Fisheries and Oceans Canada | Pêches et Océans Canada
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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2020/011

RECOVERY POTENTIAL ASSESSMENT – CULTUS LAKE SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) (2019)

Sockeye Salmon spawning on submerged talus slopes in Cultus Lake. Image credit: Fisheries and Oceans Canada

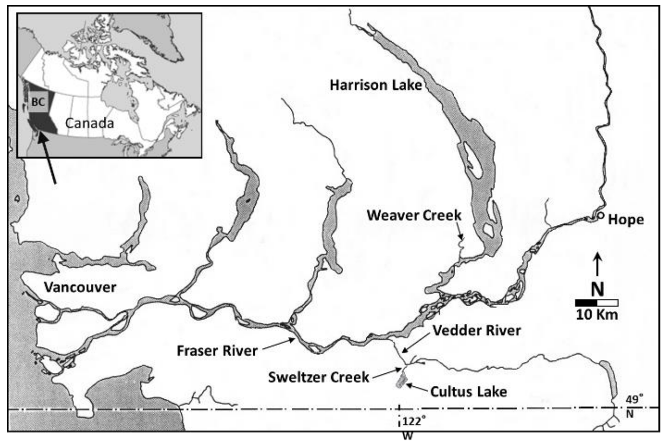

Figure 1. Map showing location of Cultus Lake.

Context:

Cultus Lake Sockeye Salmon are one of 10 Fraser River Sockeye Salmon Designatable Units (DUs) that were assessed in 2017 as threatened or endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Cultus Sockeye Salmon have been declining in abundance for the last 40 years, and the declining trend and current low abundance resulted in the DU being assessed as endangered.

DFO Science was asked to complete a Recovery Potential Assessment (RPA) to provide science advice to inform a potential listing recommendation for the addition of these 10 Fraser River Sockeye Salmon DUs to Schedule 1 of the Species at Risk Act (SARA). The advice in the RPA may be used to inform both scientific and socio-economic elements of the listing decision, as well as 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 should the species be listed. Due to some unique aspects of the Cultus DU (ongoing hatchery program and other mitigation measures, rich data availability), a separate RPA was conducted specifically for this DU. Two other RPAs are anticipated for the other 9 DUs.

This Science Advisory Report is from the October 7-10, 2019 regional peer review on Recovery Potential Assessment – Fraser River Sockeye Salmon (Oncorhynchus nerka) – Ten Designatable Units. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Cultus Lake Sockeye Salmon are the Designatable Unit (DU) of Sockeye Salmon (*Oncorhynchus nerka*) that spawn in Cultus Lake, British Columbia (BC). This DU was first assessed as Endangered in an emergency assessment by the Committee on the Status of

Endangered Wildlife in Canada (COSEWIC) in 2002 and confirmed as Endangered by COSEWIC in 2003 and again in 2017.

- Historically (1921-1970), the 4-year average abundance was 19,890 spawners but in the mid-1970s the population began to decline in abundance. Since 2006 the spawning population has been augmented by hatchery supplementation. The most recent (2015-2018) generational average of adults spawners entering the lake was 254 natural-origin and 941 hatchery-origin fish.
- Since 2010, the poor status of the population can be primarily attributed to very low rates of smolt production from the lake. Smolt-to-adult survival has also declined since the 1990s.
- Cultus Lake is undergoing cultural eutrophication, mainly resulting from excess anthropogenic nutrient loadings to the lake from the watershed and atmospheric deposition from the nutrient-contaminated regional airshed. These potentially reversible changes are generating conditions in the lake that are unsuitable for all Sockeye Salmon freshwater life stages occurring there.
- Redds, the spawning nests constructed by Pacific salmon and other species, meet the definition of a “residence” under the Species at Risk Act (SARA).
- The main anthropogenic threats and limiting factors identified for Cultus Lake Sockeye Salmon include: lake eutrophication, adult mortality associated with change in migration timing, fisheries interceptions, and climatically-mediated variability and change in freshwater habitat conditions.
- A recovery target based upon a 4-year mean of 7,000 adults entering the lake is proposed. A survival target of 2,500 adults entering the lake is also proposed. These targets may include hatchery fish if the hatchery program is designed to minimize risks to the wild population. Quantitative guidelines for hatchery supplementation are provided.
- An empirically-based population model was used to estimate the probability that the population would reach the survival and recovery targets under scenarios that evaluated key mitigation measures: hatchery supplementation, limits to fishing mortality and improving freshwater population productivity. The results showed that the probability of reaching either the survival or recovery target in 12 years (3 generations) under current conditions is unlikely, although some scenarios that included hatchery supplementation and freshwater mitigation resulted in population growth that could result in recovery over a longer period.
- Recovery or survival of a natural, self-sustaining, population will require successful mitigation of the cause of low smolt production in the lake. This could include measures to mitigate nutrient inputs to reduce cultural eutrophication that has increased over the last decade. Otherwise, the natural-origin population is predicted to continue to decline.
- Given the negative population growth rate there is no allowable harm for this population. If threats to freshwater productivity can be mitigated, and ocean survival does not decline further, it is possible that recovery could occur under limited allowable harm.
- Key uncertainties that may impact the potential for recovery include the effectiveness of measures to improve conditions in Cultus Lake for Sockeye Salmon, future changes in the survival of smolts in the ocean and rates of prespawning mortality of adults, and long-term effects of hatchery supplementation on the fitness of the natural-origin population.

INTRODUCTION

Rationale for Recovery Potential Assessment

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO), as the responsible jurisdiction for aquatic species under the *Species at Risk Act* (SARA), undertakes several actions to support implementation of the Act. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the species' potential for recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) following the COSEWIC assessment. This timing allows for the consideration of peer-reviewed scientific analyses within SARA processes, including the decision whether or not to list a species on Schedule 1, and during recovery planning if the species is listed.

Cultus Lake Sockeye Salmon are the Designatable Unit (DU) of Sockeye Salmon (*Oncorhynchus nerka*) that spawn in Cultus Lake, British Columbia (BC). This DU was first assessed as Endangered in an emergency assessment by the Committee on the Status of Wildlife in Canada (COSEWIC) in 2002 and confirmed as Endangered by COSEWIC in 2003 and again in 2017. The most recent assessment was based on the small population size and recent declining trends in adult abundance.

Cultus Lake

Cultus Lake is a small (6.3 km^2) coastal lake located in the Fraser Valley, east of Vancouver BC. Sockeye Salmon use the lake for spawning and as juvenile nursery habitat. The lake is an important recreational area and receives millions of visitors each year. The lake has been affected by local development (sewage inflows, land and shoreline development, invasive species) as well atmospheric nutrient inputs and climate change. Cultus Lake drains into the Vedder River via Seltzer Creek and then the Fraser River, which forms the migratory route for juvenile and adult Sockeye Salmon as they travel to and from the ocean. The migratory corridor has been impacted by dyking, channelization, gravel extraction and other industrial activities.

Biology, Abundance, Distribution and Life History Parameters

Biology

The life history of Cultus Lake Sockeye Salmon is typical of most lake-type Sockeye Salmon in the Fraser River. Adult spawners return from the ocean in late summer and fall and enter Cultus Lake where they spawn in the lake beginning in late November. The location and characteristics of spawning habitat are not well understood due to the difficulty in observing fish at depth. Eggs are buried in spawning nests (called redds) and juveniles emerge in spring to take up residence in the lake. Nearly all juveniles leave Cultus Lake the following spring as one-year old smolts. Most Cultus Sockeye Salmon (>90%) spend slightly more than two years in the ocean before returning as adults as 4-year olds although small fractions return at 3 and 5 years of age.

Abundance and Trends

The abundance of Cultus Lake Sockeye Salmon has been monitored since 1921 with a fish counting fence located at the outlet of the lake. Generational (4-year) average abundance has fluctuated around 20,000 spawners from the 1920s to the 1970s and has been declining since then (Figure 2). The current population spawning in the lake is dominated by fish produced by a hatchery supplementation program. The most recent generational (2015-2018) averages are 254 natural-origin spawners, and 941 hatchery-origin spawners.

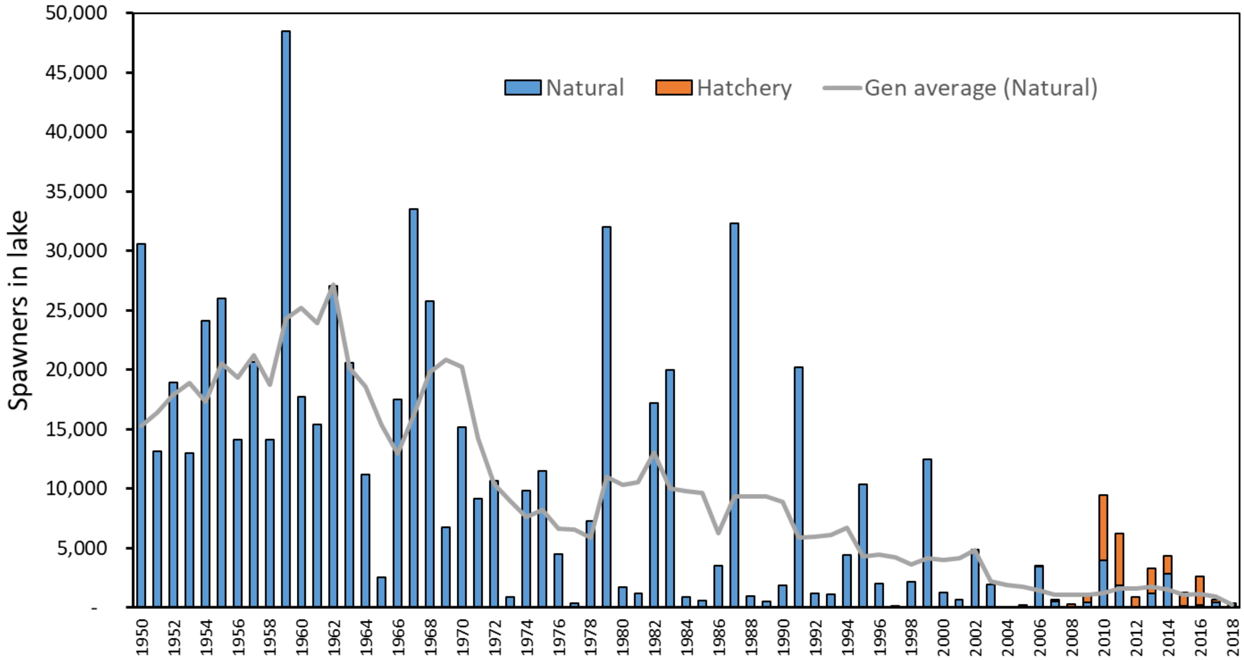

Figure 2. The number of adult salmon passed into Cultus Lake through the counting fence. Line is the 4-year generational average based on natural-origin spawners.

Life History Parameters

As a result of the long history of research and monitoring there is wealth of data available for this population. In particular, intermittent monitoring of smolt production permits computation of freshwater and marine survival rates. The rate of smolt production (smolts produced per spawner passed into the lake) has declined dramatically in the last 2 generations. Recent values of <10 smolts/spawner are well below the historical average of 75 smolts/spawner. Recent rates are also far below levels (approximately 50 smolts/spawner) required to sustain the population in the wild (Figure 3).

Smolt survival rates (from smolts leaving the lake to returning adult to the lake) have remained relatively constant over time. There has been a decline in the survival rate of smolts in the ocean (Figure 4), but this has been compensated by recent reductions in fishing mortality. Smolt survival is adequate to sustain the population if rates of smolt production can be improved to an average of >50 smolts/spawner.

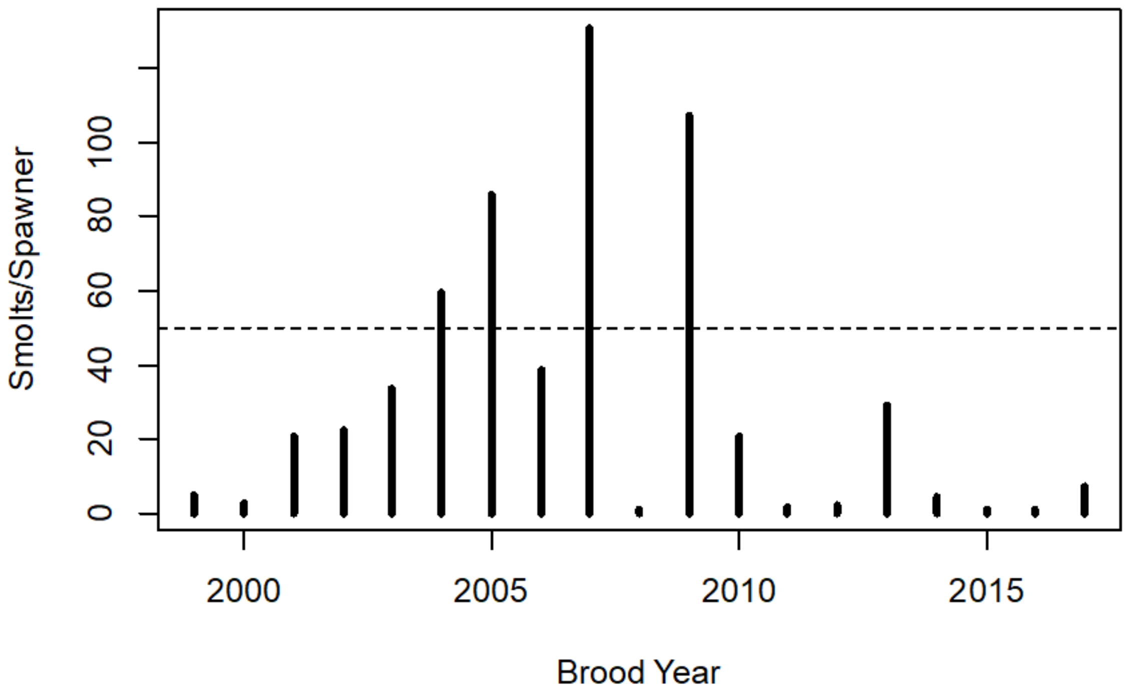

Figure 3. Time series of recent Sockeye Salmon smolt production rates from Cultus Lake. Smolts/spawner is the ratio of natural-origin smolts produced per parent spawner (natural+hatchery origin) passed into the lake 2 years earlier. Dashed line is the approximate rate of smolt production required for population survival (i.e., the replacement level) under current levels of exploitation and marine survival.

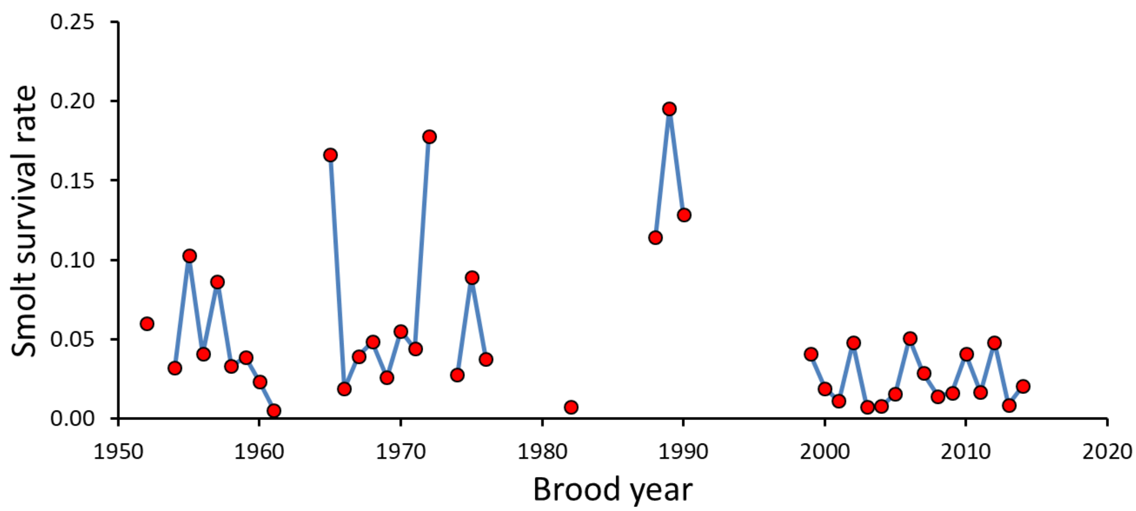

Figure 4. Smolt to adult survival, by brood year. Exploitation rate are used to remove the effects of fishing mortality on survival; for the 1999 to 2014 broods the exploitation rate used was the average of 3 series presented in DFO (2018a), augmented by a preliminary value of 0.5 for 2018.

ASSESSMENT

Habitat and Residence Requirements

Cultus Lake Sockeye Salmon rely on the lake for spawning, egg and larval incubation, and juvenile nursery habitats. The streams and rivers that connect Cultus Lake to the ocean are used by the downstream (smolt) and upstream (adult) migratory stages. Coastal and offshore regions of the Pacific Ocean are used as nursery habitats for juveniles and sub-adults.

Adult salmon spawn on beaches and the shoreline of Cultus from depths of <1m to >20m. Historically, spawners used a number of locations around the lake, but their current distribution may be more limited. Spawning fish are difficult to observe and it is unclear whether recent observations of spawning are the result of changes in habitat use, or a preference for deeper habitats where spawning occurs unobserved.

The successful incubation of eggs and larvae relies on the availability of suitable substrate and interstitial water of good quality and supply. Some degradation of spawning habitat has likely occurred; much of the lakeshore <8 m in depth has been colonized by invasive Eurasian Watermilfoil (*Myriophyllum spicatum)* rendering it unsuitable for spawning. Increased rates of deposition of organic material associated with the eutrophication of the lake, and changes to the quantity and quality of groundwater upwelling through spawning areas, may also be reducing spawning ground quality.

Once juvenile Sockeye Salmon emerge from spawning areas they take residence in the pelagic (offshore) region of the lake, and feed on zooplankton. Cultus Lake is the most productive Sockeye lake in the Fraser watershed, and produces the largest smolts because of zooplankton availability, long growing season, and current low fish abundance. In the summer and fall, juvenile nursery habitat is constrained by high temperatures in the surface waters, and low oxygen levels near the lake bottom.

Nearly all juveniles leave Cultus Lake as age-1 smolts and migrate downstream through Sweltzer Creek and the Vedder River to the Fraser River, before entering the ocean at the mouth of the Fraser River. Juveniles move north through Georgia Strait and Johnstone Strait, before entering the North Pacific Ocean. During this time growth is rapid, but mortality is considerable, likely as a result of predation. The abundance of suitable prey during the first few months at sea is thought to be critical to survival.

Most fish mature after slightly more than two years at sea, and begin their migration back to Cultus Lake. Migrating adults are vulnerable to predation from marine mammals and other large predators, and may be exposed to higher than optimal temperatures in the Fraser River and tributaries before reaching Cultus Lake. Since the mid-1990s, the timing of migration to the lake has advanced by nearly 6 weeks and is associated with higher rates of prespawning mortality among adults.

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). Following DFO's Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk (DFO 2015), redds most closely match the criteria for a residence because they are constructed. 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 eggs, and redds can contain hundreds to a few thousand eggs from a female spawner. Redds located at the spawning areas of Cultus Lake could be considered residences.

Threats and Limiting Factors to the Survival and Recovery

A threats and limiting factors assessment was conducted using the protocol outlined in DFO (2014). A threat is defined as "any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to a wildlife species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur (DFO, 2014). Results of the assessment are presented in Tables 1 and 2.

Threats

Threats that could be identified to present the greatest risk to the population are fishing mortality, lake eutrophication, and climate change. These are discussed below, but a number of other threats listed in Table 1 that were assessed as low or moderate risk could also be important. However, in some cases the lack of information precludes an evaluation of risk they present.

Cultus Lake Sockeye Salmon is the smallest population of 5 DUs of Fraser River Sockeye Salmon that form the Late Run Sockeye Salmon management aggregate. Consequently, Cultus Lake Sockeye Salmon are incidentally harvested in the various fisheries that target the more abundant Late Run Sockeye populations, as well as in some other Fraser River salmon fisheries.

Three different time series of exploitation rates are displayed in DFO (2018a) and show that fishing mortality (all fisheries) is generally low (3~20%) in years when Late Run abundances are low, but may have exceeded 50% in years of large Late Run abundance as a result of directed fisheries on larger populations. The rate of fishing removals on Cultus Lake Sockeye Salmon is difficult to estimate as the number of Cultus-origin fish found in catch sampling is very small and that precludes the development of direct estimates. The use of estimates from other, larger, populations as proxies is problematic because Cultus-bound fish may have different migratory timing and exposure to fisheries than potential proxy populations. Fishing mortality has a direct impact on the number of adults returning to the lake.

Eutrophication is the result of excessive inputs of nutrients to the lake. Anthropogenic nutrient inputs to Cultus Lake result from agricultural runoff, septic leachate, migratory gull guano deposition, and atmospheric deposition of nutrients from agricultural and industrial sources from the Fraser Valley. Nutrient inputs stimulate algal production in the lake, and that increases organic material deposition on the lake bottom. Decomposition of those materials causes oxygen depletion in the deeper strata of the lake during late summer and fall. Oxygen levels have been decreasing in the past 20 years and now reach minima that are stressful or potentially lethal to fish. Oxygen levels in the lake are strongly correlated with estimates of overwinter survival of juvenile Sockeye Salmon.

The deposition of organic material may also cause a deterioration in the quality of spawning habitats along the margins of the lake, through the clogging of spawning gravel and the reduction in oxygen levels in intragravel water.

Low oxygen levels at the lake bottom causes anaerobic processes that result in the release of nitrogen and phosphorus from lake sediments, as well as toxic contaminants and metals that might otherwise stay bound in the sediments. Hydrogen sulfide, which is toxic to fish, is also released during anaerobic metabolism. This process is known as internal loading, and is considered a threat to juvenile survival.

Cultus Lake is becoming warmer as a consequence of climate change. Currently high late-summer water temperatures at the outlet of Cultus Lake are stressful to migrating adults as they move from the Vedder River via Sweltzer Creek to Cultus Lake. The seasonal thermocline is becoming stronger and the lake is more resistant to turnover, which exacerbates the effects of low oxygen levels in the deeper parts of the lake. Thus the effects of climate change interact with eutrophication to create conditions in the lake that are less suitable for Sockeye Salmon.

Limiting factors

The natural limiting factors that present the greatest risk to Sockeye Salmon recovery are the effects of the recent (since the mid-1990s) advancement in migration timing of adult Sockeye Salmon, and the increased variability in survival of juveniles in the lake.

The timing of migration of adults into the lake has advanced by about 6 weeks for reasons that are yet unknown, and this results in fish being exposed to warmer water in the Fraser River during their migration, and a much longer period of holding in the lake before spawning. Consequently, there has been an increase in the prespawning mortality of adults, likely as a result of an increased severity of disease through protracted freshwater residence. Available data suggests this has increased over the past 20 years, and probably contributes to the low rate of smolt production observed over that period.

Increased variability in freshwater conditions was also identified as potentially limiting recovery. This is the result of the interaction of more variable climate conditions caused by climate change, and the other threats and limiting factors that affect salmon survival. These effects also likely contribute to the current low rate of smolt production, and this variation is anticipated to increase in the future.

Table 1: Threats to the survival and recovery of Cultus Lake Sockeye Salmon. Threats are ranked based upon their current biological risk score. Refer to DFO (2014) for detailed descriptions of each factor level in the table. The bracketed number following the Threat Risk ranking represents the Causal Certainty rank (1=very high. 5=very low)

Threat	Life History Stage	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population Level Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Fisheries Interceptions: Direct population losses	Adult	Known	High	Very High (1)	High (1)	Historical, Current, Anticipatory	Recurrent	Broad
Hatchery Production: Reductions of fitness in wild population	All life stages	Likely	Medium	Medium (3)	Medium (3)	Current, Anticipatory	Recurrent	Extensive
Pollution: Elevated mortality or sub-lethal effects due to aquatic pollutants	All life stages	Likely	Medium	Low (4)	Medium (4)	Historical, Current, Anticipatory	Recurrent	Extensive
Lake Eutrophication: Low oxygen in spawning beds	Eggs & alevin;	Likely	High	Medium (3)	High (3)	Historical, Current, Anticipatory	Recurrent	Extensive
Low oxygen levels in lake	Eggs, alevin & juveniles;	Known	Extreme	Very High (1)	High (1)	Historical, Current, Anticipatory	Recurrent	Extensive
Sediment internal loading	Juveniles	Known	High	Very High (1)	High (1)	Historical, Current, Anticipatory	Recurrent	Extensive
Invasive species: Watermilfoil effects on spawning sites & organic matter decomposition	Adults, eggs, alevin, juveniles	Known	Low	Low (4)	Low (4)	Historical, Current, Anticipatory	Recurrent	Broad

Threat	Life History Stage	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population Level Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Invasive species: Predation by Smallmouth Bass	Juveniles, smolts	Unknown	Unknown	Low (4)	Unknown (4)	Current, Anticipatory	Continuous	Extensive
Migration corridor habitat modifications: Dyking, channelization, enumeration fence	Adults, smolts;	Known	Unknown	Low (4)	Unknown (4)	Historical, Current, Anticipatory	Continuous	Extensive
Climate change: Freshwater: Sub-lethal to lethal lake temperatures	Juveniles	Known	Medium	Medium (3)	Medium (3)	Historical, Current, Anticipatory	Recurrent	Extensive
Interaction with eutrophication	Adults, eggs, alevin, juveniles, smolts;	Known	High	High (2)	High (2)	Historical, Current, Anticipatory	Continuous	Extensive
Climate change – marine: Impacts on fecundity, growth, survival	Adults, immatures, smolts;	Known	Medium	Medium (3)	Medium (3)	Historical, Current, Anticipatory	Continuous	Extensive
Marine competition with other species: Pink Salmon interactions	Adults, immatures, smolts;	Likely	Unknown	Low (4)	Unknown (4)	Historical, Current, Anticipatory	Continuous	Extensive
Net pen aquaculture: Disease, parasites	Adults, smolts	Likely	Unkown	Low (4)	Unknown (4)	Current	Recurrent	Broad

Table 2: Limiting factors to the survival and recovery of Cultus Lake Sockeye Salmon.

Limiting Factor	Life History Stage	Likelihood of Occurrence	Level of Impact	Causal Certainty	Population Level Threat Risk	Threat Occurrence	Threat Frequency	Threat Extent
Disease & Pathogens: e.g. *Salmonicola*, *Parvicapsula*, BKD, IHN	Adults, juveniles, smolts	Known	Medium	Low (4)	Low (4)	Historical, Current, Anticipatory	Recurrent	Broad
Change in Migration Timing: Prespawning mortality	Adults	Known	High	Medium (3)	High (3)	Historical, Current, Anticipatory	Recurrent	Extensive
Freshwater Predation: Native predators	Eggs, juveniles, smolts	Known	Medium	Medium (3)	Medium (3)	Historical, Current, Anticipatory	Continuous	Extensive
Marine Predation: Native marine mammals, piscivores, birds	Smolts, immatures, adults	Known	Low	High (2)	Low (2)	Historical, Current, Anticipatory	Continuous	Extensive
Increased Variability in Freshwater Conditions	Adults, eggs, alevin, juveniles, smolts	Known	High	Very High (1)	High (1)	Historical, Current, Anticipatory	Recurrent	Extensive
Increased Variability in Marine Conditions	Adults, immatures	Known	Medium	Medium (3)	Medium (3)	Historical, Current, Anticipatory	Recurrent	Extensive
Limited Freshwater Distribution: Susceptibility to catastrophic events	Adults, eggs, alevin, juveniles, smolts	Known	Medium	Low (4)	Medium (4)	Historical, Current, Anticipatory	Recurrent	Extensive

Recovery Targets

A recovery target based on a 4-year arithmetic mean of 7,000 spawners entering the lake was proposed as it is similar to abundances observed in the past, and sufficient to ensure that the population might not be assessed as endangered under COSEWIC criterion C (<2,500 adults) if it underwent a period of decline. A survival target of 2,500 spawners with no year less than 500 was also identified to assist in the evaluation of recovery measures. The survival or recovery targets could include hatchery-origin spawners, as long as the ongoing hatchery program met standards outlined by DFO (2018b) to reduce risks to wild populations. A risk measure known as the Proportionate Natural Influence (PNI) was used to evaluate genetic risks of hatchery supplementation and DFO (2018b) proposed that PNI values ≥ 0.72 are required to maintain a largely wild population. In most circumstances those standards imply <30% of adults spawning in the wild would be hatchery-origin fish in the recovered population. However, lower PNI values are likely during the period of recovery when hatchery supplementation is being used to boost abundance.

Scenarios for Mitigation of Threats and Alternatives to Activities

Potential mitigation measures for the key threats include:

- Continuation of the current hatchery supplementation program to mitigate poor survival in the lake.
- Management of fishing mortality to reduce the number of adult fish that interact with or are removed by fishing gear.
- Targeted management of nutrient inputs to Cultus Lake to reduce or reverse eutrophication trends. This could include upgrading sewage treatment, interrupting increasing migratory gull guano loading to the lake, mitigating nutrient runoff within the watershed, and changes to Fraser Valley agricultural practices (i.e. conservation agriculture) to reduce atmospheric deposition within the watershed.
- Prevention of introduction of other invasive species and control of those that have established themselves in the lake
- Reinstatement of the captive breeding program could be considered if the survival of hatchery smolts falls below replacement levels.

The effectiveness of the first four measures was evaluated with an empirically-based simulation model that estimated the probability of meeting the survival or recovery target (and PNI targets where applicable) after 3 generations (12 years) under various management and mitigation scenarios. Some simulations were extended to evaluate longer-term results. The simulations used freshwater and ocean survival rates from 2003-2016, under the assumption that recently observed rates would continue into the future.

Potential mitigation measures were simplified into three actions: different rates of fishing mortality, the presence or absence of the current hatchery supplementation program, and a generic approach to modelling mitigation of factors affecting survival in the lake. The specific threat being mitigated is not specified and would depend on the most likely cause(s) for the poor rates of smolt production. The method simulates mitigation by gradually (over 50 years) reducing the frequency of occurrence of very low smolt production rates that have been recently observed (Figure 2).

Two methods were developed for dealing with hatchery fish in the assessment. In the first (Method 1), all hatchery fish (lake spawners and broodstock) are considered part of the population, representing the case where hatchery management practices are appropriate to prevent significant impacts on the fitness of the wild population. In the second scenario (Method 2), hatchery-origin fish were not included in the evaluation against recovery goals. This was the approach used by COSEWIC (2017) based on the assumption that hatchery-origin fish represent a risk to the population in the wild.

All of these evaluations and the resulting uncertainty were summarized using the likelihood scale identified by the Intergovernmental Panel on Climate Change guidance note on treatment of uncertainty (Mastrandrea et al. 2010).

Results of the modelling show that under status quo scenarios (scenarios 8 or 9, Table 3) the population is very unlikely to achieve the recovery target. If all mitigation measures (hatchery, reduction in fishing mortality and mitigation of freshwater survival) are successfully applied, the population is predicted to have an increasing trajectory, and is more likely to reach the recovery target in > 6 generations (Figure 4).

Table 3. Results of the population modelling in assessing the likelihood of achieving the survival or recovery target and the population size in the last generation under several potential mitigation scenarios. Fishing column indicates the fishing mortality rates applied to the three non-dominant late run cycles (0, 0.1, 0.2). For the dominant run (2018 and every 4th year after), rates of 0, 0.25 and 0.5 were used, based on the recent observed patterns in fishing mortality. Simulations were run for 3 generations and the assessment is based on abundance in the last generation. Methods 1 and 2 refer to different ways of dealing with hatchery-origin fish in the assessment.

				Probability of meeting targets[1]				
				Survival (>2,500)		Recovery (7,000)		
Scenario	Hatchery	FW Mitigation	Fishing	Method 1	Method 2	Method 1	Method 2	PNI
1	N	N	0	**0**	**0**	**0.01**	**0**	**1**
2	N	N	0.1	**0**	**0**	**0**	**0**	**1**
3	N	N	0.2	**0**	**0**	**0**	**0**	**1**
4	N	Y	0	**0**	**0**	**0**	**0**	**1**
5	N	Y	0.1	**0**	**0**	**0**	**0**	**1**
6	N	Y	0.2	**0**	**0**	**0**	**0**	**1**
7	Y	N	0	**0.49**	**0.03**	**0.04**	**0**	**0.3**
8	Y	N	0.1	**0.31**	**0.01**	**0.01**	**0**	**0.27**
9	Y	N	0.2	**0.13**	**0**	**0**	**0**	**0.23**
10	Y	Y	0	**0.75**	**0.12**	**0.07**	**0.03**	**0.46**
11	Y	Y	0.1	**0.53**	**0.05**	**0.02**	**0.01**	**0.41**
12	Y	Y	0.2	**0.25**	**0.01**	**0**	**0**	**0.36**

[1] Colours are coded probability categories: Very Likely ≥ 0.90, Likely ≥ 0.66 (light green), About as likely as not 0.33 – 0.66 (white), Unlikely ≤ 0.33 (pale purple), Very Unlikely ≤ 0.10 (dark purple).

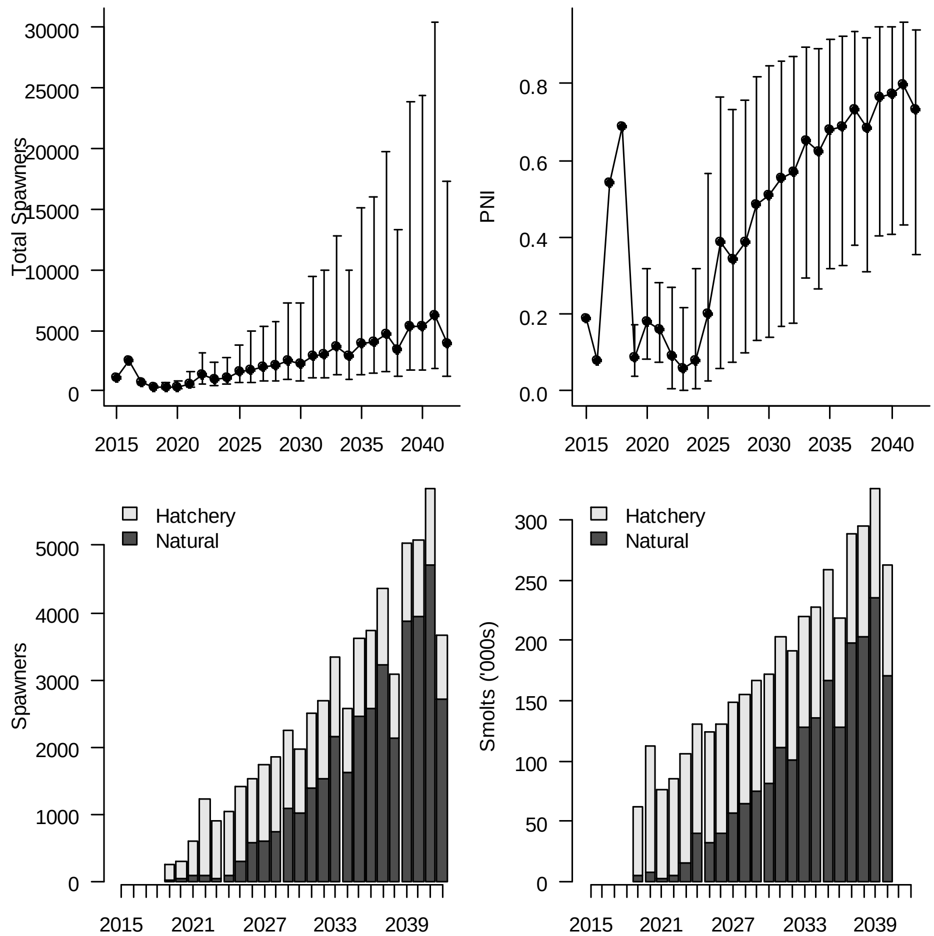

Figure 5. Simulation results for Scenario 11 in Table 3 extended to 6 generations to show that the combined effects of hatchery supplementation, reduction in fishing mortality, and freshwater mitigation can lead to population growth. The population is very unlikely (probability = 0.02) to reach the recovery goal in 3 generations, but that probability increases to 0.56 after 6 generations (based on Method 1). Further, the average PNI value in the last generation is 0.71, close to the target level. Error bars show the 90% range in simulated values.

Allowable Harm

The modelling predicted that given current conditions in the lake, the Cultus Lake Sockeye population will decline in the absence of hatchery supplementation, even if fishing mortality is eliminated. Given the negative population growth rate there is no allowable harm for this population.

If freshwater survival can be mitigated, and rates of ocean survival do not decline further, it is possible that recovery could occur under limited allowable harm. For example, if measures to increase natural-origin smolt production to sustainable levels (>50 smolts/spawner) are successful, population growth is possible. Such harm (resulting from, for example, fishing or habitat impacts) would slow the rate of recovery. It is currently not feasible to quantify the level of mortality that could be allowed in the future because the efficacy of potential measures to mitigate threats to the population is unknown.

Sources of Uncertainty

- Uncertainty in the estimates of fishing mortality on Cultus Lake Sockeye Salmon should be considered when evaluating the effects of fishing plans on recovery.
- The long-term effects of significant hatchery supplementation on the fitness of the population in the wild is unknown and was not considered in the simulation model.
- Future changes in both freshwater and marine survival as a result of climate change were also not considered in the model and may be expected to generate more pessimistic results if they were included.
- While the effects of eutrophication on Sockeye survival may be mitigated with improved management of nutrients, there is significant uncertainty about whether timely and effective management measures are likely to occur in time to contribute to recovery.
- The effect of invasive fish species is currently unknown, as is the potential for other harmful invasive fish species to be introduced to the lake.

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SOURCES OF INFORMATION

This Science Advisory Report is from the October 7-10, 2019 regional peer review on Recovery Potential Assessment – Fraser River Sockeye Salmon (*Oncorhynchus nerka*) – Ten Designatable Units. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

COSEWIC. 2017. COSEWIC Assessment and Status Report on the Sockeye Salmon (*Oncorhynchus nerka*) 24 Designatable Units in the Fraser River Drainage Basin in Canada 2017. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 179 pp.

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