have an easier route to access colder water.
3. Fry are transported in tanks by truck from Vancouver Island to the Sunshine Coast. Reducing the transportation time and decreasing the tank water temperature before release have been identified as two mitigation options. Transporting the fish from Rosewall hatchery to Sakinaw Lake via helicopter would reduce transport time and thus mortality. Refrigerating the transport tanks to keep the water temperature lower is another option that will likely decrease fry to smolt mortality. The water temperature in the transport tanks reaches a maximum temperature of approximately 16°C.
4. Releasing fry in late summer or early fall when the water is cooler and the fry are larger will likely increase fry to smolt survival.

High mortality of hatchery smolt to adult stage due to domestication impacts and lowered fitness (LF40)

1. Maintaining already established captive breeding program measures to avoid inbreeding and incorporate diversity from all individuals.
2. Reduction of domestication may benefit from equalization of family contributions to the brood animals each generation (Allendorf 1993) but minimization of the duration (number of generations) of captive breeding provides the most certain means of limitation (Williams and Hoffman 2009).

Element 18: If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.

Currently, there is enough spawning habitat to reach the two lower spawner abundance targets (500 and 1,000 spawners).

Element 19: Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17.

Reduction in mortality estimates are based on data, scientific literature and professional judgement. In some cases a reduction in mortality was not possible to estimate due to the nature of the mitigation or the lack of scientific information (Table 16).

MITIGATION SCENARIO

Element 20: Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

The following parameters in the PVA were changed to simulate the proposed mitigation.

Terminal Migration and Spawning

Pre-spawn mortality was changed from 10% to 5% to simulate the removal of River Otter predation within Sakinaw Creek. The remaining 5% is due to in-lake pre-spawn mortality that cannot be mitigated.

Freshwater Incubation, Freshwater Rearing, and Hatchery

Freshwater survival for hatchery fish was doubled which is a feasible increase in freshwater survival that has been achieved in other lakes. The increase could be possible with a reduction in predation in the lake and increased initial survival after being transported to the lake from the hatchery.

Freshwater survival of naturally produced fish was doubled to simulate any freshwater-related mitigation factors that increase egg to fry and/or fry to smolt survival.

Marine Migration and Rearing

Harbour Seal predation rates on Chinook and Coho Salmon in the Strait of Georgia have been estimated to range from 40% to 47%, respectively (Nelson et al., *in prep*). Assuming that Sakinaw Sockeye experience similar predation and that half of this predation could be mitigated, this would increase marine survival to 2.5%. This was used as a starting point and best-case scenario to illustrate how much marine survival needs to increase to have an effect on population recovery. The exploitation rate remained constant at 5% and the captive brood program was at its current production (1900 captive adults).

The rate changes described above were evaluated using the PVA model (Table 17). An increase in population abundance (stock state indicator 1) occurred with 30% probability for total spawners. The parameter changes also led to a stock state indicator 2 being achieved with 59% probability. Stock state indicator 3 occurred at 15% probability. Higher abundance recovery targets occurred at 0% probability. Density-dependence was a factor in limiting recovery probabilities, similar to what is described in the Recovery Targets section.

Element 21: Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.

Model runs were not done for captive brood sizes larger than 1900 adults. Increasing the fry output of the hatchery would affect population performance measures but this would come at a financial cost that could be beneficial to explore.

PVA model parameters used are provided in Table 27 and Table 28 of Appendix B.

ALLOWABLE HARM ASSESSMENT

Element 22: Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.

Currently, the factors that are preventing the recovery are Sakinaw Sockeye are not human induced, but are limiting factors, including high levels of predation, changing ocean conditions and other unknown causes of high at sea mortality. The Sakinaw Sockeye population is currently maintained by the release of fry into Sakinaw Lake from an enhancement program. Without the enhancement program, and with current life history stage survival rates and very low marine survival, anadromous Sakinaw Sockeye would likely become extinct.

Fisheries management plans implemented during the 1990s have been effective in reducing exploitation of Sakinaw Sockeye. The average exploitation rate for Sakinaw Sockeye from 2011 to 2015 was 5% of the returns. Model results indicated that further decreasing the exploitation rate to 0% would have little effect on recovery due to how small the population is and how low current marine survival (0.5%) is. Therefore, maintaining the current 5% exploitation rate per year does not change the trajectory of the recovery of Sakinaw Sockeye, though should be kept to the lowest levels possible.

Although spawning and rearing habitat is currently not limiting Sakinaw Sockeye productivity, every measure should be taken to protect and to maintain the quality and quantity of Sakinaw Sockeye spawning and rearing habitat.

Given the high early life history stage mortality and the extremely low marine survival of Sakinaw Sockeye, minimal allowable harm should be permitted at this time, and be reduced below current levels to the extent possible. This level of harm may allow for some activities to be undertaken while working towards maintaining survival and moving towards recovery of the population. If the Sakinaw Sockeye enhancement program were discontinued, then no allowable harm should be permitted as the Sakinaw Sockeye population is currently dependent on the hatchery for survival.

SOURCES OF UNCERTAINTY

There are no natural fry to smolt survival data for Sakinaw Sockeye. The number of natural fry produced each year was estimated based on average Sakinaw Sockeye female fecundity, a sex ratio of 0.5 and average Sockeye egg to fry survival rates (9%) from other populations (Bradford 1995). A survival rate was then calculated by dividing the number of natural smolts counted at the dam divided by the number of fry produced the previous year for an average of 19% (SD: ± 18%).

There is uncertainty in the exploitation rate estimates. Analyses of test fishery data to determine exploitation rate have a lot of uncertainty during years with very low returns (e.g. 1999 onward) (DFO, unpublished report). There has also been no sensitivity analysis of exploitation rates to changes in migration delay. The estimates also assumed a 100% northern diversion of Sakinaw Sockeye returns.

The number of Sakinaw Sockeye caught by Aboriginal groups in food, social and ceremonial (FSC) fisheries is unknown because there is no sampling program (e.g. DNA sampling) for fish caught in these fisheries.

Pre-spawn mortality of adults in the lake is unknown but believed to be low (Table 18). On years with low returns, when dive surveys are more reliable, pre-spawn mortality has been estimated at less than 10%.

CONCLUSIONS AND ADVICE

Sakinaw Sockeye experience numerous threats and limiting factors that affect their productivity. Currently, the greatest limiting factor is very low marine survival (<0.5%; smolt to adult). There are currently no direct mitigation measures to improve, or reduce the impact of, this factor. There is also no way of knowing if, or when, marine survival will increase to a rate that will allow Sakinaw Sockeye to be self-sustainable. The only way to sustain this stock, under current conditions, and to prevent another extirpation event, is to continue with the captive brood program and the annual release of hatchery fry for the foreseeable future.

Fry to smolt survival is also low (13 to 19%) relative to other populations. However, even a two fold increase in fry to smolt survival will not be sufficient for the population to recover with the current marine survival rate. We advise that the research programs described below be developed and implemented so that management actions can be better informed by program results and possibly increase freshwater survival rates for all associated life stages.

We also recommend that if a new hatchery were to be built to supply fry for release at Sakinaw Lake that the hatchery water supply come from a surface water source. Currently, Sakinaw Sockeye fry are reared in groundwater at Rosewall hatchery. Groundwater stays at a consistent low temperature throughout the year, leading to relatively slow fry growth and later releases as compared with hatcheries that source surface water. Surface water warms during the spring and summer as air temperature increases. Warmer water increases the growth rate of Sockeye fry which allows them to be released earlier relative to fish raised in groundwater. This also acclimatizes them to warmer lake water for when they are released during the late spring and summer, which increases fry to smolt survival. A suitable hatchery site has been identified in the Pender Harbour area for a long-term program. This will allow fed, clipped fry to be released in mid-June to possibly duplicate the earlier Ouillet survival rates. Construction of a new hatchery at Pender Harbour will cost approximately $250,000 to build and $100,000 annually to operate.

The smolt survival data since 2003 indicate that the earlier June releases from Ouillet survive (28%) at double the rate of the Rosewall fry (13.8%). The difference in survival is possibly due to the fact that earlier released fish are being released into lake water that is approximately 15 °C compared to late June fish that are being released in 20 to 24 °C water. Releasing fish over deep water away from the shoreline is also recommended as fry will have an easier route to access colder water.

To date the hatchery program has been beneficial to maintenance and restoration of the natural Sakinaw Sockeye population. However, as described above, there is little evidence for the likelihood of restoring depleted wild populations with hatchery fish, especially if the conditions responsible for the original population decline have not been addressed (Fraser 2008). There are also genetic concerns associated with captive programs.

Of more concern is the level of domestication that has occurred in the closed captive breeding program since its inception in the early 2000s. Since domestication is the process of the captive population becoming adapted to its current habitat (the hatchery), there is no way to avoid domestication of a captively-bred hatchery-maintained population. Moreover, the degree of domestication, and the associated loss of fitness or adaptation to the wild environment, cannot be measured with microsatellite loci.

Fish being released from the program currently have been reared in captivity for at least four generations. Reduced fitness of captive salmon released in the wild environment has been observed in other systems. Furthermore, analysis indicated that the release of captively-bred individuals into rebuilding wild populations after four to six generations of captivity was as likely to prevent as to facilitate wild population recovery. Due to these issues, we are requesting advice on the continuation of the captive brood program.

Other recommendations are to continue the operation and staffing of the dam and fishway; escapement and smolt programs; habitat restoration efforts; monitoring and reduction of juvenile predation; management of water flows; and fishery management practices that limit fishing mortality.

RESEARCH RECOMMENDATIONS

Research is proposed to better understand the effects of the highest scored threats and limiting factors. The threat or limiting factor that the research addresses is in parentheses.

TERMINAL MIGRATION AND SPAWNING

1. Conduct genetic analysis of Seal and Sea Lion scat from the Sunshine Coast area to determine the proportion of their diet that is composed of Sakinaw Sockeye. There is ongoing research by DFO, UBC and PSF related to this; however, fish are only identified to species and not population. (LF1)
2. Changes to the habitat upslope (i.e. terrestrial) of the spawning beaches needs to be documented to determine to what extent these activities have affected groundwater supply to the spawning beaches.
3. Research needs to be done to see if the spawning beach water quality (i.e. dissolved oxygen concentrations) has been affected by road construction, logging, residential development or other activities. If dissolved oxygen concentrations are suboptimal then restoration options will be explored.

FRESHWATER INCUBATION

1. Determine the abundance, size, and composition of predators at the spawning beaches to estimate the effect these predators are having on egg to fry survival. (LF14)

2. Study the effectiveness of protecting spawning areas with the use of tangle nets or protective covers to potentially increase egg to fry survival rates. (LF14)

FRESHWATER REARING

1. A better understanding of the lake ecosystem is needed. Research needs to be conducted to assess the abundance of Kokanee in Sakinaw Lake. DNA samples need to be collected to determine if Kokanee are genetically distinct from Sakinaw Sockeye. If the ecotypes are closely related an interesting paradox is that continuing to release Sockeye fry may be detrimental to Kokanee since the hatchery Sockeye fry compete with Kokanee. It is conceivable that the best chance for the return of wild Sakinaw Sockeye may be to protect kokanee by not releasing hatchery fry. When/if marine survival conditions improve, the species may increase in abundance naturally through natural outmigration of occasional kokanee that go to sea and return to Sakinaw Lake, perhaps establishing a self-sustaining natural population. Kokanee spawning areas also need to be determined. (LF21)
2. Conduct a limnological study of Sakinaw Lake to determine whether there has been a change in the productivity of the lake and zooplankton abundance and community composition. The last such survey was conducted in 2004. An initial literature review should also be carried out. (LF18)
3. Perform lake surveys or surveys within the creeks that drain into Sakinaw Lake to estimate lamprey population size to help determine the effect lamprey are having on fry to smolt survival. (LF22)
4. Dramatically increase hatchery fry production to overwhelm depensation effects that may be occurring within the lake or at sea to increase fry to smolt and smolt to adult survival. (LF21)
5. Produce and release hatchery smolts instead of fry, or as well as fry, and use coded-wired tags to test for differences in survival rates based on release location and life history stage.

MARINE MIGRATION AND REARING

1. Collect a time series of length and weight data for Sakinaw Sockeye to determine if there are potential growth rate responses to Pink and Chum salmon abundances in the north Pacific Ocean. Data could be provided from fish killed in the creek by River Otters given that handling returns in the fishway is too harmful. Scales and DNA should also be collected from these fish. (LF29)
2. Analyze oil spill movement modeling to determine the extent and magnitude an oil spill would affect Sakinaw Sockeye habitat. (LF31)
3. Closer linkages and collaboration among climate modelers and oceanographers to try and better anticipate future ocean conditions that might be more or less favorable for the survival of Sakinaw Sockeye. (LF32)
4. Analyze Sakinaw Sockeye smolts for parasites and pathogens. (LF35)
5. Perform salt water challenge tests on Sakinaw Sockeye smolts. (LF35)

HATCHERY

1. Conduct a Sakinaw Sockeye hatchery program review with the intention of identifying opportunities to improve survival through experimentation, as well as identifying clear hatchery origin spawner abundance and genetic broodstock management objectives.

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TABLES

Table 1 Natural origin and hatchery smolt length (mm ± SD) from fish sub-sampled at the Sakinaw Creek dam.

Year	Natural smolt length (mm ± SD)	Sample size (n)	Hatchery smolt length (mm ± SD)	Sample size (n)
1994	122.4	n/a	-	-
1995	139.2	n/a	-	-
1996	133.0	n/a	-	-
1997	129.0	n/a	-	-
2003	117.3 ± 13.0	246	122.5 ± 11.0	754
2004	120.2 ± 20.0	39	155.7 ± 25.4	24
2005	168.0 ± 9.9	2	154.2 ± 85.2	6
2006	-	-	126.5 ± 10.1	2303
2007	138.2 ± 15.3	14	-	-
2008	-	-	130.7 ± 9.7	37
2009	114.4 ± 7.8	11	123.8 ± 9.6	121
2010	-	-	127.1 ± 15.4	392
2011	-	-	129.9 ± 15.9	178
2012	-	-	116.1 ± 6.6	126
2013	129.1 ± 19.0	217	119.5 ± 11.0	211
2014	116.7 ± 9.7	47	116.2 ± 9.5	637
2015	111.1 ± 13.5	127	114.4 ± 11.7	175
2016	110.2 ± 10.4	41	111.2 ± 10.1	190

Table 2 Fishery sample identifications (sum of probabilities) for Sakinaw Lake Sockeye from 2001 to 2016.

Year	Area 1 – 101	Area 12	Area 12 – Blinkhorn	Area 13	Area 20	Area 20 – San Juan	US Area 7	Total
2004	-	0.97	-	-	-	-	-	0.97
2008	-	-	-	-	-	-	0.79	0.79
2009	-	2	-	-	-	-	-	2
2010	-	1	-	-	-	-	-	1
2011	-	6	-	2	1	-	-	9
2012	1	6	-	1.98	1	-	-	9.98
2013	-	3	-	-	2	-	-	5
2015	-	4	-	-	-	2	1	7
2016	-	-	1	-	-	1	-	2
Total	**1**	**22.97**	**1**	**3.98**	**4**	**3**	**1.79**	**37.74**

Table 3 Sakinaw Sockeye adult counts 1947-1994 (from BC-16 data). Insufficient data exists for 1995, 1997 and 1998. Counts in 1996 and 2002 used a fishway trap. 1999-2001 estimates are based on dive surveys at spawning beaches which are biased low compared to fishway counts due to in-lake mortality (estimated at up to 10% bias). 2003-2014 counts are from a digital video system set up in the fishway. "Estimate class" represents quality associated with the data collection: U = Unknown data collection; Type 1 data are a very good population estimate (nearly every fish counted through video tunnel); Type 2 data are still a very good population estimate (nearly every fish counted through video tunnel or fishway trap with perhaps a small portion of the population missed); Type 4 data are missing some days at the end of the migration when some fish may still be going through the fishway but are still a reasonable estimate of the population; Type 6 data are reliable for presence/absence only. = Hatchery fish were not clipped BY 2008-2010.*

Brood Year	Estimate Class	Clipped Jacks	Unclipped Jacks	Clipped Adults	Unclipped Adults	Total
1947	U	-	-	-	3500	3500
1948	U	-	-	-	4600	4600
1949	U	-	-	-	3931	3931
1950	U	-	-	-	2473	2473
1951	U	-	-	-	3450	3450
1952	U	-	-	-	6222	6222
1953	U	-	-	-	1131	1131
1954	U	-	-	-	4143	4143
1955	U	-	-	-	5079	5079
1956	U	-	-	-	2150	2150
1957	U	-	-	-	4300	4300
1958	U	-	-	-	4250	4250
1959	U	-	-	-	13000	13000
1960	U	-	-	-	4500	4500
1961	U	-	-	-	750	750
1962	U	-	-	-	3500	3500
1963	U	-	-	-	7500	7500
1964	U	-	-	-	3500	3500
1965	U	-	-	-	750	750
1966	U	-	-	-	3500	3500
1967	U	-	-	-	6000	6000
1968	U	-	-	-	14000	14000

Brood Year	Estimate Class	Clipped Jacks	Unclipped Jacks	Clipped Adults	Unclipped Adults	Total
1969	U	-	-	-	1200	1200
1970	U	-	-	-	5000	5000
1971	U	-	-	-	8000	8000
1972	U	-	-	-	4500	4500
1973	U	-	-	-	1500	1500
1974	U	-	-	-	6000	6000
1975	U	-	-	-	16000	16000
1976	U	-	-	-	6000	6000
1977	U	-	-	-	1200	1200
1978	U	-	-	-	4000	4000
1979	U	-	-	-	11000	11000
1980	U	-	-	-	2800	2800
1981	U	-	-	-	3000	3000
1982	U	-	-	-	3400	3400
1983	U	-	-	-	1600	1600
1984	U	-	-	-	1115	1115
1985	U	-	-	-	2400	2400
1986	U	-	-	-	5400	5400
1987	U	-	-	-	4200	4200
1988	U	-	-	-	2500	2500
1989	U	-	-	-	1000	1000
1990	U	-	-	-	1200	1200
1991	U	-	-	-	500	500
1992	U	-	-	-	1000	1000
1993	U	-	-	-	250	250
1994	U	-	-	-	250	250
1995	NI	-	-	-	-	-
1996	Type 4	-	-	-	222	222

Brood Year	Estimate Class	Clipped Jacks	Unclipped Jacks	Clipped Adults	Unclipped Adults	Total
1997	Type 6	-	-	-	Present, not counted	Present, not counted
1998	Type 6	-	-	-	Present, not counted	Present, not counted
1999	Type 4	-	-	-	14	14
2000	Type 4	-	-	-	112	112
2001	Type 4	-	-	-	87	87
2002	Type 2	-	-	-	78	78
2003	Type 1	-	-	-	3	3
2004	Type 1	-	-	0	99	99
2005	Type 1	-	-	7	21	28
2006	Type 1	-	-	0	1	1
2007	Type 1	-	-	0	0	0
2008	Type 1	-	-	0	0	0
2009	Type 1	-	-	1	0	1
2010	Type 2	-	-	28	1	29
2011	Type 1	-	-	555	0	555
2012	Type 2	-	-	0*	243*	243
2013	Type 1	-	29	0*	114*	143
2014	Type 1	10	2	0*	452*	464
2015	Type 1	20	6	462	233	721
2016	Type 1	1	0	144	27	172

Table 4 Hatchery fry released, smolt counts and survival rates.

	Fry released (#)			Smolt count (#)			Survival (%)		
Brood year	**Natural origin brood**	**Captive brood**	**Total**	**Clipped**	**Unclipped**	**Total**	**Hatchery fry to smolt**	**Marine (hatchery - clipped)**	**Marine (natural origin - unclipped)**
1992	-	-	-	-	15,880	-	-	-	-
1993	-	-	-	-	2,760	-	-	-	-
1994	-	-	-	-	2,500	-	-	-	-
1995	-	-	-	-	5,200	-	-	-	-
1996	-	-	-	-	-	-	-	-	-
1997	-	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	-
2000	14,981	0	14,981	-	-	-	-	-	-
2001	31,922	0	31,922	8,080	4,334	12,414	25.31	0.087	0.485
2002	2,784	0	2,784	39	103	142	1.40%	0.000	0.971
2003	0	0	0	2	11	13	n/a	n/a	n/a
2004	25,927	0	25,927	8,357	2,926	11,283	32.23	0.000	0.000
2005	7,588	87,877	95,465	3,739	272	4,011	3.92	0.027	0.000
2006	0	84,626	84,626	11,982	182	12,164	14.16	0.234	0.549

Fry released (#)				Smolt count (#)			Survival (%)		
Brood year	Natural origin brood	Captive brood	Total	Clipped	Unclipped	Total	Hatchery fry to smolt	Marine (hatchery - clipped)	Marine (natural origin - unclipped)
2007	0	420,781	420,781	62,370	222	62,592	14.88	0.890	n/a
2008	0	726,376	726,376	404	69,538	69,942	9.63	0.347	n/a
2009	0	329,360	329,360	0	32,892	32,892	9.99	0.347	n/a
2010	5,110	1,368,712	1,373,822	0	162,877	162,877	11.86	0.278	n/a
2011	0	963,328	963,328	224,575	27,960	252,535	23.31	0.206%	0.833
2012	0	856,205	856,205	121,610	4,435	126,045	14.20	0.118	0.609
2013	0	320,416	320,416	164,65	632	17,097	5.14	-	-
2014	0	644,699	644,699	78,156	722	78,878	12.10	-	-
2015	0	329,077	329,077	-	-	-	-	-	-

Table 5 All spawners and natural origin and wild adult recruit data used for recruitment analysis. Exploitation rate estimates are provided in Table 6.

Brood Year	All Spawners	Natural Origin and Wild Adult Recruits
1966	3,500	9,434
1967	6,000	16,000
1968	14,000	7,500
1969	1,200	2,113
1970	5,000	11,538
1971	8,000	24,615
1972	4,500	8,955
1973	1,500	3,636
1974	6,000	9,302
1975	16,000	13,750
1976	6,000	3,733
1977	1,200	4,286
1978	4,000	7,907
1983	1,600	4,901
1984	1,115	3,177
1985	2,400	1,304
1986	5,400	2,339
1989	1,000	449
1990	1,200	490
1996	222	147
1999	14	3
2000	112	104
2001	58	22
2006	1	1
2007	0	0
2008	0	0
2010	16	0
2011	555	254

Table 6 Exploitation rates estimated for Sakinaw Sockeye from 1970 to 2016 and run reconstruction method descriptions and sources.

Return Year	Exploitation Rate	Reconstruction Method or Source
1970	0.47	Starr 1984
1971	0.50	
1972	0.40	
1973	0.29	
1974	0.48	
1975	0.35	
1976	0.33	
1977	0.67	
1978	0.57	
1979	0.20	
1980	0.25	
1981	0.3	
1982	0.57	
1983	-	No analysis
1984	-	
1985	-	
1986	-	
1987	0.14	Murray and Wood 2002
1988	0.21	
1989	0.23	
1990	0.49	
1991	-	
1992	-	
1993	0.44	

Return Year	Exploitation Rate	Reconstruction Method or Source
1994	0.49	
1995	0.41	
1996	-	Early Stuart as indicator
1997	0.15	
1998	-	
1999	0.19	Reconstruction using average run timing and best fit of preseason PSC model
2000	0.24	
2001	0.31	
2002	0.08	Reconstruction using average run timing and preliminary post season HR estimates
2003	0.13	
2004	0.05	Reconstruction using annual run timing and post season HR estimates
2005	0.03	
2006	-	No analysis (0 or 1 adult was counted at the fishway during these years)
2007	-	
2008	-	
2009	-	
2010	0.12	Average of various analyses done by M. Folkes (DFO) and D. O'Brien (DFO)
2011	0.18	
2012	0.06	Estimation by D. O'Brien (DFO)
2013	0.05	
2014	0.01	
2015	0.06	
2016	-	No analysis

Table 7 Ricker stock-recruit parameters for Sakinaw Sockeye.

Parameters	Ricker[6]
a	1.02
b	13,000
R_{max}	13,029
S_{max}	12,800
μ_{MSY}	0.44
S_{MSY}	5,588

Table 8 Average dissolved oxygen concentrations (mg/L) measured during February and March, 2013 at Morgan's, Fraser's, Snag beach (all Sharon's beach sub-beaches) and Haskins beach (DFO, unpublished data).

Date	Morgan's	Fraser's	Snag	Haskins
05-Feb	3.29	8.53	8.53	9.26
13-Feb	1.92	9.10	12.47	8.83
19-Feb	9.45	14.45	12.32	11.47
27-Feb	11.33	13.81	13.00	8.65
07-Mar	12.86	15.13	14.33	10.13
12-Mar	11.48	13.43	11.26	9.61
19-Mar	10.92	13.31	12.23	8.51
27-Mar	8.94	13.11	11.42	11.61

[6] $R = Se^{a[1-(\frac{S}{b})]}$

Table 9 Threats to the survival and recovery of Sakinaw Sockeye Salmon. Threats are ranked based on their current biological risk score.

Life History Stage	Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population -Level Risk	Threat Occurrence	Threat Frequency	Threat Extent
Marine Migration and Rearing	Pollution: Elevated mortality or sub-lethal effects due to aquatic pollutants	Likely	Medium	Low	Medium (4)	Historical/ Current/ Anticipatory	Recurrent	Extensive
Terminal Migration and Spawning, Freshwater Incubation and Freshwater Rearing	Habitat degradation: Habitat integrity degraded sufficiently to negatively impact smolt staging, rearing or early seaward migration requirements	Known	Low	High	Low (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
Terminal Migration and Spawning	Fishing: Increased adult mortality due to terminal fisheries	Known	Low	Very High	Low (1)	Historical/ Current/ Anticipatory	Recurrent	Restricted

Table 10 Limiting factors to the survival and recovery of Sakinaw Sockeye. Only limiting factors that were scored as medium or higher are presented. Limiting factors are ranked based on their risk score.

Life History Stage	Limiting Factor	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population-Level Risk	Limiting Factor Occurrence	Limiting Factor Frequency	Limiting Factor Extent
Terminal Migration and Spawning	Large losses due to predation (LF1)	Known	Extreme	High	High (2)	Historical/ Current/ Anticipatory	Continuous	Extensive
Freshwater Incubation	Predation on eggs and alevins (by sculpins, Cutthroat Trout, Peamouth Chub, Coho, birds, etc.) (LF14)	Known	High	Low	High (4)	Historical/ Current/ Anticipatory	Continuous	Extensive
Marine Migration and Rearing	"Warm ocean" food webs favor below average smolt-to-adult survival and below average returns (LF32)	Known	Extreme	Medium	High (3)	Historical/ Current/ Anticipatory	Recurrent	Extensive
Marine Migration & Rearing	Competition exceeds historic reference range and is associated with density dependent growth or survival outcomes that are negative for Sakinaw Sockeye (LF29)	Likely	High	Low	High (4)	Current/ Anticipatory	Continuous	Extensive
Marine Migration and Rearing	Predator abundance and assumed levels of predation on smolts and adults exceed reference range. State change is associated with reduced survival and well below average adult returns (LF33)	Known	Extreme	High	High (2)	Historical/ Current	Continuous	Extensive

Life History Stage	Limiting Factor	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population-Level Risk	Limiting Factor Occurrence	Limiting Factor Frequency	Limiting Factor Extent
Freshwater Rearing	High levels of competition or predation (from native or exotic spp) reduce lake carrying capacity for wild fry-smolts (LF21)	Known	Medium	Low	Medium (4)	Current/ Anticipatory	Continuous	Extensive
Freshwater Rearing	High rates of parasitism reduce the lake carrying capacity for wild fry-smolts (LF22)	Known	Medium	Low	Medium (4)	Current/ Anticipatory	Continuous	Extensive
Freshwater Rearing	Variable food web structure (spp. Changes) leads to sub-average carrying capacity for fry-smolts (LF18)	Likely	Medium	Low	Medium (4)	Current/ Anticipatory	Continuous	Extensive
Marine Migration and Rearing	Parasite or pathogen incidence & impacts on growth or survival expressed at epidemic levels associated with below average growth, survival and adult returns (LF35)	Likely	Medium	Low	Medium (4)	Historical/Current/ Anticipatory	Continuous	Extensive

Table 11 Counts of out-migrating Sakinaw Sockeye smolts examined for the presence of copepods on their gills.

	Year													
Copepods Present	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
No	936	63	4	2,234	14	32	123	298	165	115	419	670	179	208
Yes	64	0	4	69	0	5	9	94	13	11	26	14	123	23
Total Fish	1,000	63	8	2,303	14	37	132	392	178	126	445	684	302	231

Table 12 Proposed Sakinaw Sockeye stock state indicators and recovery targets.

Interim Stock State Indicator	Description
1) Population growth	Growth in the generational average by increasing the total spawner abundance relative to the brood year (4 years prior) for at least 3 out of 4 consecutive years after the recovery plan is implemented.
2) 500 total spawners	An average of 500 annually over a four year period with no fewer than 100 fish.
3) 1,000 total spawners	An average 1,000 annually over a four year period with no fewer than 500 fish. COSEWIC Criterion D1 and 2005 recovery target.

Recovery Target	Description
1) 2,440 total spawners	S_{gen}. Achieve in any year.
2) 4,470 total spawners	80% S_{msy}. Achieve in any year.
3) Spawning at Sharon's, Haskins and Ruby beaches	The three spawning beaches that have been used most recently. To reach recovery target 5 it is likely that all five spawning beaches would be required to provide spawning habitat for all spawners.

Table 13 Performance measures used to assess population trajectories of the number of spawning Sakinaw Sockeye. N_t refers to the number of wild or natural spawners in year t. Avg denotes an average across return years.

Stock State Indicator	**Rule**	**Statistic**
1 –Total spawner population growth	Generational growth (Avg(N_t:N_{t-3}) > Avg(N_{t-4}:N_{t-7})) AND cycle over cycle growth in 3 of 4 consecutive yrs (e.g. N_t>N_{t-4}, AND N_{t-1}>N_{t-5},…)	% of years target met
2 – An average of 500 total spawners annually over a four year period with no fewer than 100 fish.	Avg(N_t:N_{t-3}) >= *GenLimit* (500 spawners) and N_t > *CycleLimit* (100 spawners)	% of years target met
3 – An average 1,000 total spawners annually over a four year period with no fewer than 500 fish.	The same as recovery target 2, except 1,000 (*GenLimit*) and 500 (*CycleLimit*) spawners.	% of years target met
Recovery Target	**Rule**	**Statistic**
1 – 2,440 total spawners	(Proportion of trials with all abundances during the fifth generation ($N_{2033:2037}$) ≥ 2,440) x 100	Probability that all 4 cycle lines exceeded target in year 17 to 20
2 – 4,470 total spawners	(Proportion of trials with all abundances during the fifth generation ($N_{2033:2037}$) ≥ 4,470) x 100	Probability that all 4 cycle lines exceeded target in year 17 to 20
Extinction	$N_{T,t}$ < *ExtLimit*	True/False per simulation (or % of simulations over multiple trials) with 4 consecutive years where spawner abundance < *ExtLimit*

Table 14 Spawning beach total area and area used based on a 2012 dive survey (J. Wilson, unpublished data).

Spawning Beach	Total Area (m^2)	Used Area (m^2)
Morgan’s	1,625	900
Fraser’s	345	225
Snag	600	230
Haskins	175	35
Ruby	300	?
Kokomo	?	?
Prospectors	?	?
Total	**3,045**	**1,390**

Table 15 Summary of 100 year simulations (1,000 trials) that went extinct (%) and the percentage of years that interim stock state indicators and recovery targets were met for wild and total spawners. All simulations presented below included a captive brood program of 1900 adults.

Run	Marine Survival (%)	Fresh-water Survival	Extinct[7] (% of simulations)	Interim Stock State Indicators and Recovery Targets (% of years target met)									
				Increase population abundance		500 spawners		1,000 spawners		2,440 spawners		4,470 spawners	
				Wild	Total	Wild	Total	Wild	Total	Wild	Total	Wild	Total
1	0.49	Present	2	25	27	0	0	0	0	0	0	0	0
2	1	Present	0	25	26	0	0	0	0	0	0	0	0
3	2	Present	0	24	27	0	4	0	0	0	0	0	0
4	3	Present	0	25	27	0	19	0	2	0	0	0	0
5	4	Present	0	26	28	0	39	0	6	0	0	0	0
6	8	Present	0	28	29	5	76	0	31	0	0	0	0
7	12	Present	0	29	30	8	82	1	43	0	0	0	0
8	0.49	1.5x	1	25	27	0	0	0	0	0	0	0	0
9	1	1.5x	0	25	27	0	1	0	0	0	0	0	0
10	2	1.5x	0	25	27	0	19	0	2	0	0	0	0
11	3	1.5x	0	26	29	1	46	0	9	0	0	0	0
12	4	1.5x	0	27	29	2	63	0	19	0	0	0	0
13	8	1.5x	0	30	31	8	81	1	43	0	0	0	0
14	12	1.5x	0	30	31	9	79	1	46	0	0	0	0

[7] Extinction was defined as a simulation that resulted in < 50 total spawners.

Run	Marine Survival (%)	Fresh-water Survival	Extinct[7] (% of simulations)	Interim Stock State Indicators and Recovery Targets (% of years target met)									
				Increase population abundance		500 spawners		1,000 spawners		2,440 spawners		4,470 spawners	
				Wild	Total	Wild	Total	Wild	Total	Wild	Total	Wild	Total
15	0.49	2x	1	25	28	0	0	0	0	0	0	0	0
16	1	2x	0	25	27	0	4	0	0	0	0	0	0
17	2	2x	0	26	28	1	38	0	6	0	0	0	0
18	3	2x	0	28	30	2	63	0	19	0	0	0	0
19	4	2x	0	29	30	5	75	0	30	0	0	0	0
20	8	2x	0	31	31	8	79	1	46	0	0	0	0
21	12	2x	0	31	31	8	74	1	44	0	1	0	0

Table 16 Threats and factors that affect Sakinaw Sockeye productivity by life stage, proposed mitigation measures and their estimated reduction in mortality. Only threats and factors with mitigation are presented.

Life History Stage	Threat/Limiting Factor	Mitigation	Reduction in Mortality
Terminal Migration and Spawning	Increased adult mortality due to terminal fisheries	• Develop sampling program with First Nations to determine the number of Sakinaw Sockeye caught by Aboriginal groups in food, social and ceremonial (FSC) fisheries, as it is currently unknown. • Continue fisheries management policies that restrict fishing in Johnstone Strait until the end of July when approximately 50% of the Sakinaw Sockeye have returned to Sakinaw Lake.	Negligible
	Large losses due to predation (LF1)	• A management plan that addresses seals, Sea Lions and River Otters. Trapping of River Otters is a potential mitigation option to increase the number of spawning Sakinaw Sockeye. • Scare away predators at the fishway. Staff presence at the dam is necessary during migration to minimize predation. • Staff is needed to adjust flow from lake and to clear blockages in the fishway and weir.	Years with observed River Otter kills average 5% of escapement.
Freshwater Incubation	Predation on eggs and alevins (by sculpins, Cutthroat Trout, Peamouth Chub, Coho, birds, etc.) (LF14)	• Predator exclusion cages or tangle nets on the spawning beaches to protect the eggs and alevins. More research is needed to see to determine if this is a causal factor for reduced freshwater productivity.	Difficult to know the magnitude without further research but could be as high as 25% (Foote and Brown 1998).
Freshwater Rearing	High levels of competition or predation (from native or exotic spp) reduce lake carrying capacity for wild fry-smolts (LF21)	• A better understanding of potential predator and competitor (e.g. Cutthroat, Kokanee) dynamics is required to see if this is a causal factor for reduced fry to smolt survival. Possible mitigation includes the removal of competitors and predators through increased recreational fishing pressure or removing individuals from their spawning grounds through coordination with local stewardship groups.	Difficult to quantify without further research. It could be as high as 40% (Nowak et al. 2004, Beauchamp et al. 2005).

Life History Stage	Threat/Limiting Factor	Mitigation	Reduction in Mortality
Marine Migration and Rearing	"Warm ocean" food webs favor below average smolt-to-adult survival and below average returns (LF32)	• Releasing more fry into the lake than is being done currently would increase the number of out-migrating smolts and returning adults. However, this does not directly mitigate the limiting factor of poor marine survival. This option would also have a significant increase in financial cost.	No change in mortality unless depensatory mortality is occurring.
	Predator abundance and assumed levels of predation on smolts and adults exceed reference range. State change is associated with reduced survival and well below average adult returns (LF33)	• Same as *large losses due to predation (LF1).*	There are no data on the effect of this factor. An estimate would be 5%.
	Elevated mortality or sub-lethal effects due to aquatic pollutants (LF31)	• Sechelt First Nation is involved with a coastal zone planning process that includes the area near the mouth of Sakinaw Creek. • Spill response plans that have adequate resources to quickly respond to a spill. • Water, land use and industrial waste management plans, and other similar environmental protection plans, to reduce run-off or pollutants from land into the ocean.	Difficult to quantify and assessments are limited.
Terminal Migration and Spawning; Freshwater Incubation; and Freshwater Rearing	Habitat integrity degraded sufficiently to negatively impact all juvenile stages, smolt staging, rearing or early seaward migration requirements	• Restrict development, forestry, and other industrial activities upslope of Sakinaw Sockeye spawning habitat to reduce sediment, slope stability and groundwater effects to the spawning beaches. • Restore natural fluctuation in lake levels to reduce nearshore benthic vegetation that is decreasing the availability of spawning habitat. • Continue annual spawning ground dive surveys to monitor spawning habitat to document changes in	Difficult to quantify reduction in mortality but would maintain spawning habitat quality.

Life History Stage	Threat/Limiting Factor	Mitigation	Reduction in Mortality
		habitat quality so that restoration can be done where necessary.	
Hatchery	High mortality of hatchery fry to smolt stage (LF39)	• A new hatchery site with surface water for a long-term program in the Pender Harbour area. Will allow fed, clipped fry to be released in mid-June to possibly duplicate the earlier Ouillet survival rates. • Since 2012, fry have been released over deeper water where fish can swim directly downward to cooler water; however, increases in fry to smolt survival have not been observed. • Reducing the transportation time and decreasing the tank water temperature before release have been identified as two mitigation options. Transporting the fish from Rosewall hatchery to Sakinaw Lake via helicopter would reduce transport time and thus mortality. • Refrigerating the transport tanks to keep the water temperature lower. • Releasing fry in late summer or early fall when the fry are larger.	Difficult to estimate but a maximum decrease in mortality would be from 20 to 25% based on higher fry to smolt survival rates observed in other systems (K. Hyatt, DFO, pers. comm.).

Table 17 Summary of 100 year simulations (1,000 trials) based on mitigation options. Values are percentage of years the population went extinct and or reached the recovery targets for wild and total spawners. All simulations presented below included a captive brood program of 1900 adults.

Parameters Changed	**Extinct (% of sims.)**	**Recovery Targets (% of years target met)**									
		Increase population abundance		**500 spawners**		**1,000 spawners**		**2,440 spawners**		**4,470 spawners**	
		Wild	**Natural**	**Wild**	**Total**	**Wild**	**Total**	**Wild**	**Total**	**Wild**	**Total**
Marine survival =. 2.5%, Freshwater survival incr. 100%, Pre-spawn mortality = 5%	0	28	30	2	59	0	15	0	0	0	0

Table 18 Fishway counts as fish enter the lake and dive counts. Dive counts are not reliable estimates of number of fish in the lake or associated in-lake mortality given the difficulty in finding the fish in a large lake and number of days between dives.

Year	Fishway Count	Dive Count Total
1999	No count	0
2000	No count	20
2001	60	29
2002	78	43
2003	3	No dives
2004	99	91
2005	24	22
2006	1	No dives
2007	0	No dives
2008	0	No dives
2009	1	0
2010	29	24
2011	554	465
2012	244	219
2013	143	135
2014	464	286
2015	721	No dives
2016	172	No dives

FIGURES

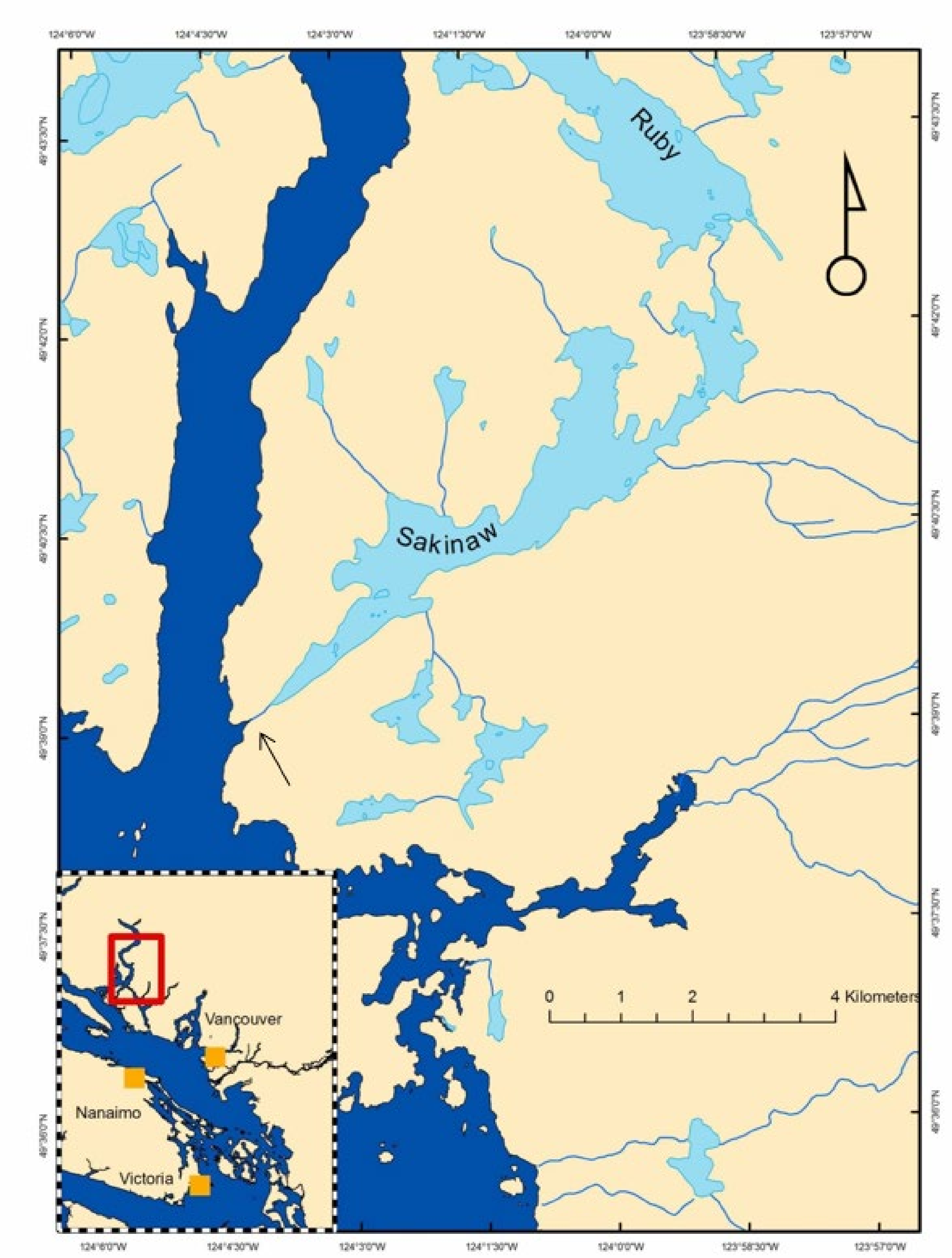

Figure 1 Sakinaw Lake (light blue) located on the Sechelt Peninsula, BC coast. Strait of Georgia is to the west (dark blue).

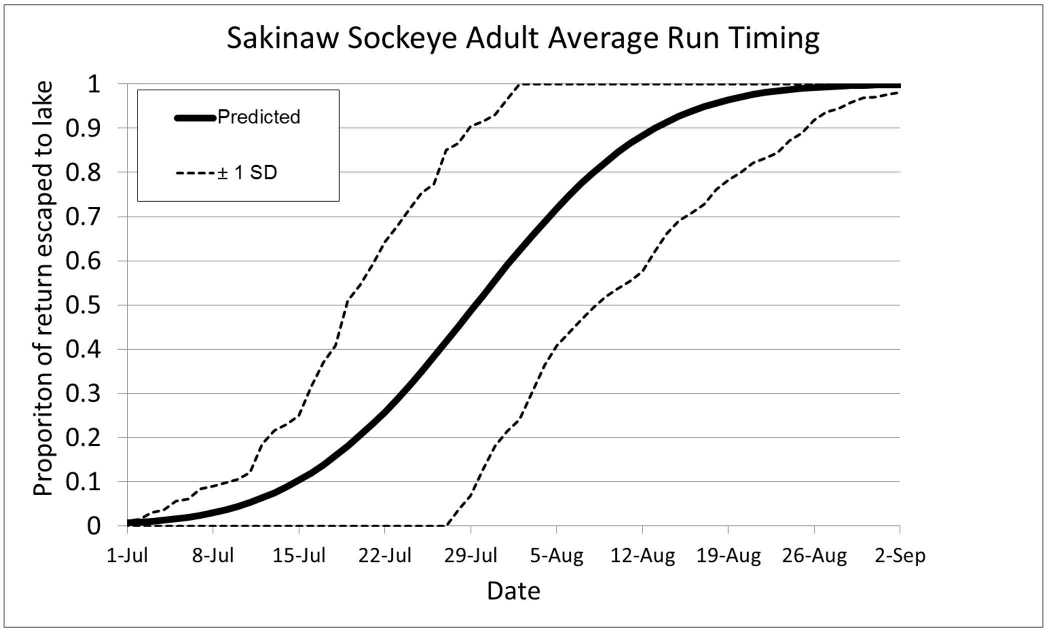

Figure 2 Sakinaw Sockeye adult average run timing.

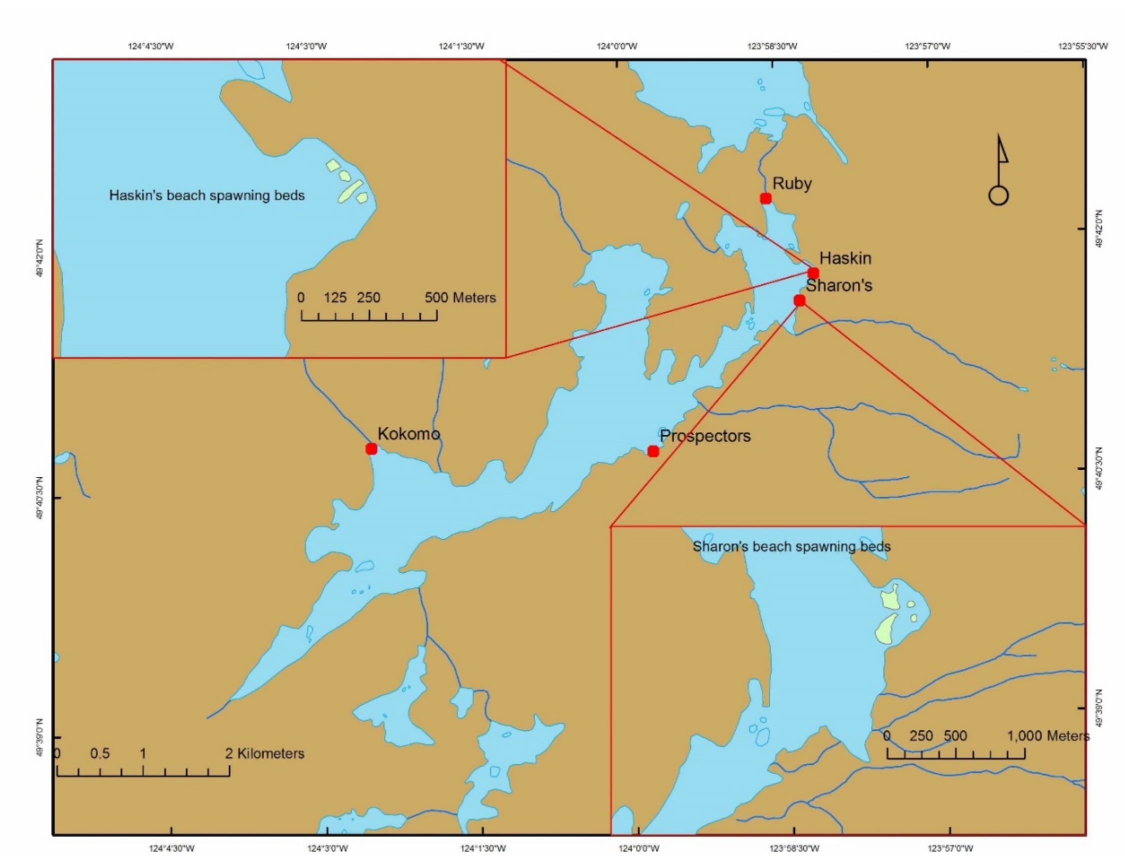

Figure 3 Sakinaw Lake spawning beaches. Spawning is currently known to occur at Sharon's and Haskins beaches. Light green polygons represent spawning beds.

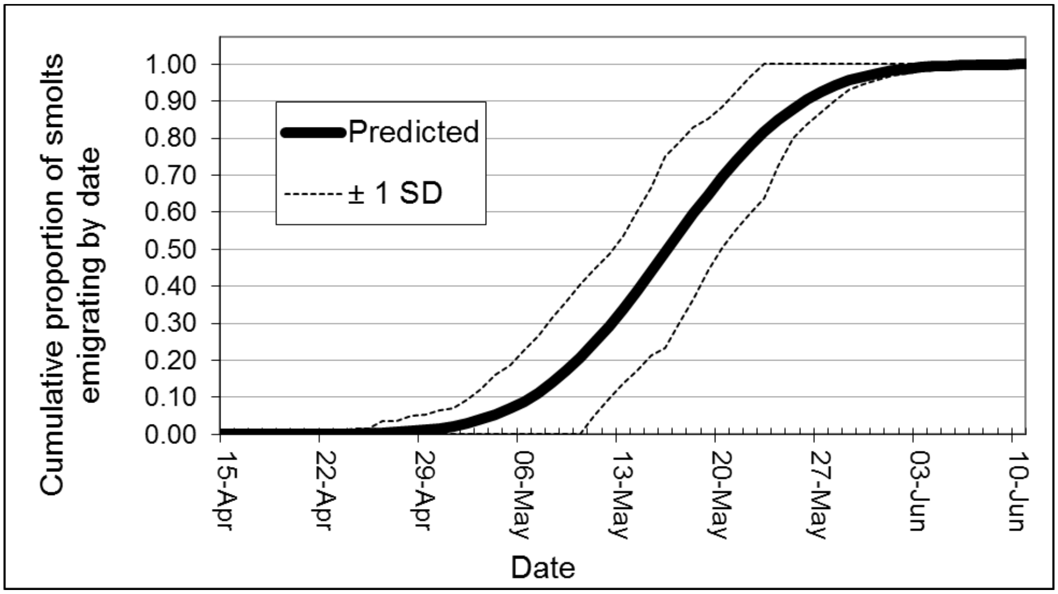

Figure 4 Sakinaw Sockeye smolt average run timing.

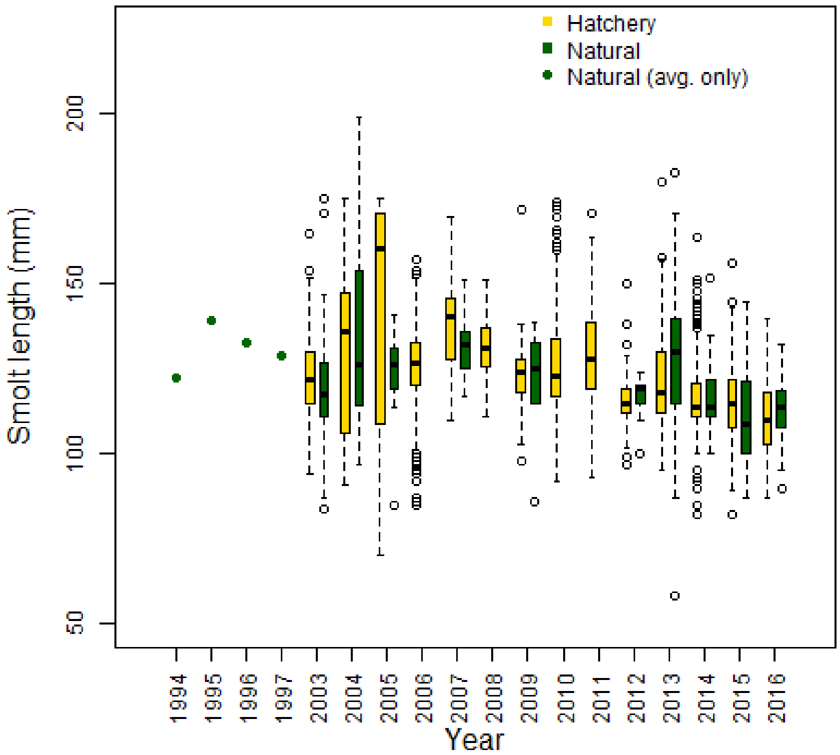

Figure 5 Natural origin and hatchery smolt lengths (mm) from 1994 to 1997 and 2003 to 2016. Only averages are available for 1994 to 1997 (Murray and Wood 2002). An outlier (hatchery, 242 mm) in 2004 and (hatchery, 310 mm) in 2005 were removed for graphical purposes.

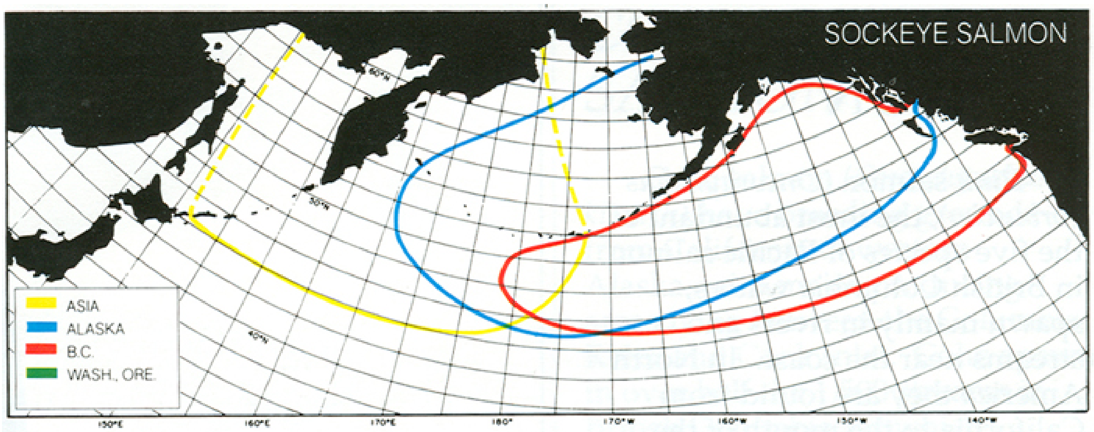

Figure 6 Generalized distribution of adult Sockeye Salmon in the north Pacific Ocean (Groot 1994).

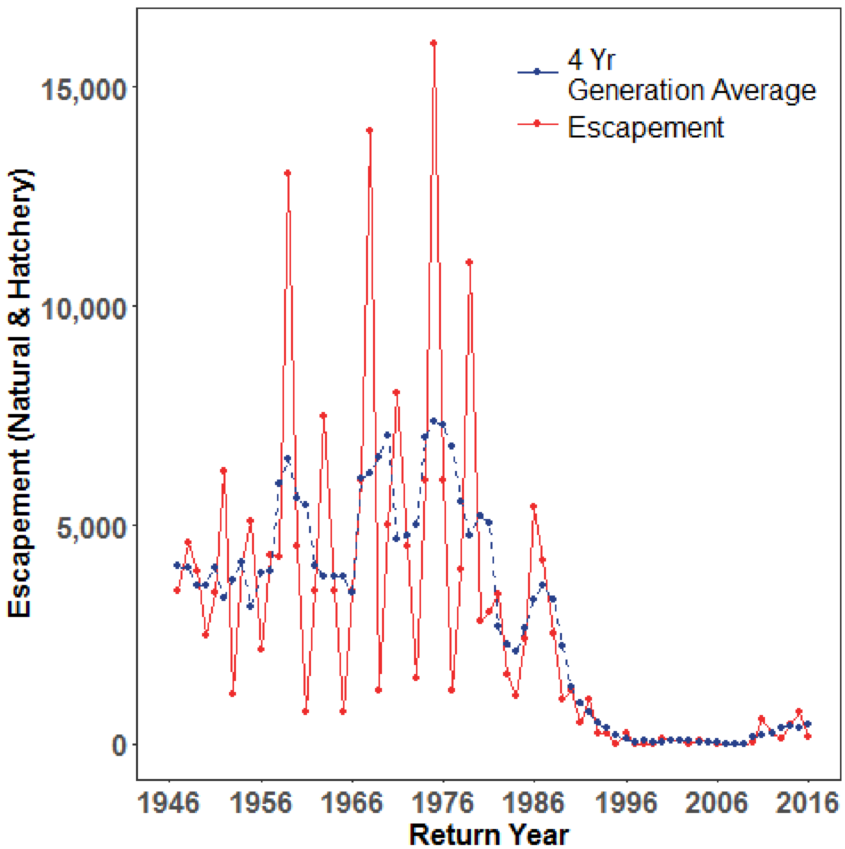

Figure 7 Sakinaw Sockeye escapement from 1947 to 2016. The counts from 1953 to 1994 are from BC-16 data. Insufficient data exists for 1995, 1997, and 1998 so they were not included. Data for 1999 to 2001 are based on dive surveys at spawning beaches which are biased low compared to fishway counts due to in-lake mortality (estimated at up to 10% bias). Counts from 2003 to 2016 are from a digital video system set up in the fishway. See Table 3 for tabular escapement data and data quality descriptions.

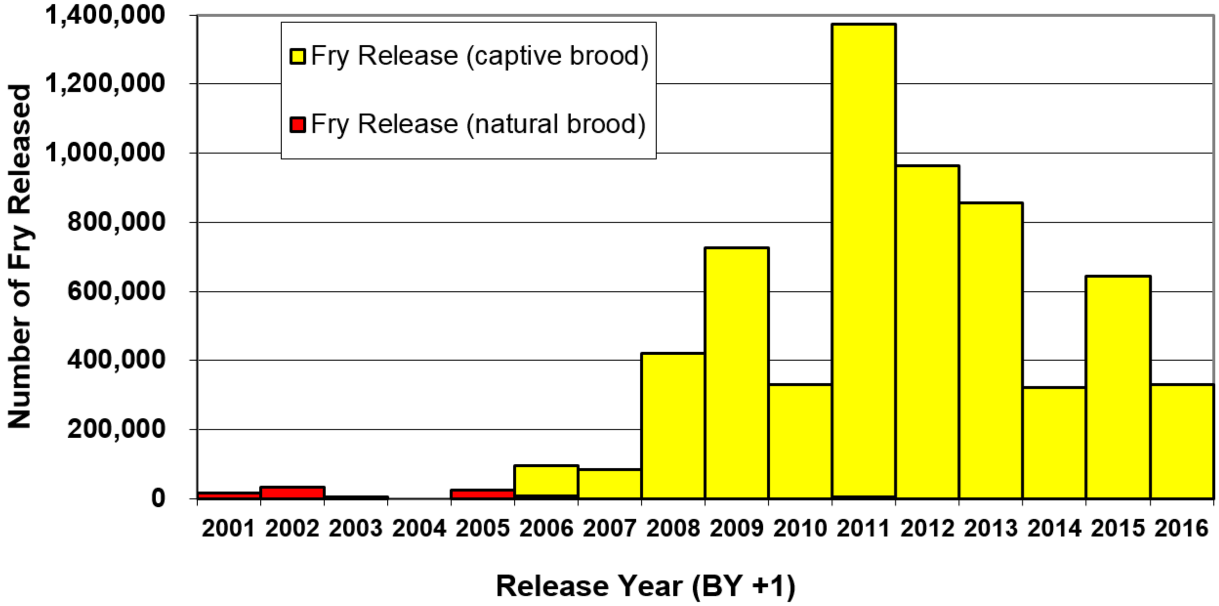

Figure 8 The number of captive and natural brood hatchery fry released by release year (brood year + 1).

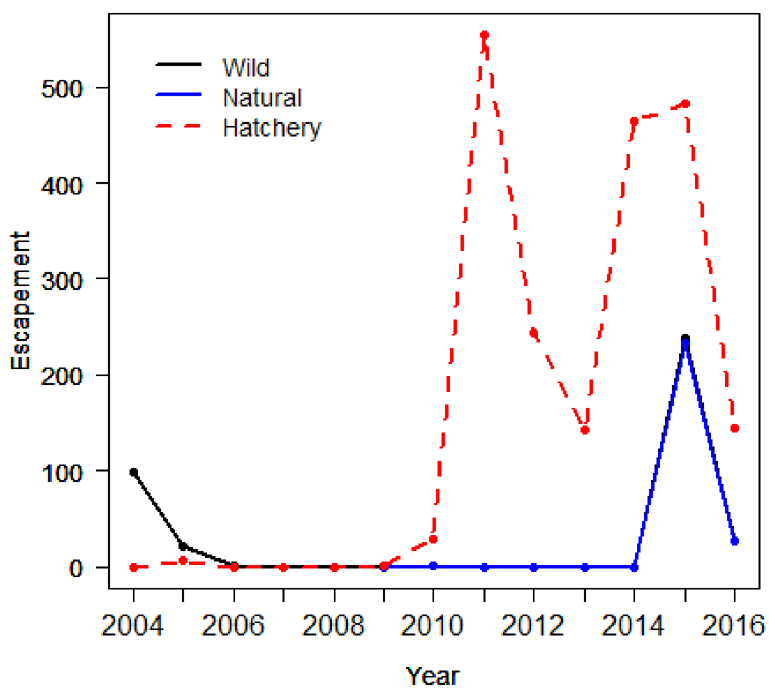

Figure 9 Natural origin and hatchery Sakinaw Sockeye escapement from 2004 to 2016.

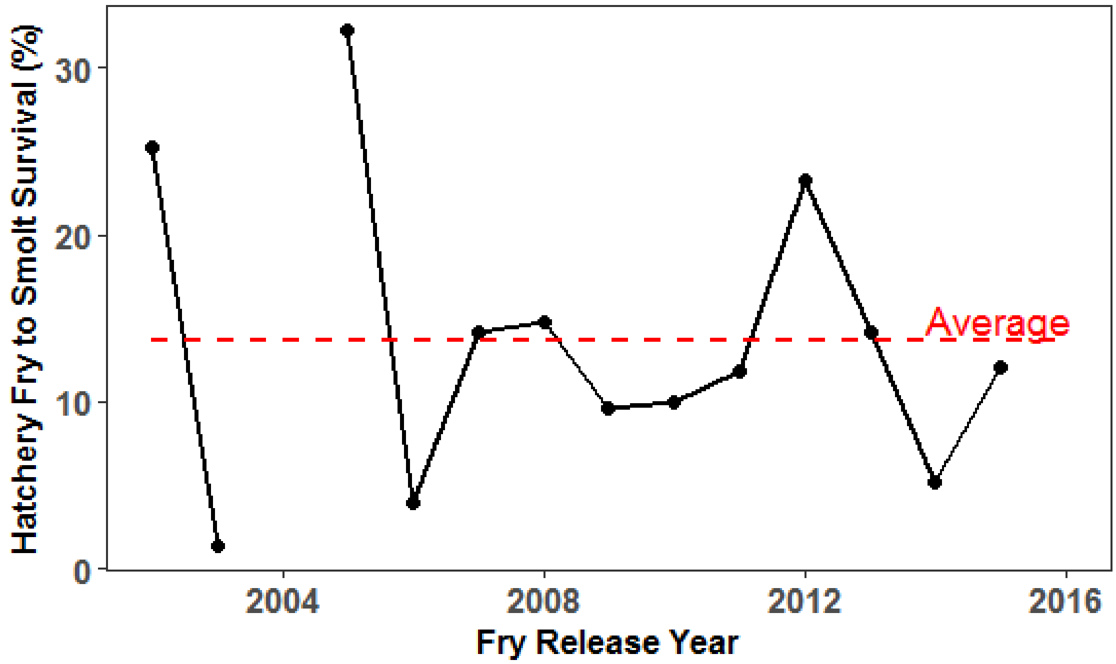

Figure 10 Hatchery fry to smolt survival rates (%) from 2002 to 2015 (fry release year).

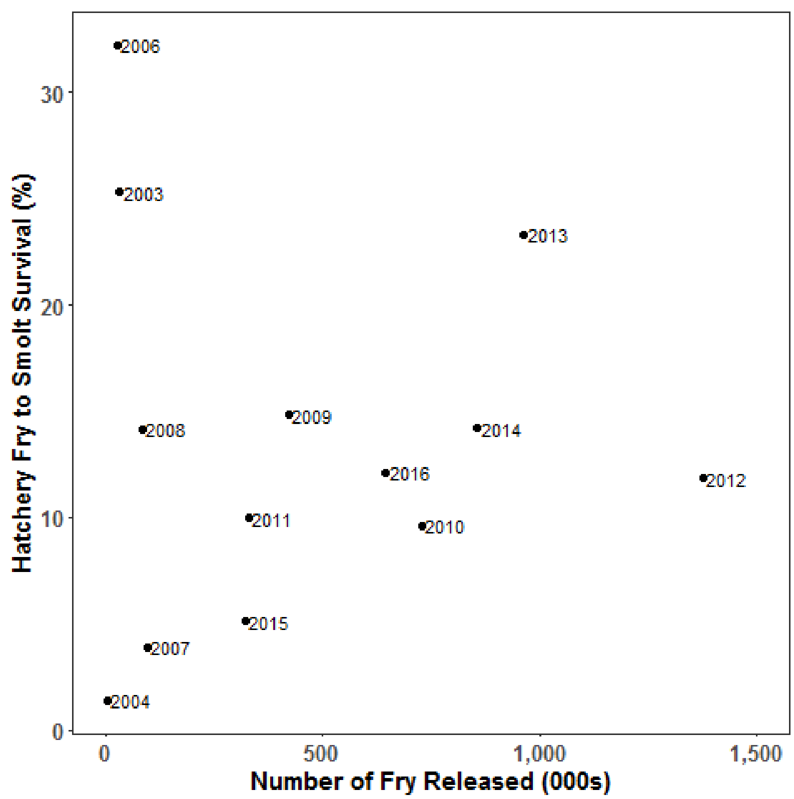

Figure 11 Freshwater survival rate (%) of Sakinaw Sockeye fry to smolts relative to the number of fry released.

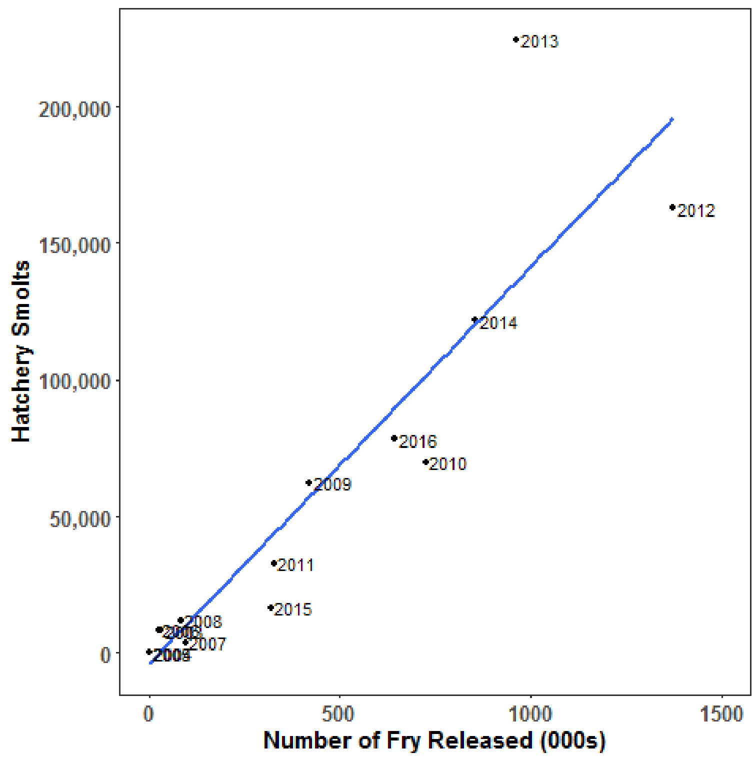

Figure 12 The relationship between the number of fry released and the number hatchery smolts counted at the dam. Years are smolt year (BY + 2).

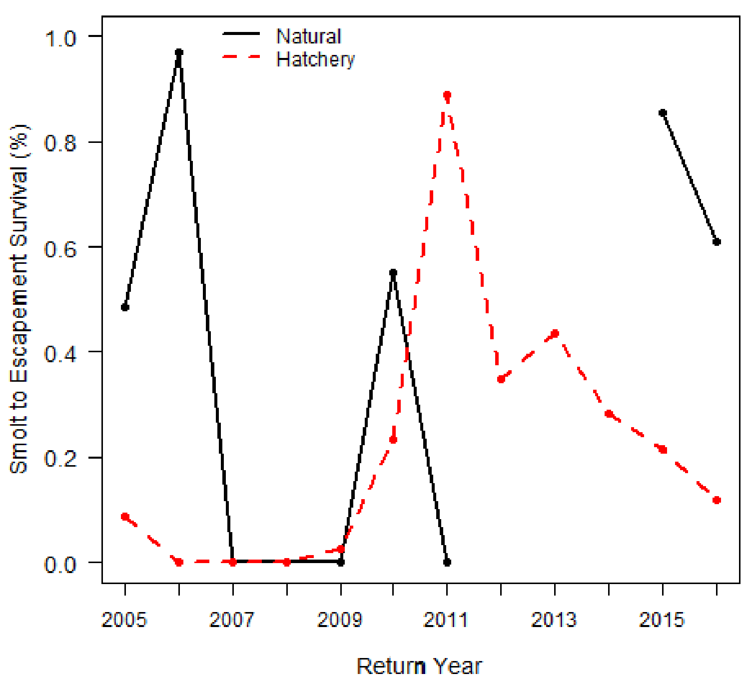

Figure 13 Marine survival (smolt to escapement) of natural and hatchery Sakinaw Sockeye from 2005 to 2015 (return year).

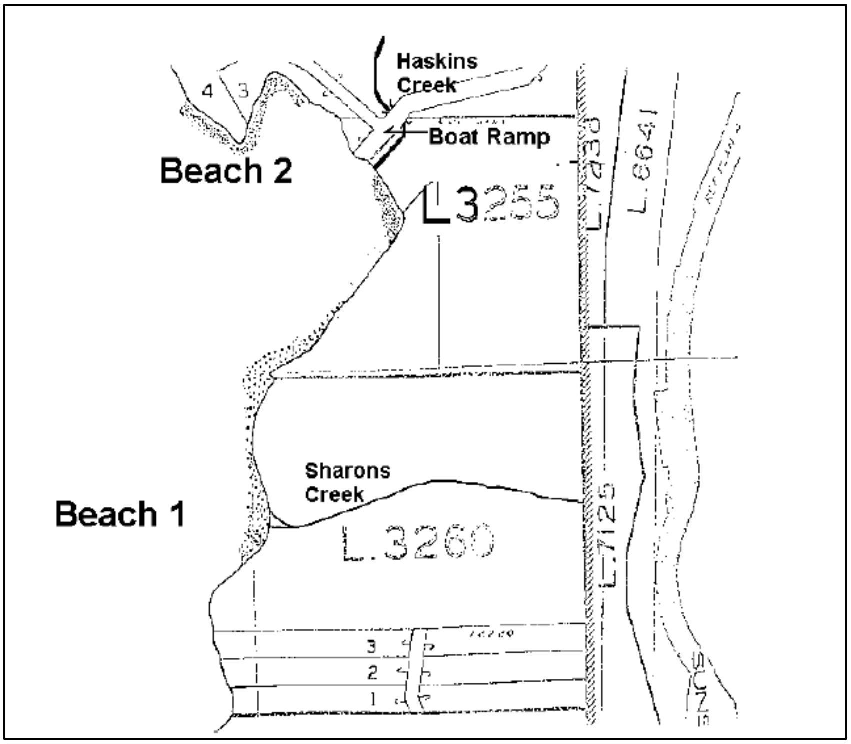

Figure 14 Locations of Sharon's (Beach 1) and Haskins (Beach 2) spawning beaches in Sakinaw Lake (Murray and Wood 2002).

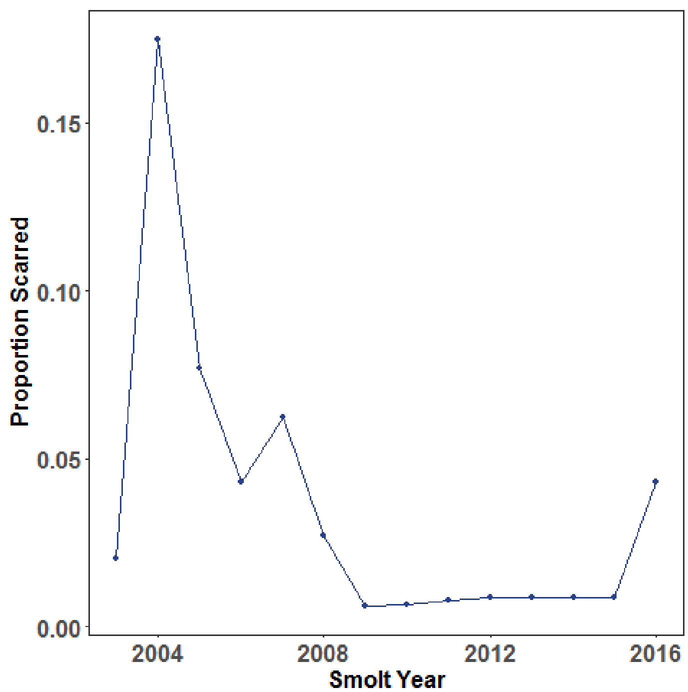

Figure 15 Proportion of out-migrating Sakinaw smolts with lamprey scars.

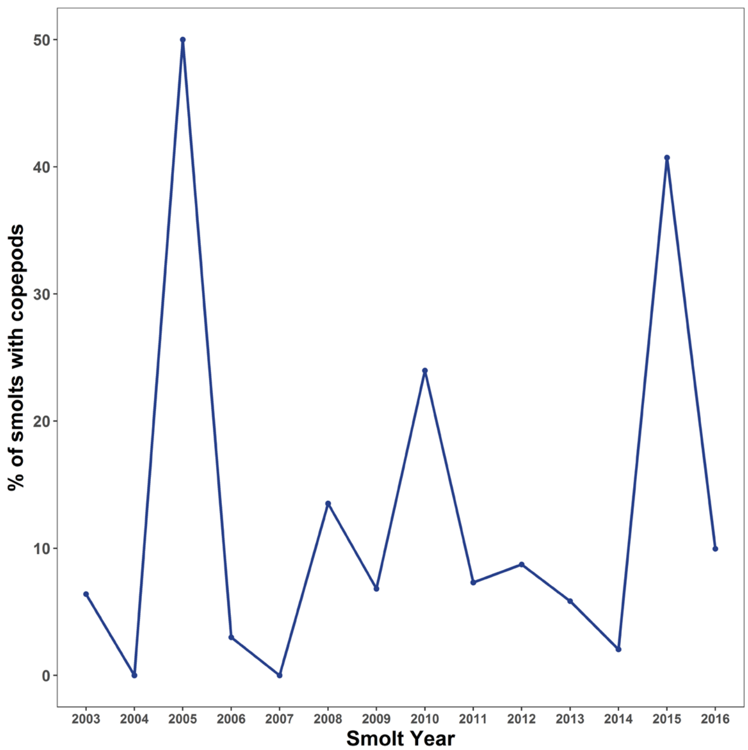

Figure 16 Proportion of sub-sampled smolts out-migrating from Sakinaw Lake with copepods on their gills. In 2005, only 8 fish were sub-sampled.

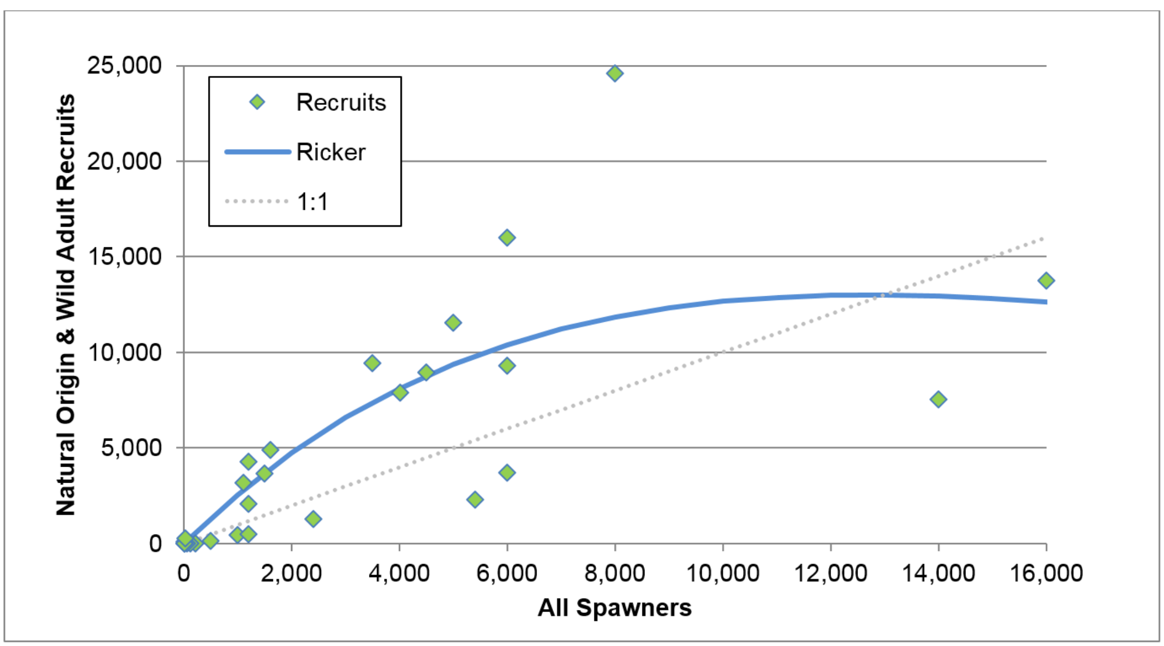

Figure 17 Sakinaw Sockeye natural origin recruits and all spawners with a standard Ricker stock-recruitment model fit to the data ($R = Se^{a[1-(\frac{S}{b})]}$).

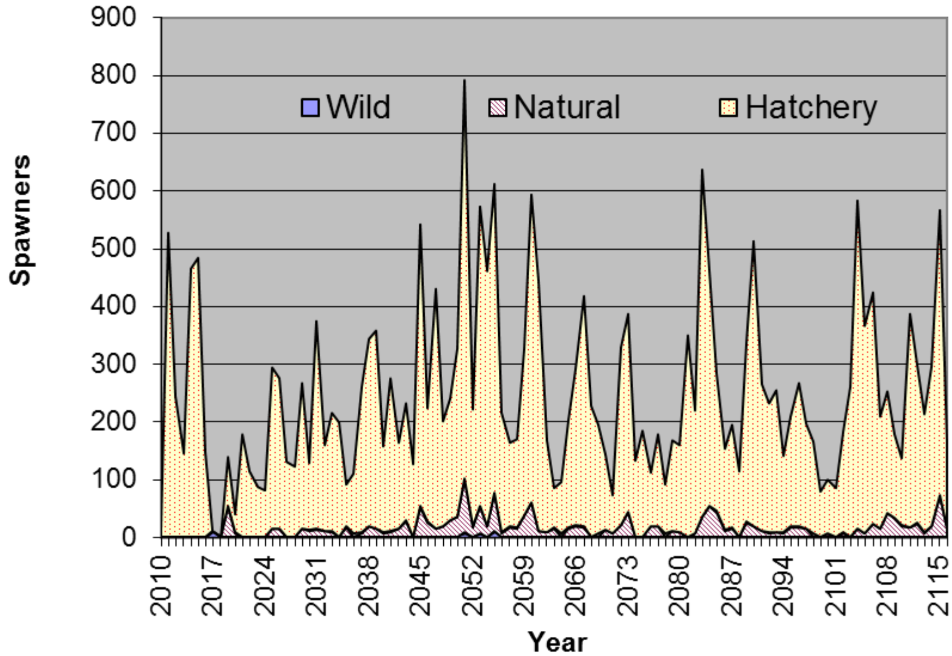

Figure 18 One trial of a 100 year population viability simulation under current conditions.

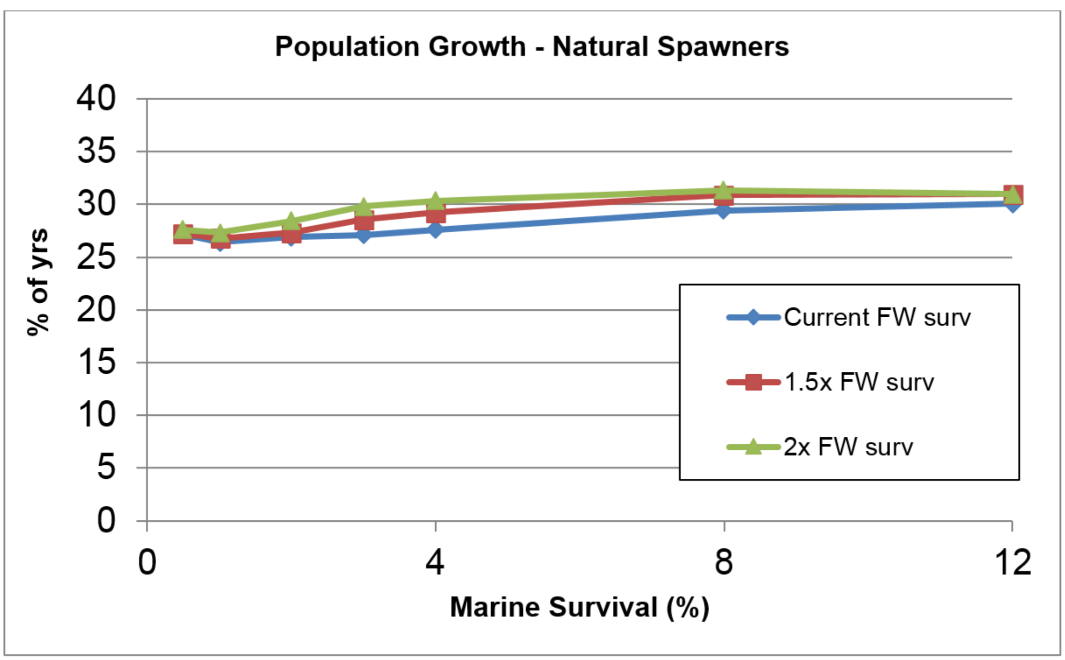

Figure 19 Percentage of years (probability) the stock state indicator is met for natural spawners based on PVA model.

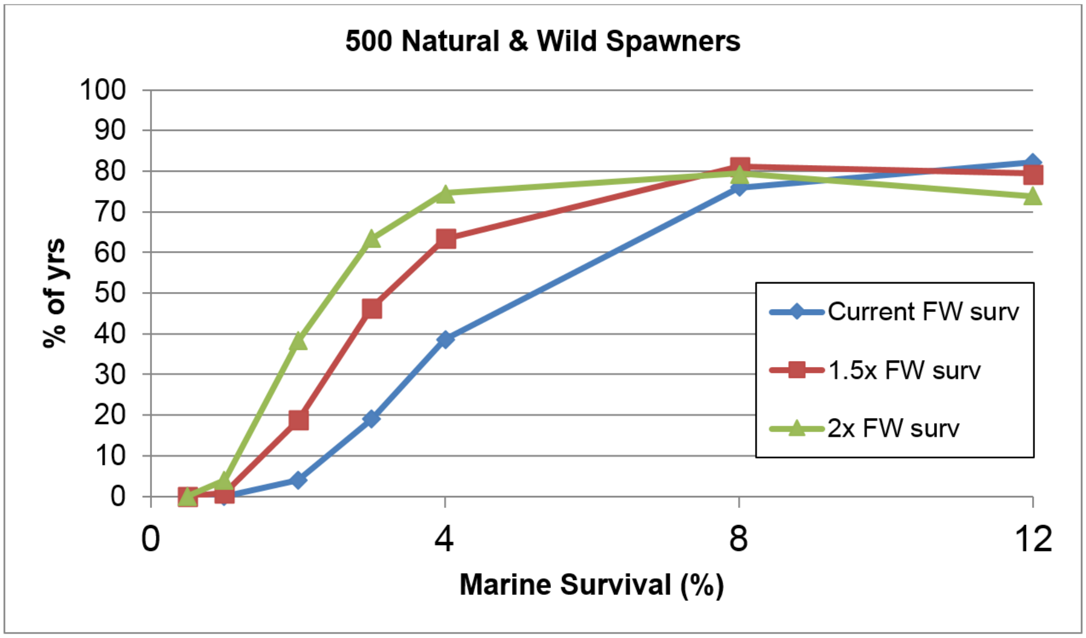

Figure 20 Percentage of years (probability) the stock state indicator is met for natural and wild spawners based on PVA model.

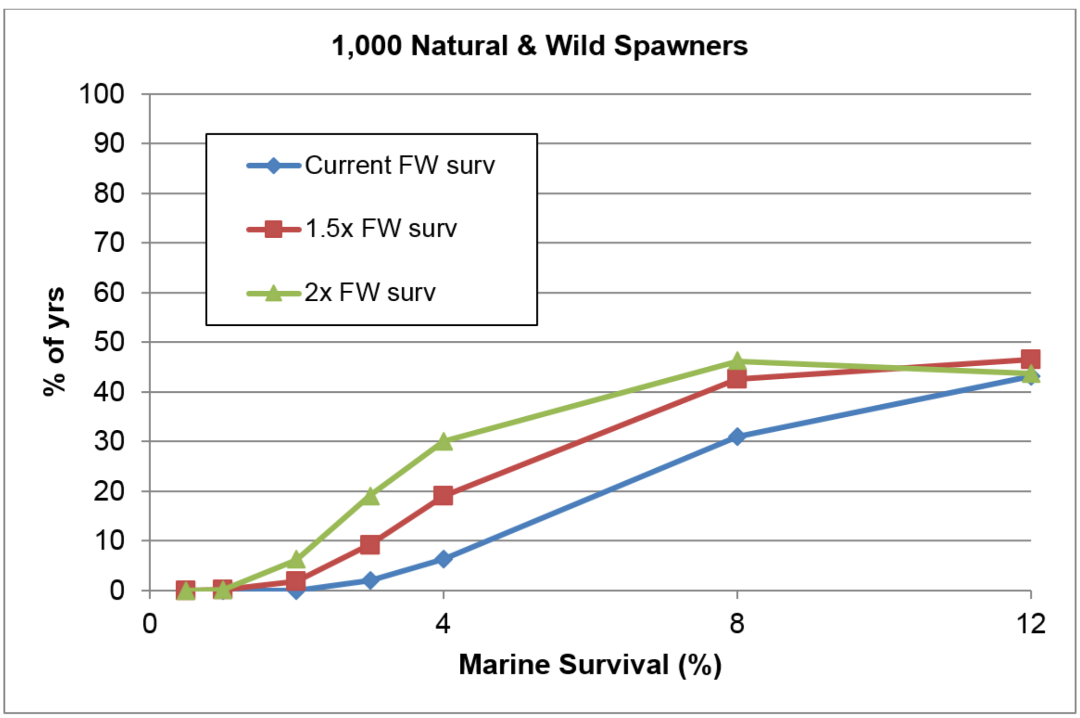

Figure 21 Percentage of years (probability) the stock state indicator is met for natural spawners based on PVA model.

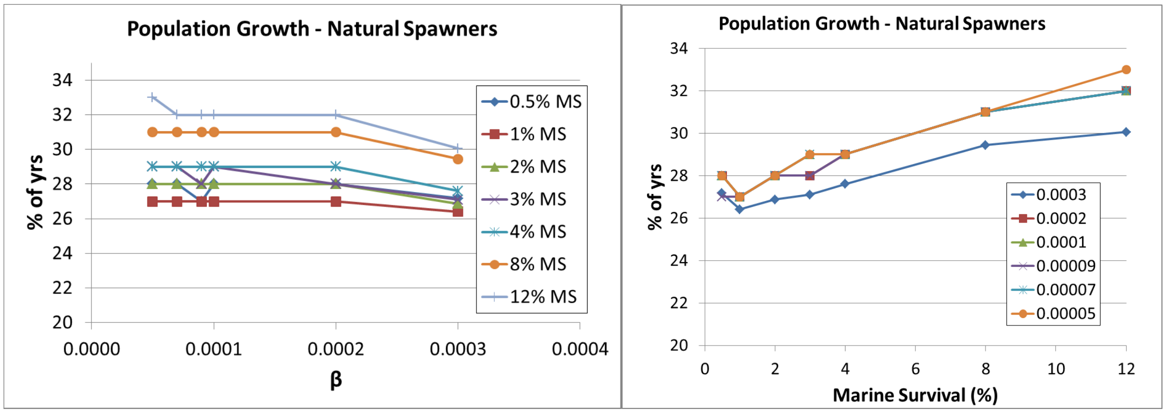

Figure 22 Ricker β parameter sensitivity analysis for population growth for natural spawners.

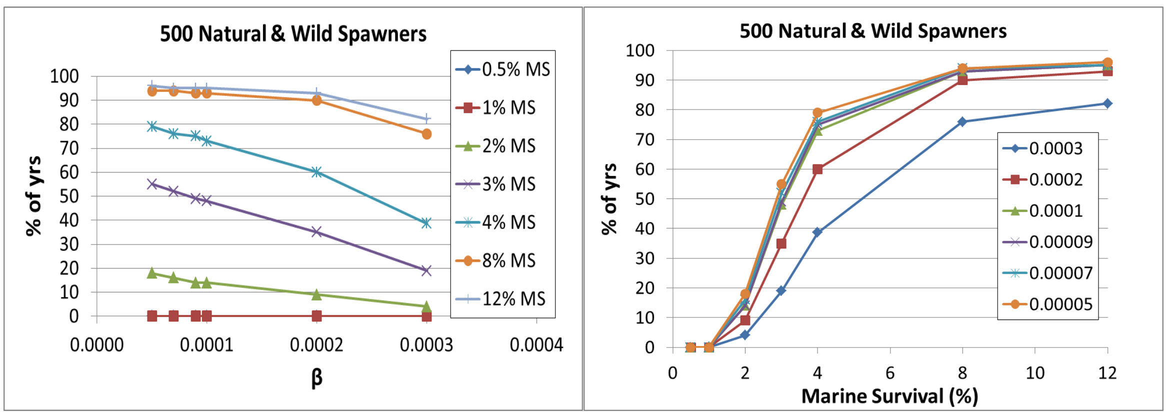

Figure 23 Ricker β parameter sensitivity analysis for 500 natural and wild spawners.

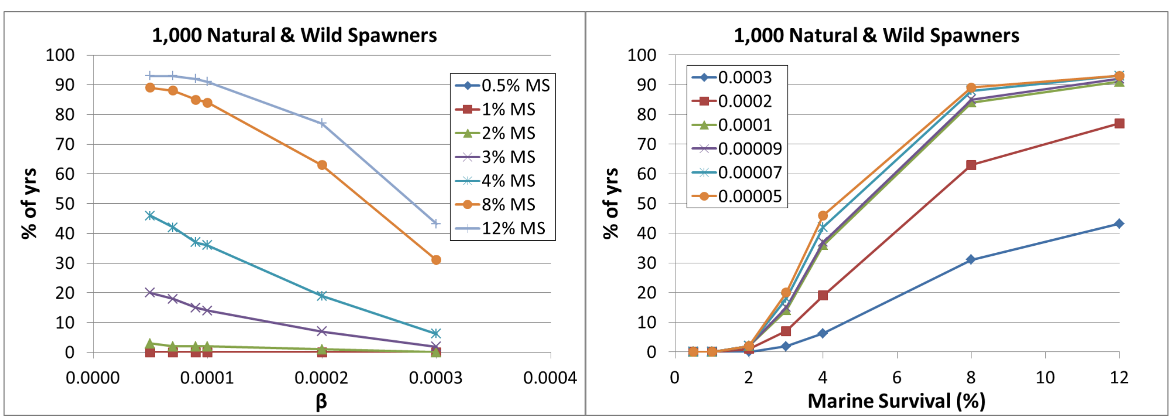

Figure 24 Ricker β parameter sensitivity analysis for 1,000 natural and wild spawners.

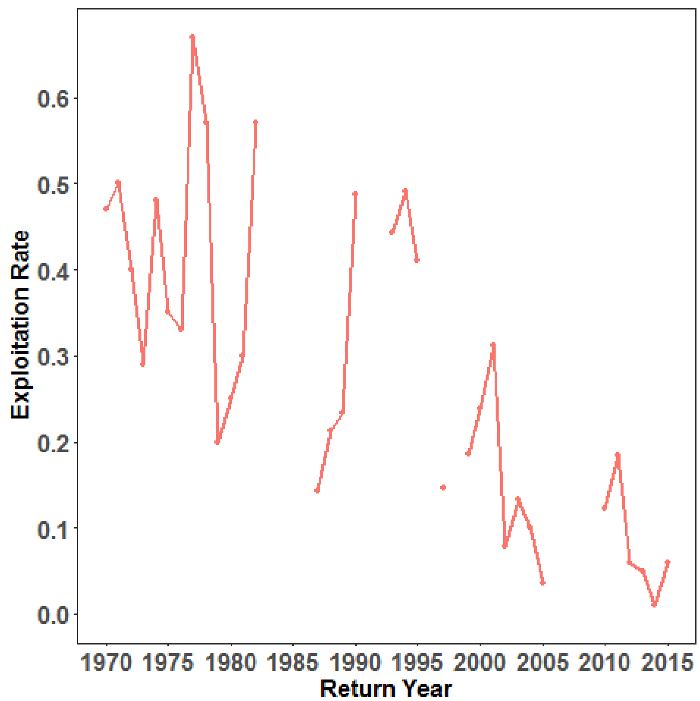

Figure 25 Exploitation rates of Sakinaw Sockeye from 1970 to 2015 (Starr 1984, Murray and Wood 2002, Folkes et al 2006 (unpublished), Folkes 2012a (unpublished), Folkes 2012b (unpublished), Folkes 2013 (unpublished), D. O'Brien, DFO, pers. comm.). Missing years either had poor test fishing estimates (1983 to 1985, 1991, 1992, 1996 and 1998) or 0 or 1 fish escaped (2006 to 2009) and exploitation rate could not be estimated.

APPENDIX A – SAKINAW SOCKEYE THREATS AND LIMITING FACTORS WORKSHOP SUMMARY

The full workshop report *Factors Limiting Sockeye Production in the Sakinaw Watershed: A Risk Assessment Methodology Incorporating Sockeye Biology Experts and Local Knowledge Experts* was compiled by Isobel Pearsall. A summary of the report is provided below.

BACKGROUND

DFO has developed a risk assessment methodology to aid in the identification and prioritization of factors that limit salmonid production, both now and in the future under various climate change scenarios. This methodology has been adapted from an "Ecological Risk Assessment for the Effects of Fishing" (ERAEF) framework that was initially developed to inform an ecosystem-based approach to fisheries management in Australia (Hobday et al., 2011).

The modified risk assessment methodology allows us to assess the biological risk posed by man-made and natural stressors acting on Pacific salmon throughout their life cycle in freshwater, estuarine and marine environments, utilizing a life history model approach to assess consequence of these stressors on the productivity and capacity of the population and its habitat.

The primary goal of the workshop was to solicit input on the threats and limiting factors that may affect Sakinaw Sockeye survival and to determine their relative impacts on production as well as identifying where critical knowledge gaps occur. Ranking of the factors posing the highest risk to current productivity of Sakinaw Sockeye will allow for effective prioritization of management responses.

The second goal of the workshop was to discuss the current and possible future recovery measures/strategies to stimulate the possible recovery of Sakinaw Sockeye through remediation, restoration and/or conservation.

RISK ASSESSMENT PROCESS

At the workshop a first pass (Level 1) risk assessment was conducted using expert opinion to determine the risk posed by human and natural factors limiting the productive capacity of the Sakinaw watershed to produce Sockeye salmon. These threats and limiting factors were assessed for two time frames, first based on "current conditions", and second based on "future conditions - 50 years in the future". Carrying out the analysis over these two time periods allowed us to examine how the impacts of various stressors are predicted to, or could change under ongoing climate change. At some future date, the highest ranked risks may be re-assessed based on more quantitative methods and relationships (Level 2).

The framework for this risk-assessment was based on accepted methods from the Government of Canada Treasury Board and Hobday (2011). These have been adapted to salmon in watersheds by evaluating the biological risk to each life history stage. Biological risk is determined from two variables: Exposure and Impact. The term "exposure" is synonymous with the term "likelihood" which is used in some risk assessment methodologies, while the term "impact" is synonymous with the term "consequence".

Thus, the biological risk of a threat or limiting factor was related to the amount of exposure that the population has to this factor (in both time and space) and the impact it has on the population. The impact is related to the percent change in the return of Sockeye to the river, but changes in key biological characteristics such as age at maturity, sex composition, fecundity, and run timing of the Sockeye populations were also considered. The following graph shows how biological risk increases as both impact and exposure increase.

Risk Assessment Scoring Process

During the workshop, the key threats and limiting factors that are affecting Sockeye returning to Sakinaw Lake were examined. An initial scoring of the “exposure” and “impact” for key threats and limiting factors was carried out by 2 anonymous reviewers prior to the workshop.

The group considered these scores, determined whether they agreed or not, and a final consensus score was reached by the group after discussion. The final consensus scores were placed into an Excel spreadsheet, and automatic calculations were performed to determine a final “Biological Risk Score”.

Colour-coding of these scores enabled easy visual interpretation of the level of risk for each threat or limiting factor, with dark red denoting “Very High Risk”, pale red “High Risk”, orange “Medium Risk” and pale green “Low Risk” or “Very Low Risk”.

Scoring the “Exposure” Term

Exposure is based on combining 1) the spatial scale of the threat or limiting factor, and 2) the temporal scale of the threat or limiting factor.

The methodology required expert opinions and/or knowledge of data or reports as each term was scored, and then discussed with others in the group to develop a consensus value. Rationale and citation of existing data/reports were documented. Once these two scores were entered into the Excel Spreadsheet, the final value for the “Exposure” term was automatically calculated.

a. The Spatial Scale Score

Threats and limiting factors are rated in terms of the spatial scale based on the percentage of the critical habitat of a particular life history stage which is affected, or on the percentage of the population itself that is affected (Table 19). A full rationale was provided for this score.

Critical habitat was defined as any area of habitat that is necessary for the survival or recovery of Sakinaw Sockeye.

Table 19 Spatial impact score guide.

Score	Level of spatial scale affected (by life history stage)
Low (1)	Less than 10% of the critical habitat or the population is affected
Moderate (2)	10-20% of the critical habitat or the population is affected
Medium (3)	30-40% of the critical habitat or the population is affected
High (4)	50%-70% of the critical habitat or the population is affected
Very High (5)	80% or more of the critical habitat or the population is affected

b. The Temporal Scale Score

The frequency at which an identified factor limits production of the species is called the "temporal score". The 5 categories of temporal frequency are described in Table 20 below.

The expert opinion on the temporal score was supported by a short rationale and/or citation of documented knowledge such as data or reports.

Table 20 Temporal impact score guide.

Score	Frequency of the threat or limiting factor occurring
Low (1)	Once per decade (Very rare)
Moderate (2)	Twice per decade (Occurs but uncommon)
Medium (3)	Three to four times per decade (Sometimes occurs)
High (4)	5-7 times per decade (Frequent)
Very High (5)	8 + times per decade (Continual)

Scoring the "Impact" Term

The "impact" score is based on the expected magnitude of impact of the factor on the subsequent adult return. Sockeye have a complex life history, with each stage susceptible to a myriad of factors which ultimately affect the number of adults returning to spawn. The possible impact scores related to change in subsequent return to river are shown in Table 21. Longer term change resulting from impacts on sex ratio, fecundity, age of maturity, size, etc. also could be significant.

Each expert participant decided upon the impact score for each threat or limiting factor, and then the group as a whole was required to agree on a score which was entered into the Excel spreadsheet for that particular threat or limiting factor. Again, the full rationale for how a particular impact score was derived was provided. If there was disagreement amongst the experts, or if key information was lacking, the Hobday method suggests the highest impact score be assigned to that particular factor.

Table 21 Impact criteria to score potential risk.

Level	Score	Description
Minor	1	Less than 10% change in subsequent return to river.
Moderate	2	11-20% change in subsequent return to river.
Major	3	21-30% change in subsequent return to river.
Severe	4	31-50% change in subsequent return to river.
Critical	5	50% + change in subsequent return to river.

Recording the uncertainty/confidence levels in scores

There is always some level of uncertainty associated with predicting impacts of any threat or limiting factor on fish or fish habitat. Uncertainty can arise due to a lack of information, or could arise when predicting the effectiveness of new or innovative mitigation measures. In addition, there may be synergistic effects where two or more effects in combination express an effect greater than would have been expressed individually. These are difficult to identify and hence have the potential of being overlooked or underestimated. Acknowledging this uncertainty does not preclude making sound management decisions, but the uncertainly does need to be described and taken into account at this risk assessment stage.

Thus, this risk assessment methodology requires that workshop participants provided confidence ratings for the risk scores that are produced from the Level 1 risk assessment. These ratings may be 1 (low confidence) or 2 (medium confidence) or 3 (high confidence) (Table 22).

Table 22 Confidence scores.

Confidence	Rationale
Low	• Data exist but are considered poor, or conflicting, or • No data exist, or • Substantial disagreement among experts
Med	• Data exist but some key gaps • Some disagreement between experts
High	• Data exist and are considered sound, or • Consensus between experts, or • Risk is constrained by logical consideration

Current and Future Trends

Finally, workshop participants were also be asked to provide scores for the following:

Current Trend –In the context of the last 10 years is this threat or limiting factor increasing, decreasing or showing no trend? Score this between (1) strongly decreasing, (2) somewhat decreasing, (3) stable, (4) somewhat increasing, and strongly increasing (5).

Future Trend – What will be the trend 50 years from today? This will require workshop participants to discuss the predicted impacts of climate change. Score this between (1) strongly decreasing, (2) somewhat decreasing, (3) stable, (4) somewhat increasing, and strongly increasing (5).

Table 23 Results of Sakinaw Sockeye risk assessment scoring.

A. Terminal Migration & Spawning

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1. Safe holding habitat in estuary/river prior to lake entry	LF1: Large losses from predation	5	5	5	H	Very High	3	3	Very High
2. Large volume of preferred water (VOPW, low temp, high O2) in estuary & Sakinaw creek	LF2: Significant reductions in water quality in estuary and Sakinaw creek (i.e. high temp, low O2) which impact migration	1	1	1	H	Very Low	3	3	Very Low
3. Adequate flows to facilitate upstream passage of spawners	LF3: Low flows delay, prevent passage at lake entry & increases pre-spawn losses.	1	1	1	H	Very Low	3	3	Very Low
4. Unrestricted access though fishway and rock weirs	LF4: Obstructions causing delays or lack of passage at fishway, rock weirs or dam during migration.	1	1	1	H	Very Low	3	3	Very Low
5. Adequate water quality in the lake	LF5. Reductions to lacustrine water quality	1	1	1	H	Very Low	3	3	Very Low
6. Spawning habitat quantity sufficient to fully "seed" fry rearing habitat.	LF6: Inadequate spawning habitat (i.e. production potential limited by initial fry recruitment, not lake carrying capacity)	1	1	1	M	Very Low	4	5	Moderate
7. Low levels of predation in the lake and spawning grounds.	LF7a. Bear predation, otter, bird seal predation on holding and spawning adults	1	1	1	H	Very Low	3	3	Very Low

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
7. Low levels of predation in the lake and spawning grounds.	LF7b: Mortality due to unauthorized fishing	1	1	1	H	Very Low	3	3	Very Low
8. Minimal anthropogenic disturbance to spawning grounds	LF8: Disturbance to natural spawning activity due to anthropogenic impacts	1	1	1	H	Very Low	3	3	Very Low

B. Freshwater Incubation

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasin g5=significan t increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1.H2O quality doesn't limit incubation success	LF10: H2O quality limits incubation success	1	1	1	M	Very Low	3	3	Very Low
2.Stable flow regime	LF11a: Variable to low water levels lead to fall-winter exposure and desiccation risk to eggs and alevins.	1	1	1	H	Very Low	3	3	Very Low
	LF11b: Variable to high water levels leading to redd scour & egg losses.	1	1	1	H	Very Low	3	3	Very Low
3.Appropriate spawning gravel	LF12: Quality limits incubation success i.e.high losses due to fines deposition, egg/alevin burial.	1	1	1	H	Very Low	3	4	Low
4.Minimal disturbance to redds	LF13: Biodisturbance of redds.	1	1	1	H	Very Low	3	3	Very Low

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
5.Minimal predation of eggs and alevins	LF14: Predation on eggs and alevins by sculpins, Cutthroat Trout, Peamouth Chub, Coho, birds etc.	5	5	4	L	Very High	3	3	Very High

C. Freshwater Rearing

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1. Adequate water quality exhibiting moderate temp, high oxygen, low light for summer rearing; low temp, high oxygen, low light for over-wintering.	LF16: Reductions in water quality severe enough to reduce average carrying capacity of lake for fry-smolt production.	1	1	1	H	Very Low	3	3	Very Low
2. Nutrient levels support the carrying capacity for fry-smolt production.	LF17: Variable to low nutrient levels reduce average carrying capacity of lake for fry-smolt production.	1	1	1	H	Very Low	3	3	Very Low
3. Stable food-web structure supports historic average carrying capacity for fry-smolts.	LF18: Variable food-web structure (spp changes) leads to sub-average carrying capacity for fry-smolts.	3	3	3	L	Moderate	3	3	Moderate
4. Adequate water levels	LF19: Variable to low water levels leading to stranding or increased predation.	1	1	1	H	Very Low	3	3	Very Low

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
5. Low levels of intraspecific competition associated with carrying capacity limits for wild fry-smolt production	LF20: High levels of intraspecific competition (from wild or hatchery-origin fish) reduce carrying capacity for wild fry-smolts.	1	1	1	H	Very Low	3	3	Very Low
6.Low levels of interspecific competition or predation associated with carrying capacity limits for wild fry-smolt production.	LF21: High levels of competition or predation (from native or exotic spp) reduce lake carrying capacity for wild fry-smolts.	5	5	3	L	High	3	3	High
7.Low levels parasitism associated with carrying capacity limits for wild fry-smolt production.	LF22: High rates of parasitism reduces the lake carrying capacity for wild fry-smolts.	5	5	3	L	High	3	3	High
8.Lack of other sources of interference	LF 23: Interference (noise/light) from boats, float-homes and summer cottages.	1	1	1	H	Very Low	3	3	Very Low
9. Low levels of fish disease	LF24: Mortality of fitness impacts as a result of disease e.g. due to IHN, BKD etc.	1	1	1	L	Very Low	3	3	Very Low
10. Adequate rearing habitat	LF25: Mortality or fitness impacts as a result of loss of habitat.	1	1	1	H	Very Low	3	3	Very Low

D. Marine Migration/Rearing

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1. Physical integrity and connectivity of habitat adequate to satisfy inshore staging, rearing or early seaward migration requirements.	LF27: Habitat integrity degraded sufficiently to negatively impact smolt staging, rearing or early seaward migration requirements.	1	1	1	H	Very Low	4	5	Moderate
2. Water quality of estuarine and nearshore habitat adequate to satisfy: inshore staging, rearing, or early seaward migration requirements.	LF28: Water quality of estuarine habitat inadequate to satisfy: early staging, rearing, or seaward migration requirements.	1	1	1	H	Very Low	3	4	Low
3. Competition with other salmon does not exceed historic reference range associated with average to above average growth, survival, returns of Sakinaw Sockeye.	LF29: Competition exceeds historic reference range and is associated with density dependent growth or survival outcomes that are negative for Sakinaw Sockeye.	4	4	4	L	High	3	4	Very High
4. Minimal competition or predation from aquatic invasive species (AIS).	LF30: High mortality due to predation and competition of AIS on Sockeye in the N. Pacific.	1	1	1	H	Very Low	3	3	Very Low
5. Minimal aquatic pollutants (oil, PDBEs, PCBs, DDT, Hg, pesticides, herbicides etc…)	LF31: Elevated mortality or sub-lethal effects due to aquatic pollutants.	3	3	3	L	Moderate	3	5	Very High
6. "Cool-ocean" food-webs favor average to above average smolt-to-adult survival for salmon and average to above average returns.	LF32: "Warm-ocean" food-webs favor below average smolt-to-adult survival for salmon and below average returns.	5	4	5	M	Very High	3	5	Very High

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
7. Predator abundance within reference range associated with average to above average survival and returns.	LF33: Predator abundance and assumed levels of predation on smolts exceed reference range. State change is associated with reduced survival and well below average adult returns.	5	5	5	H	Very High	3	4	Very High
8. Harmful algal bloom frequency and magnitude within reference range associated with average to above average survival.	LF34: Harmful algal bloom frequency & magnitude above "normal" reference range and are associated with below average survival.	1	1	2	L	Very Low	3	3	Very Low
9. Parasite or pathogen incidence and impacts on growth or survival remain at endemic (versus epidemic) levels associated with average to above average smolt growth, survival and adult returns.	LF35: Parasite or pathogen incidence & impacts on growth or survival expressed at epidemic levels associated with below average growth, survival and adult returns.	4	4	3	L	Moderate	3	3	Moderate

E. Harvest

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1. Sustainable Fishery impacts	LF36: Overfishing with result that target escapements are not met.	2	3	2	H	Low	3	3	Low

F. Hatchery Impacts

Life History Requirement	Threat/Limiting Factor	SPATIAL SCALE What % of the critical habitat is affected? (1 low to 5 high)	TEMPORAL SCALE How often in 10 years will this happen? (1 rarely to 5 frequent)	IMPACT What will be the change in returning adults? 1=low to 5=high impact	CONFIDENCE How much confidence do you have in this scoring? L=low M=medium H=very confident	Current Biol. Risk category	Current Trend 1=decreasing 5=significant increase	Future trend (over the next 50 years). 1=decreasing 5= significant increase	Future Biological Risk Category
1. Appropriate rearing conditions resulting in high hatchery survival e.g appropriate water quality, temperature, lack of disease, no overcrowding etc.	LF37. High mortality of hatchery egg to eyed egg stage.	1	1	1	H	Very Low	3	3	Very Low
2. Appropriate rearing conditions resulting in high hatchery survival e.g. appropriate water quality, temperature, lack of disease, no overcrowding etc.	LF38. High mortality of hatchery egg to fry stage.	1	1	1	H	Very Low	3	3	Very Low
3. Low competition or predation impacts when hatchery fry are released into the lake	LF39: High mortality of hatchery fry to smolt stage.	3	4	3	M	Moderate	3	3	Moderate
4. Fitness of hatchery production is not compromised due to domestication	LF40: High mortality of hatchery smolt to adult stage due to domestication impacts and lowered fitness.	1	1	1	H	Very Low	5	5	Moderate

APPENDIX B – POPULATION VIABILITY ANALYSIS BACKGROUND

The PVA model was constructed based on a smolt-spawner recruitment relationship. The data for Sakinaw Sockeye were limited with only 13 data points (Table 24). Our likelihood formulation assumes that error in predicted smolt numbers is log normally distributed. We estimated parameters of the spawner-to-smolt recruitment relationship by maximizing the log of the Bayesian probability of the parameters given the data (Korman and Grout 2008). See Korman and Grout (2008) for more details.

Model fit was insensitive to α and β priors. The freshwater production variance (sigma) was very high (1.5) due to a limited amount of smolt-spawner data. If the large variation were to hold true for a larger data set, recovery targets of relatively low abundance (e.g. 1,000 spawners) would not be met very frequently (< 20% probability) even at a relatively high (8%) marine survival rate. Therefore, we assumed that with a larger dataset for Sakinaw Sockeye it would have a variance more similar to Cultus Lake Sockeye and used that model's (Korman and Grout 2008) value of 0.61.

The parameter δ in the Cultus model controlled the extent of the depensation and is the number of effective spawners needed to reduce the expected number of recruits by 50% relative to a model without depensation. In the case when δ=0 (no depensation), e^{α} represents freshwater stock productivity (i.e., maximum smolts/spawner if δ =0) and 1/β is the spawning stock size at which smolt production is maximized (sometimes referred to as S_{opt} or carrying capacity if δ =0). This parameter was set to 0 in simulations for this assessment as there was limited data to determine whether depensation was occurring.

Marine survival data were limited to years when marine survival was low (2001 to 2014 BY). This gave us very little information regarding the smolt-spawner relationship at higher marine survival rates. The mean wild and natural marine survival was 0.0049. The average standard deviations were computed on log-transformed values standardized around a mean of 0 to be consistent with the simulation approach. The standard deviation was very large (3.18, logit space) due to years with 0% marine survival and limited data. The variance is likely positively biased due to the very large uncertainty in the estimated number of Sakinaw Sockeye recruits in the catch. Therefore, we used Chilko Sockeye variance (n=51, SD=0.63, logit space), similar to the approach by Korman and Grout (2008), as both smolt numbers and catch are relatively well determined for this stock.

Similar to marine survival, there were not sufficient data to calculate the proportion returning at age 4 for Sakinaw Lake Sockeye so the mean and SD for Cultus Lake Sockeye was used (logit space: 4.70 and 2.23, respectively). The average exploitation rate from 2011 to 2015 (return year) was 5%. This value was used as the current exploitation rate for model simulations (Figure 25). A sex ratio of 0.5 was also assumed.

The PVA model does not account for the potential deterioration of fitness in hatchery-reared fish, nor any of the risks that are necessarily associated with a long-term hatchery operation, such as disease outbreaks or equipment failures.

The hatchery program does not use supplementation (i.e., capturing returning adults for spawn and raise their eggs in the hatchery) for supplying fry to Sakinaw Lake. Therefore, this portion of the PVA model was not used for Sakinaw Sockeye.

Table 24 Sakinaw Sockeye spawner and unclipped smolt data used for smolt-spawner model fitting.

Brood Year	Spawners	Unclipped Smolts
1992	1,000	15,880
1993	250	12,760
1994	250	2,500
2001	58	4,334
2002	62	103
2003	3	11
2004	37	2,926
2005	14	272
2006	1	182
2011	555	27,960
2012	243	4,435
2013	143	632
2014	464	722

Table 25 Summary of model indices and state variables. Note list of error terms is not inclusive of all stochastic elements in the model but only those defined in text describing model.

Indices

Variable or subscript	Description
Stock type (st)	St= W for wild, H for hatchery, U for unclipped
Year (t)	Year

State Variables

Variable or subscript	Description
Sm	# of Smolts
p	Proportion of effective spawners (pW+pH+pU=1)
Sp	# of spawners
R	# of pre-fishery recruits
pa	Proportion of adults returning by age
MS	Marine survival rate
Esc	# of spawners at weir
C	# of pre-fishery recruits that are caught
$\hat{R}$	# of forecasted pre-fishery recruits
Brood	# of spawners taken for broodstock
h	Harvest rate (a state variable if not fixed)
PSM	Pre-spawn mortality rate

State Variables for Hatchery Stock

Variable or subscript	Description
SupEggs	Total eggs collected for hatchery production at fence
CBEggs	# eggs produced from captive broodstock
Fry_H	# fed fry produced in the hatchery and released to lake

Error Terms (used in text)

Variable or subscript	Description
v	Residual from spawner-smolt relationship
ω	Residual from expected marine survival rate
τ	Residual from expected recruitment

Table 26 Initial conditions used for simulation. Exploitation rate for 2016 was assumed.

Calendar Year	Wild Spawners	Hatchery Spawners	Wild Smolts	Exploitation Rate	Captive Brood Eggs	Supplemental Eggs	Fed Fry
2010	1	15	-	-	-	-	0
2011	0	527	-	-	-	7,076	0
2012	243	0	-	0.06	-	-	0
2013	0	143	27,960	0.05	-	-	856,205
2014	0	464	4,435	0.01	-	-	320,416
2015	239	482	632	0.06	860,213	-	644,699
2016	27	145	722	0.05	449,555	-	329,077

Table 27 Summary of default parameters used in PVA simulation. Note that α, β, σ, and δ values used in the simulation are random draws from a posterior distribution generated from the historic spawner and smolt data and prior distributions specified in the table. Other parameter values used in alternate model scenarios are shown in Table 29. See Table 28 for parameters that influence hatchery production.

Stochastic Variables

Parameter	Description	Estimate
α	Smolts/spawner at low stock size	Posterior (uniform prior)
β	Density dependence in smolt production	Posterior(normal prior: $1/\mu_\beta$=4,700, σ_β(CV)=1.0)
σ	SD of spawner-to-smolt relationship	Sample from posterior. (Used Cultus Sockeye value 0.61)
μ_a	Mean proportion at age a = 4 (Cultus)	4.695 (in logit) 0.96 (in linear)
σ_a	Standard deviation in proportion at age a=4 (Cultus)	2.229 (in logit) 0.07 (in linear)
μ_{ms}	Arithmetic mean marine survival rate	0.0049 (see Table 29)
σ_{ms}	SD of log-transformed marine survival rate (Chilko)	0.63 (see Table 29)
ρ_{ms}	Lag-1 autocorrelation in marine survival rate	0.505 (see Table 29)
μ_{psm}	Arithmetic mean of pre-spawn mortality rate	0.10 (see Table 29)
σ_{psm}	SD of log-transformed pre-spawn mortality rate	0.05 (see Table 29)
ρ_{psm}	Lag-1 autocorrelation in pre-spawn mortality rate	0
σ_{for}	SD of pre-season forecast (log space)	1.0

Deterministic Variables

Parameter	Description	Estimate
E	Relative increase in number of naturally-spawned smolts produced due to freshwater enhancement	See Table 6
h_t	Harvest rate due to fishing	See Table 6
GenLimit	Generational average population size that must be equal to or exceeded to meet recovery target 1 and 2	500 or 1000 (recovery target 1 and 2, respectively)
CycleLimit	Cycle-specific population size that must be equal to or exceeded to meet recovery target 1 and 2	100 or 500 (recovery target 1 and 2, respectively)
ExtLimit	Population size that must be equal to or exceeded to avoid quasi-extinction	50

Table 28 Summary of PVA model parameters that determine hatchery production. Other parameter values used in alternate model scenarios are shown in Table 29.

Parameter	Description	Estimate
h_H	Maximum harvest rate on unclipped returns to weir due to broodstock capture	0.5
MaxTake	Maximum number of unclipped returns taken for broodstock	0
Fecundity	Average fecundity of captive brood fish	1,773
WF	Average fecundity of wild fish	2,049
sx	Proportion of females in broodstock	0.5
CBEggTake	Number of eggs retained from captive brood to create the next generation of captive brood fish	Captive brood size x 1.1
CBEggs	Total number of eggs produced from captive brood in a given year	(Captive brood size x sx x Fecundity) – CBEggTake
FryCap	Capacity of hatchery to produce fed fry for release	2,000,000
CBEgg_EyedEgg_Surv	Egg to eyed egg survival rate for captive brood eggs	0.8
Egg_FedFry_Surv	Eyed egg to fed fry survival rate for captive brood eggs	0.89
Lake_FedFry_Smolt_Surv	Survival rate from release of fed fry in lake to migration past fence as smolt	0.14
ϕ_{st}	Relative marine survival of hatchery (st=H) and unclipped stocks (st=U)	ϕ_H =0.47, ϕ_U =1.0
E_H	Relative improvement in in-lake survival of hatchery fish due to habitat improvement	Varied from 1 to 2

Table 29 Summary of management scenarios and parameter values used in the PVA. Current or baseline parameter values are highlighted in bold.

Parameter Name	Parameters	Scenario	Values
Posteriors	α, β, σ	All	2.888, 0.00033, 0.61 (Cultus)
Harvest Rate	E_{min}, h, ER_{cap}	Current	0,0.05, 1
		Varying ER	0, 0.05, 0.1, 0.15
Marine Survival Rate	μ_{ms}/σ_{ms} $/\rho_{ms}/\omega_{t-1}$	Current	0.0049/0.63/2.86/0.505
		Increasing MS	(0.02, 0.04, 0.06…)/0.63/2.86/0.505
Pre-spawn Mortality Rate	μ_{PSM}/σ_{PSM} $/\rho_{PSM}$	Current	0.03/0.05/0
Freshwater Habitat Enhancement	$E/E_d/E_H/$	Current	1.0
	E/E_H	Enhancement	1.5/1.5 and 2.0/2.0
Survival of Hatchery Smolts Relative to Wild Smolts	Φ_H	Current	0.47
Reproductive Success of Clipped Spawners	Φ_U	Current	1
Hatchery Capacity	FryCap	2,000,000 fry	2,000,000
Hatchery Operation		No captive brood or supplementation	
		Captive brood only	750 adults

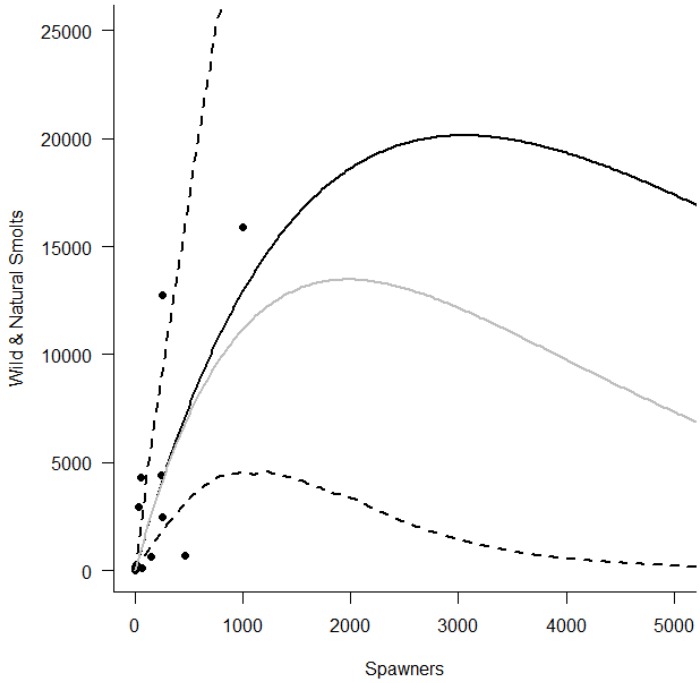

Figure 26 Model fits and 95% confidence limits for Sakinaw Sockeye wild and natural smolts-to-all spawners. Dotted lines are 95% confidence limits for Bayesian fit, black line is Bayesian fit with prior and grey line is regression fit with no prior.

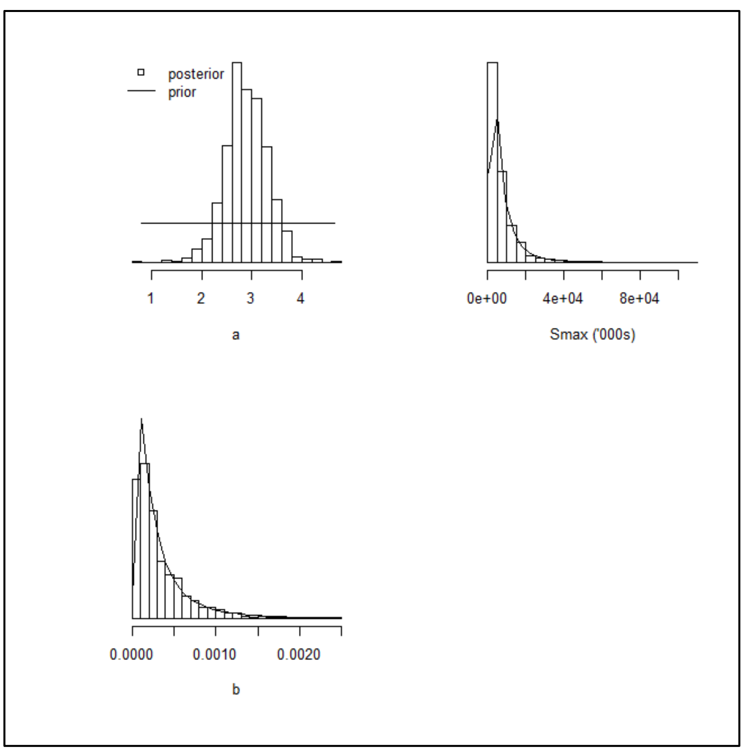

Figure 27 Bayesian prior and posterior distributions of Ricker alpha and beta parameters.

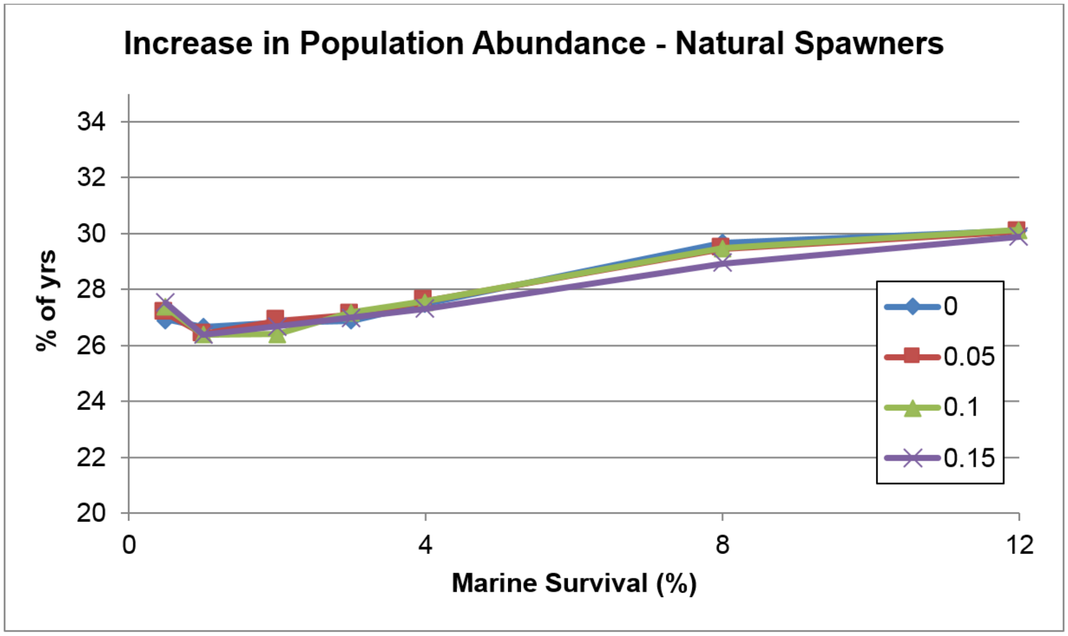

Figure 28 Probability of achieving an increase in population abundance (stock state indicator 1) with increasing marine survival over various exploitation rate scenarios.

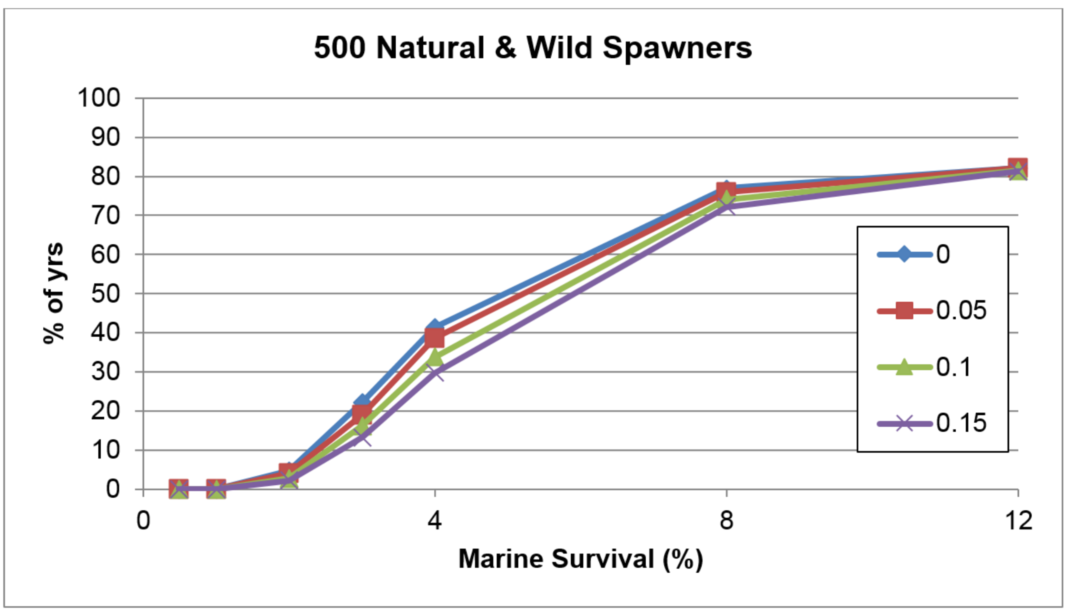

Figure 29 Probability of achieving 500 natural and wild spawners (stock state indicator 2) with increasing marine survival over various exploitation rate scenarios.

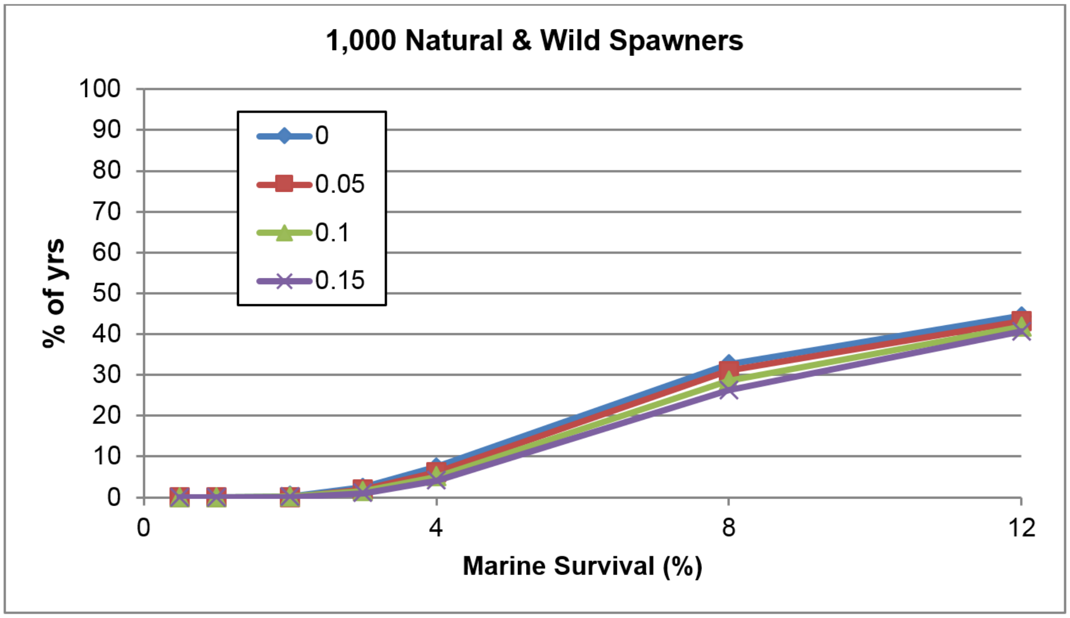

Figure 30 Probability of achieving 1,000 natural and wild spawners (stock state indicator 3) with increasing marine survival over various exploitation rate scenarios.

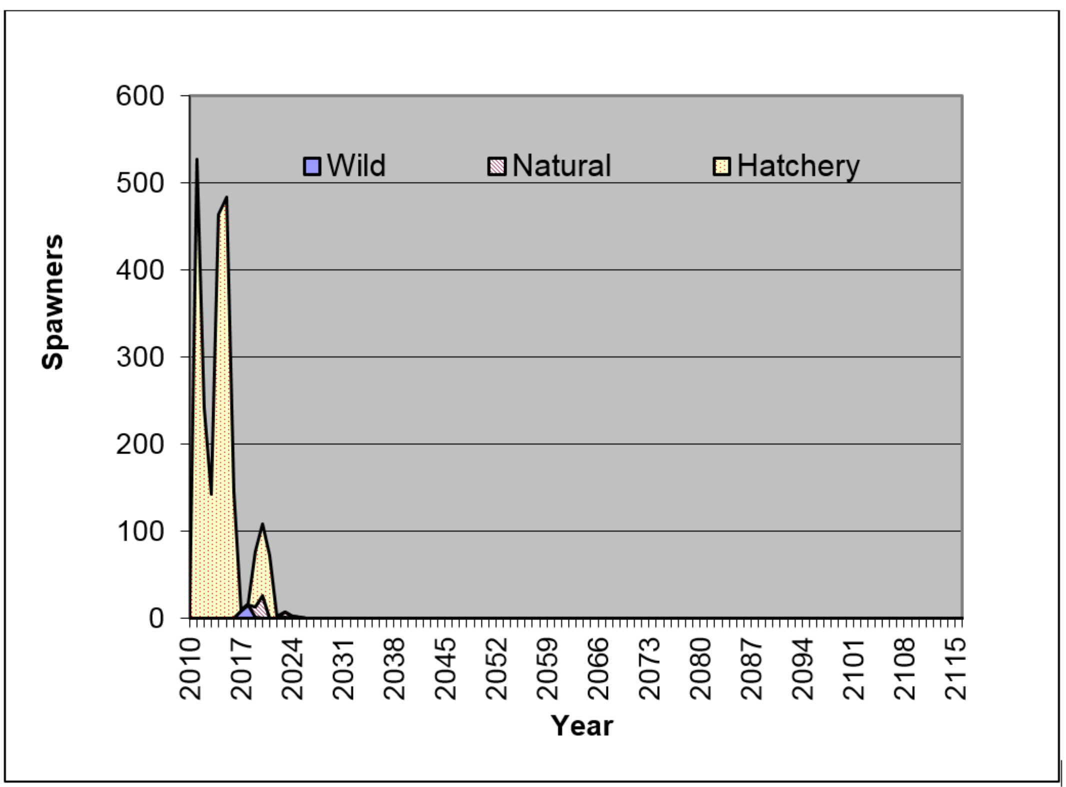

Figure 31 One trial of a PVA simulation for current conditions with no captive brood program.

APPENDIX C – OVERVIEW OF SAKINAW LAKE SOCKEYE POPULATION VIABILITY MODEL

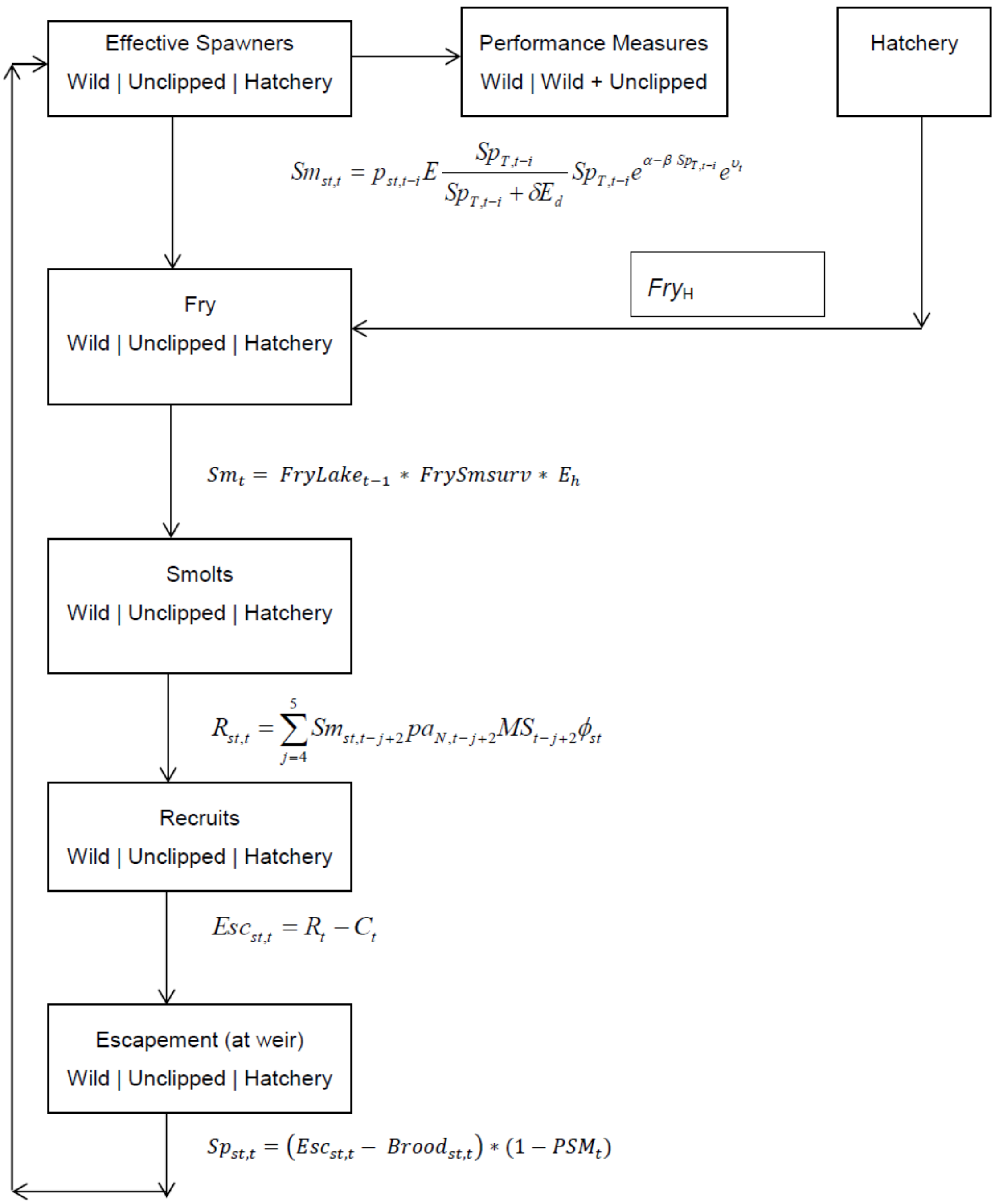

Figure 32 Overview of Sakinaw Lake Sockeye population viability model. See Korman and Grout (2008) for description of equations and additional ones not shown here.

APPENDIX D – OVERVIEW OF THE HATCHERY COMPONENT FOR THE SAKINAW LAKE SOCKEYE POPULATION MODEL

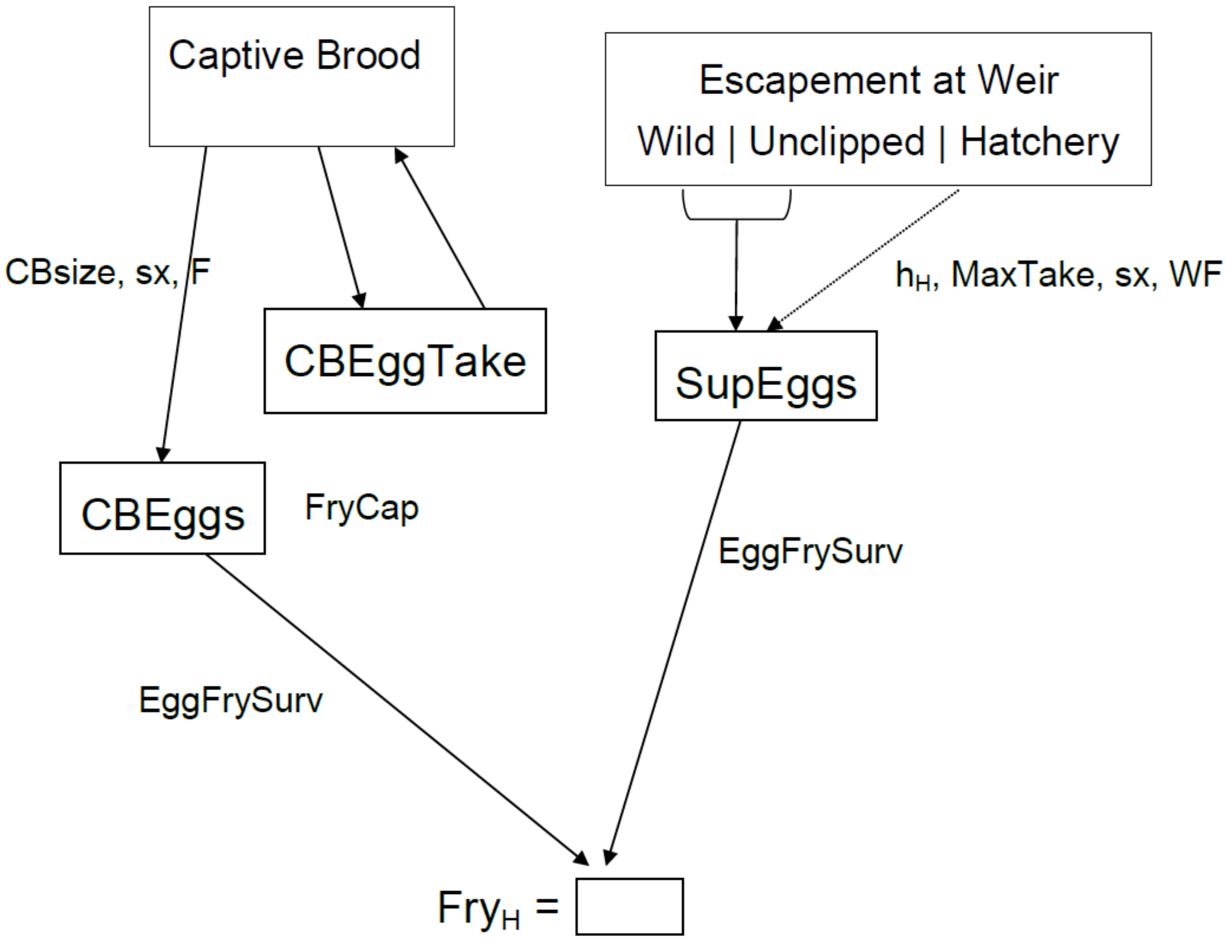

Figure 33 Overview of hatchery component of Sakinaw Lake Sockeye population viability model. See Table 28 and Table 29 for definitions of terms. Supplemental egg collection (SupEggs) from the weir was not included in the modeling for this assessment but can be included if required.

APPENDIX E – SAKINAW LAKE SOCKEYE SIMPLE LIFE HISTORY MODEL

Table 30 Present day scenario life stage mortality rates, escapement, rate of change and recruits per spawner.Red numbers are known with some confidence, black are estimated from biostandards or anecdotal observations, green values are estimates from the scientific literature.

Present Day Scenario				
	Affecting Rate	**Life Stage**	**Sockeye**	**Mortality Rates**
A. Terminal Migration & Spawning	Mature Adult	Upstream adults	500	10%
		Spawners	450	-
B. Freshwater Incubation	Egg to Fry	Eggs laid	461,025	91.0%
C. Freshwater Rearing	Fry to Smolt	Fry	41,492	80.8%
D. Marine Migration/Rearing	Marine Survival	Smolts	7,967	99.5%
E. Harvest	Exploitation	Wild adult recruits	39	5.0%
		Escapement	**37**	-
		Rate of Change	**-93%**	**-**
		Recruits/Spawner	**0.07**	**-**

Table 31 Present day scenario life stage mortality rates, escapement, rate of change and recruits per spawner. Red numbers are known with some confidence, black are estimated from biostandards or anecdotal observations, green values are estimates from the scientific literature.

Increased Marine Survival Scenario – 7.0%				
	Affecting Rate	**Life Stage**	**Sockeye**	**Mortality Rates**
A. Terminal Migration & Spawning	Mature Adult	Upstream adults	500	10%
		Spawners	450	-
B. Freshwater Incubation	Egg to Fry	Eggs laid	461,025	91.0%
C. Freshwater Rearing	Fry to Smolt	Fry	41,492	80.8%
D. Marine Migration/Rearing	Marine Survival	Smolts	7,967	93.0%
E. Harvest	Exploitation	Wild adult recruits	558	5.0%
		Escapement	**530**	-
		Rate of Change	**+6%**	-
		Recruits/Spawner	**1.06**	-